







Report from the

International Master Summer School "Biodiversity Monitoring", Preda, Parc Ela, Switzerland, 14–25 August 2019



Edited by Jürgen Dengler

Teachers

Regula Billeter, Patryk Czortek, Jürgen Dengler, Kirsten Edelbauer, Jamyra Gehler, Dieter Müller, Jürg Paul Müller, Julia Pawłowska, Claudio Signer, Annette Stephani, Piotr Tykarski, Marta Wrzosek

Participants

Dilek Batkita, Sylwia Budzynska, Anna Dębska, Urszula Drwęcka, Filip Gabarkiewicz, Adrian Hochreutener, Luca Hoppler, Carmen Isaak, Fabien Hiltebrand, Tanja Koch, Josua Lay, Durelle Yolande Fossi Mevoutsa, Szymon Sitek, Sandro Stoller, Livia Wyss

Recommended citation

Dengler, J. (ed.) 2020. *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.

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

Table of contents	3
Preface	6
References	7
The permanent plots	8
References	8
Reports from student projects	10
What are important variables to explain vascular plant and fungi species richness in the Val Mulix?	11
Abstract	11
Introduction	11
Methods	12
Study site	12
Field sampling	13
Analyses of scale-dependence of richness-environment relationships	13
Analyses of taxon-dependence of richness-environment relationships	13
Results	14
Scale-dependence of richness-environment relationships	14
Taxon-dependence of richness-environment relationships	15
Discussion	16
Species richness - predictor relationships	16
Potential error sources	18
Conclusion	18
References	19
Effects of environmental parameters on canopy height of vascular plants along an altitudinal gradi	ent
in alpine grasslands of Val Mulix (canton of Grisons, Switzerland)	21
Abstract	21
Introduction	21
Methods	22
Study area and field sampling	22
Statistical analysis	23
Results	24
Data	24
Candidate models	25
Relative importance and effect sizes of predictors	26
Discussion	29
Effect of elevation on the canopy height of vascular plants	29
Effect of inclination (slope) on the canopy height of vascular plants	29
Effect of HLI (Heat Load Index) on the canopy height of vascular plants	29

Monitoring of small mammals' diversity with Mostela camera trap	ping along an altitudinal gradient in
Appendices	31
References	30
Acknowledgements	30
Implications	30

monitoring of small mammals diversity with mostela camera trapping along an attitudin	al gradient in
Val Mulix, Switzerland	32
Abstract	32
Introduction	32
Methods	33
Study area	33
Field sampling and species determination	34
Statistical analyses	36
Results	37
Catch success and species richness	37
Relative abundance and height distribution of the individual species	39
Habitat use	42
Activity patterns	42
Attractivity of the Mostela	43
Discussion	44
Catch success and species richness	44
Relative abundance and height distribution of the individual species	46
Habitat use	48
Activity patterns	48
Attractivity of the Mostela	49
References	49
Appendix	52

Plant biodiversity in an alluvial plain in Preda in the Swiss Alps: A modelling approach to determine driving factors influencing species richness

iving factors influencing species richness	60
Abstract	60
Introduction	60
Methods	61
Study area	61
Field sampling	62
Data preparation	62
Analysis	63
How to measure biodiversity?	65
Results	66
Cross-section of the transect	66
Soil texture type and pH	66
Red list species and grouping of vegetation	67
Multiple linear regression model	68
Shannon Index and Evenness	69
Discussion	70
References	71

Appendix	73
Appendix I: List of all observed species	77
References	77
Appendix II: Photo plates	92
The venue	92
Habitats and species in Preda	93
Activities of the Summer School	96

Preface

Jürgen Dengler

The Master Summer School "Biodiversity Monitoring" was planned as a joint international class for Master students in Environment and Natural Resources of the Zurich University of Applied Sciences in Wädenswil and the Master programs of the Faculty of Biology of the University of Warsaw. Both students and teachers are from both universities. It is planned to be conducted alternatingly in Parc Ela, a regional nature park in Grisons, Switzerland, and in and around the Białowieża National Park in Eastern Poland. After planning in both universities in 2018 and early 2019, it was conducted for the first time in summer 2019 in Preda, Parc Ela Switzerland. Unfortunately the first scheduled conductance in Poland in summer 2020 had to be cancelled due to the Corona pandemic.

The main topics of the Summer School are how to sample and monitor 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", we are going to establishing a set of permanent plots along one or two major environmental gradients in the Swiss and Polish sited. This will allow resampling every second year and subsequent time series analyses. Apart from acquiring knowledge on species determination and standardised biodiversity sampling, the Summer School also provides deeper insights 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, logically the Summer School is conducted in English.

The Summer School "Biodiversity Monitoring" was conducted for the first time from 14–25 August 2019 in the Sonnenhof in Preda, Grisons, with 16 participants and 12 teachers from Switzerland and Poland. The first part was dedicated to the reconnaiscance of the habitats in the surrounding and to the establishment of the permanent monitoring transect on whose plots in 2019 and in subsequent years always all four taxonomic groups will be sampled, i.e. vascular plants, orthopterans, small mammals and fungi. In the second part, students conducted in total five research projects, partly using the data from the monitoring transect, partly additionally sampled data and partly a combination of both.

This reader mainly comprises the scientific reports from four of the research projects, accompanied by 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 baseline material for the next conductance and the conservation authorities of the canton and the Parc Ela and other partners with a documentation of the findings and thus complements an earlier mini-report (Dengler 2020).

Enjoy reading!

References

- Allan, E., Bossdorf, O., Dormann, C.F., Prati, D., Gossner, M.M., Tscharntke, T., Blüthgen, N., Bellach, M., Birkhofer, K., (...)
 & Fischer, M. 2014. Interannual variation in land-use intensity enhances grassland multidiversity. *Proceedings of the National Academy of Sciences of the USA* 111: 308–313.
- Dengler, J. 2020. Internationale Summer School "Biodiversity Monitoring": Lernen, wie man Biodiversität erfasst und ihre Veränderungen analysiert. *IUNR Magazin* 2020(1): 6–7.
- Zulka, K.P., Abensperg-Traun, M., Milasowszky, N., Bieringer, G., Gereben-Krenn, B.-A., Holzinger, W., Hölzler, G., Rabitsch, W., Reischütz, A., (...) & Zechmeister, H. 2014. Species richness in dry grassland patches in eastern Austria: a multi-taxon study on the role of local, landscape and habitat quality variables. *Agriculture, Ecosystems & Environment* 182: 25–36.

The permanent plots

Jürgen Dengler

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 EDGG multi-scale "biodiversity plots" of EDGG (Dengler et al. 2016), and the non-forest plots among them are contributed to the GrassPlot database (Dengler et al. 2018, 2020). On the other hand, the plots combined with some additional co-occurrence plots sampled by I. Dembicz and J. Dengler are part of the DarkDivNet (Pärtel et al. 2019) 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 every approx. 100 m of elevation between 1750 and 2650 m a.s.l. (plots C01–C09 and N1C). At approx. 2050 m a.s.l., in addition to plot N1C in near-natural forest we established a second plot A1C 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).

All 13 permanent plots were georeferenced with a Differential-GPS, marked in two corners with coloured wooden poles and additionally with magnets burried in the soil to allow precise relocation in future sampling campaigns. Moreover, each of the 13 permanent plots was equiped with a pair of tempurature loggers, one 10 cm below soil surface and one 10 cm above soil surface to record over the next years in 30 min intervals the actual temperature. Following, the protocol of Dengler et al. (2016), in each of these 13 100-m² plots and two nested subseries in two opposite corners of 0.0001, 0.001, 0.01, 0.1, 1 and 10 m² vascular plant species composition was recorded. In the 10-m² plots additionally coverage of each species in % was estimated and some simple structural and environmental variables recorded. Moreover, for each of the 13 permanent plots (partly excluding C10 and C11) the species composition was also recorded for small mammals, orthopterans and macroscopic fungi. Moreover, following Pärtel et al. (2019), in each of the 13 plots, three simple plant functional traits were measured for each occurring vascular plant species, namely canopy height, leaf length and leaf width. Finally, also following Pärtel et al. (2019), for A1C and N1C, additionally the species composition of the surrounding 2500 m² plot was recorded and a mixed soil sample for metagenomic assessment taken.

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 have carried out five research projects in small teams of 3–4 students. These reports were prepared in the style of a scientific paper. The four project works with reasonable quality are presented in the following, while we refrain from presenting the report of the fifth group due to quality issues. Please note that the four presented projects are published as submitted by the students, except minor adjustments in the layout. The responsibility for the content solely rests with the authors.

11

What are important variables to explain vascular plant and fungi species richness in the Val Mulix?

Tanja Koch, Sandro Stoller & Livia Wyss

Abstract

Different factors are influencing species richness and community structures at different scales and along elevational gradients. Val Mulix (Switzerland) represented a ideal site to set up permanent plots to look at the changes of vascular plant and fungi species richness at different grain sizes and along an elevational gradient. We found vegetation type to be a strong predictor for plant species richness at most grain sizes and especially alluvial plains to be very species rich. This could be explained by a heterogeneous landscape shaped by regular flooding events and the intermediate disturbance hypothesis. In general, the results should be interpreted with caution due to low sample sizes, approximation of environmental parameter measurements and data gaps and not yet availability of data series from past years.

Introduction

The species richness of plants and fungi is determined by different environmental factors. For example, the altitude of a transect has substantial effects on the abundance of vascular plants and also fungi, which has already been shown in different studies (Küffer and Senn-Irlet, 2005; Pouska, 2011; Theurillat et al., 2003).

But also other parameters can strongly influence the composition. In our investigations in an inner alpine area near the village Preda in Switzerland (CH) we wanted to work out which environmental factors significantly influence the abundance of the flora (fungi and vascular plants). Since only the multiscale approach was used to determine the vascular plant species, it should also be investigated whether there are differences in the significance of individual environmental variables in relation to the respective subplot sizes. Background of these considerations were investigations of Dufour et al., 2006, where it could be shown, that in small scales, ecological interaction controls diversity, but on a larger scale, environmental parameters of a site are more important for the diversity of an ecosystem. Therefore, different environmental variables have been measured along with the species richness of vascular plants (such as soil pH, aspect of the plot, microrelief etc.).

We were also interested in figure out whether the Intermediate Disturbance Hypothesis (Grime, 1973) could be confirmed on our study site near Preda. Studies based on this hypothesis indicate that plant diversity is greater in extensively used pastures than in unused pastures (Kammer and Möhl, 2002; Schütz et al., 2003). Because the plots over the study site have been used differently and some have been slightly grazed and others were not, we were interested, whether the grazing has had an effect on the species richness or not.

At the beginning it was thought that we would exclusively focus on the vascular plants, but since we also had the data on the abundance of fungi in the area available, we wondered whether the diversity of these is also strongly influenced by the vegetation types (forest, shrub and meadow) and the land use as could be demonstrated in other studies (Küffer et al, 2008; Oehl et al., 2003) or whether it might be related to the amount of coverage of the individual plots by (dead) wood (Ódor et al., 2006; Sætersdal et al., 2004) or all or neither of them. However, since the species abundance of only a single group is not a good indicator of biodiversity abundance (Berglund and Jonsson, 2001), the data on fungi have to be partly considered separately from the vascular plants.

Methods

Study site

The study site was selected as a result of the Summer School on Biodiversity Monitoring of the Zurich University of Applied Sciences (ZHAW) in Wädenswil. The investigated plots were located near the village Preda in the Val Mulix in the canton of Grisons, Switzerland. The plots examined are all located in the Ela Nature Park, which is the largest regional nature park in Switzerland. The climate in Preda is temperate but cold and has a considerable amount of precipitation during the year (Klima Preda, n.D.).

Extensive agriculture up to little or no use at all or alluvial processes characterize the alpine landscape, in which 13 plots, each of them with an edge length of ten meters (area of $100m^2$), were defined. These consist of two subplots each with an edge length of 3.16 meters (area of $10m^2$), which were determined in the northwestern (NW) and southeastern (SE) corners of the large plots. The plots were placed between an elevation of 1705 and 2588 meters of altitude (*Figure 1*), with a distance of around 100 meters of altitudinal difference between the $100m^2$ plots. Plots C1 – C11 were placed along an elevational gradient. (A1 and N1 are additional plots whose data we also used, since they were examined with regard to the same parameters even though they were not placed along the gradient.)



Fig. 1. Map of the study area and spatial distribution of our plots.

Field sampling

In the subplots of 10m², the existing taxa of vascular plants were determined by field work of students and lecturers of the University of Applied Sciences in Wädenswil, Switzerland and of the University of Warsaw, Poland using the multiscale method (Turtureanu et al., 2014, Kuzemko et al., 2016). The multiscale method involves the stepwise investigation of small plots of an area of 0.0001, 0.001, 0.01, 0.1, 1, $10m^2$ in the northwestern and southeastern corners of a $100m^2$ plot. In each size of the small plots, the existing plants are determined before moving on to the next larger plot and determining the additional plants there. Afterwards the parts of the coverings by the determined vascular plant species in the two $10m^2$ subplots (NW and SE) were estimated. Finally, the remaining area of the $10m^2$ plot, which has not yet been examined, was then examined and the additional species, which were not present in the subplots, have then been determined. The richness of fungi species was examined only in the 100m² plot with no stepwise investigation. No fungi investigation was made for the Plots C10 and C11 in the alluvial plain. Structural parameters such as the cover of the shrub, herb and moss layers and that of litter, gravel as well as stones and rocks were estimated as well as environmental parameters such as elevation, aspect, inclination, southing, maximal microrelief and soil depth and pH (see Results.csv in the data folder). Structural and environmental parameters were only measured at the 100m² scale and used as an approximation for smaller scales also.

Analyses of scale-dependence of richness-environment relationships

Richness-environment relationships were assessed for total species richness separately at each of the different scales ranging from 0.0001 to 100 m^2 (n = 13 for 100 m^2 , n = 26 for smaller grain sizes). A first visual inspection of the data showed a good symmetry, so there was no need for transformation.

With a correlation matrix, we checked if the predictor variable were independent from each other. Two parameters were considered as dependent when |r| > 0.6 and in such cases, we kept the one we considered ecologically more meaningful. The predictor *Heat load index* included NA's and was therefore excluded.

We ran a linear model with the species richness at 100m² including quadratic terms to check for unimodal relationships. We got significant p-values for the tree predictors *pH*, *inclination* and *vegetation type*. No significant quadratic term occurred while the non-quadratic was not significant. Because our main purpose was to look at changes in species richness along an elevational gradient, we decided to also include *elevation*, although it was not significant in the linear model. With those predictors, we performed a global linear model (function *Im* in R). Model selection was performed with multi model inference (Burnham and Anderson, 2002, implemented in R-package MuMIn version 1.42.1; Bartoń 2015) within an information-theoretical approach. Model validity was assessed by Corrected Akaike's Information Criteria (AICc) and importance values were calculated to assess the importance of the different parameters in explaining species richness at each scale. The direction of relationship was determined by the estimate of the global model.

Analyses of taxon-dependence of richness-environment relationships

The patterns of vascular plant and fungi richness were compared at 100m² grain size because the multiscale method was not applied to the fungi.

For the comparison of the species richness of vascular plants and fungi, we made analyses with the predictors *elevation*, *pH*, *amount of dead wood and land-use type*. Additionally, the exponent z of the

SAR (species-area relationship) which is needed to assess the ß-diversity was included as third dependent variable (Dengler et al. 2014). The statistical analysis was performed in the same manner as mentioned above with the R-package *MuMIn*.

Because the importance values of some parameters in our model were "unusual" and hard to interpret, we additionally tested and visualized the relationship of total plant species richness at 100m² to the parameters *vegetation type* and *land-use type* which are important predictors of species richness according to the literature (Fischer et al., 2008; Łuczaj & Sadowska, 1997; Schütz et al., 2003; Zechmeister et al., 2003). We used *Welch two sample t-test* for the land-use type analyses and *One-way ANOVA* and *Tukey post-hoc test* (Hothorn et al., 2008) for the vegetation type analyses. All analyses have been performed with RStudio Version 3.5.1 (R Core Team, 2018).

Results

Scale-dependence of richness-environment relationships

Multimodel inference showed that vegetation type was over all scales a very important factor with mostly higher species richness in the alluvial plain than in the three other vegetation types forest, shrub and grassland (*Figure 2, Table 1*). *Elevation* was only important at very small scale (positive) and at very big scale (negative). *pH* was in general not a very important factor.



Fig. 2. Change of relative importance of the 4 variables included in the full models for total species richness across the studied scales.

Grain size	0.0001 m ²	0.001 m²	0.01 m²	0.1 m²	1 m²	10 m²	100 m²
Elevation	0.73	0.27	0.34	0.31	0.25	0.3	0.95
рН	0.21	0.27	0.36	0.36	0.3	0.44	0.13
Inclination	0.28	0.18	0.44	0.97	0.47	0.18	0.42
Vegetation type	0.95	0.89	0.77	0.99	0.86	0.87	1
Forest vs. Alluvial plain	-	-	-	-	-	-	-
Grassland vs. Alluvial plain	+	+	+	-	-	-	-
Shrub vs. Alluvial plain	+	-	-	-	-	-	-

Table 1. Parameter estimates for the seven grain sizes based on multimodel inference (n = 13 for 100 m2 and 26 for all smaller grain sizes).

Taxon-dependence of richness-environment relationships

The importance values from the *MuMIn* show us unexpected results. For the vascular plants, the amount of *dead wood* is the most important factor with a negative relationship. For the fungi, *elevation* (negative) was an important factor explaining total species richness in the plots. *Dead wood* is only second most influential predictor and shows a negative relationship. In general, the predictors explained little in the variability of z-values of vascular plants (*Table 2*).

Table 2. Predictors of 100 m2 richness for the two taxonomic groups and of the z-value of vascular plants only as measure of b-diversity based on multimodel inference.

	Vasc.10	Fungi.10	z-value Vasc. plants
Elevation	0.08 +	0.97 -	0.256 -
рН	0.36 +	0.07 +	0.102 -
Land.use	0.1	0.06	0.099
Dead.wood	0.74 -	0.43 -	0.119 -
Grazing vs. abandoned	+	-	+

Without running a global linear model but only checking for differences in means, there were no significant differences in a) vascular plant species richness (Welch t-test, p = 0.08, t = -1.95, df = 9.69) and b) fungi species richness (Welch t-test, p = 0.57, t = -0.58, df = 13.4) under different *land-use types* (*Figure 3*).



Fig. 3. Differences in species richness under different land-use types for vascular plants (left) and fungi (right).

Vascular plant species richness differed highly significantly among the different *vegetation types* (ANOVA, p< 0.001, $F_{3,22}$ = 41.59, R^2 =0.83) but fungi species richness did not (ANOVA, p = 0.07, $F_{2,19}$ = 3.065, R^2 =0.244), see *Figure 4*.



Fig. 4. Differences in species richness among different vegetation types for vascular plants (left) and fungi (right). Small letters indicate homogenous groups when p < 0.05 according to Tukeys post-hoc-Test (only for vascular plants).

Discussion

Species richness - predictor relationships

Our analyses showed that the *vegetation type* is a very important predictor and of great importance to explain species richness (*Figure 2, Table 1*). This is also consistent with the results of past research (Küffer et al., 2008; Łuczaj & Sadowska, 1997). It could also be shown, that in the alluvial plain area, a higher richness of vascular plants can be found on almost all grain sizes (*Table 1*). This would also be congruent with past research, which has shown that river and stream habitats have a particularly high species richness. The reason for this is that flooding creates greater heterogeneity in landscapes (Mouw

et al., 2009; Ferreira & Stohlgren, 1999). However, the high species richness could have also been positively influenced by the grazing of horses, which took place in this specific areas and which can have a positive influence on species richness (Schütz et al., 2003). However, it should be noted that both grazing and flooding would be in accordance with the Intermediate Disturbance Hypothesis, which states that diversity is highest in moderate disturbances (Grime, 1973; Kammer and Möhl, 2002; Schütz et al., 2003). Another possible explanation would be, that both floodplain areas were approximately at the intermediate altitude of the 'belt of high species richness' which has been modeled in the study of Wohlgemuth et al., 2008 where they predicted the highest species richness for vascular plants. Above and below this belt the species richness decreases, which would be the case in our site and therefore would fit the model (Wohlgemuth et al., 2008). The only exceptions were the three smallest grain sizes which showed greater abundance of species in grasslands than in the alluvial plain plots (*Table 1*). Again this could be explained by the regular disturbance events which create also bare ground in contrast to the rather stable plant communities in alpine grasslands (Mouw et al., 2009). There we could expect to find much denser plant stands and higher plant species richness on small grain sizes due to a long history of competition for e.g. nutrients and light.

We also found differences in the meaning of certain predictors between the scales. This observation is not new either, as it was already established by Turtureanu et al., 2014, who justified it by saying that niche variables are important at very fine scales, while heterogeneity and parameters associated with disturbance gain influence at larger scales. However, we can only partially confirm this statement, since, for example, the predictor *elevation* had a great importance in our investigations with very small and very large scales, but with different modes of action (positive/negative), see *Figure 2* and *Table 1*. The *inclination* was of great importance only for the medium plot size. The reason for this is not quite clear to us, it could also be an error in the data or a false relationship.

In our investigations, our selected predictors *elevation*, *pH*, *dead wood and land use type* generally explained very little in the variability of z-values (see *Table 2*), with all besides the predictor *land use* having a negative effect. These small effects mean, that the environmental parameters do not show a clear relationship across all grainsizes (aka plot sizes). Therefore, the z-values do give information about a low species-area relationship. The (low) negative variability in the data in relation to elevation could be explained by the fact, that *elevation* has a negative effect on species richness, which was also observed in other literature and can be explained partially through the linkage of *elevation* and temperature (Küffer and Senn-Irlet, 2005; Pouska, 2011; Theurillat et al., 2003; Vittoz et al., 2010). Also, it is known, that a low soil *pH* leads to a decrease in nutrient availability (Foth, 1990) and therefore, the species richness in alpine vascular plants is influenced directly and indirectly via effects of the *pH* on other studies found a unimodal relationship between soil *pH* and species richness, which is not the case in our study site (Vonlanthen et al., 2006), the relationship is relatively linear in our data set. Nonetheless, we must stress that these values - as already mentioned - are all quite low.

The reason for the negative directional influence of *dead wood* on plant species richness is not clear. We have decided to consider dead wood in our analyses, as we have investigated the species richness of both taxa and *dead wood* content (and its quality) in similar investigations had an extremely important influence on the diversity of fungi (Ódor et al., 2006; Pouska, 2011; Sætersdal et al., 2004) but also on certain plants species in forests (Burrascano et al., 2008). This could at least partly explain why the variable became so important in the analyses, even if this cannot be fully explained and could also have to do with a 'fake correlation'. In *Table 2* we are also able to see, that elevation is a very important

predictor for the species richness in fungi but not in plants. The fact that it has only a weak influence on plants is in contrast to other reports (see above). The negative strong influence of *elevation* on fungal diversity was partly explained in other studies by the fact that at higher elevations there are fewer trees and thus *(dead) wood*, which is why, at least wood-inhabiting fungi also occur less frequently in higher elevations (Küffer and Senn-Irlet, 2005; Pouska, 2011;. This absence of wood may also have influenced our results, although the amount of *dead wood* was a less good predictor of the abundance of fungi.

What surprised us very much, however, was the fact that there were no differences between the richness regarding *land use* and *vegetation type* (see *Figure 3* and *Figure 4*). We would have expected this, since other experiments were able to measure such effects of the *land use* type (Fischer et al., 2008; Schütz et al., 2003; Zechmeister et al., 2003). In the case of *land use*, we can partly explain it by the fact that grazing here takes place only very selectively and at very low intensity and therefore its effect is not noticeable. With the *vegetation types* we cannot explain the result, since other studies have found large differences in both vascular plants (Łuczaj & Sadowska, 1997) and fungi (Dittrich et al, 2014; Oehl et al., 2003). Perhaps other factors are simply of greater importance for the species richness in the measured plots than these two factors.

Potential error sources

Of course, our results should be enjoyed with caution. There are several factors that may have influenced the results. For example, our studies on land use and intermediate disturbance hypothesis are based on the current land use survey in mid-August 2019 and the precise information on land use intensity is lacking. The multiscale method also harbours the danger of pseudo replications. And our analyses took place on the basis of only 13 $100m^2$ plots, which is why the statistical power is relatively low. In addition, only one *pH* value per subplot was measured, although variations in *pH* can already occur on smaller scales. The data for the fungi are not complete either (two plots are missing completely), which is why we could not perform the statistical analyses in the same way. In addition, numerous factors that could have an influence on species richness were not measured. For example, all soil characteristics such as water content, organic matter content, etc. but also the temperature and precipitation patterns of the plots.

Conclusion

In conclusion, it can be said that we were able to confirm numerous existing ecological findings on our plots in Val Mulix. There were some discrepancies, for example regarding land use and vegetation type, but we were able to explain some of them.

In conclusion, it must be said that only the long-term observation of these plots can provide insights that can be of greater importance for the understanding of the ecosystem in the inner Alpine region. We strongly recommend that during the next measurements and re-observation of the plots, various soil parameters should also be measured and the pH values should be determined on a smaller scale. This will probably provide interesting insights into small-scale effects and influences. If, in addition, long-term observations are made and it is possible to investigate whether and to what extent the species richness and the composition of the species change, statistical analyses in connection with the climate in the region must also be carried out. For example, it could then be investigated how certain habitats react to climate changes, which should provide very exciting insights, especially in the context of climate change.

References

- Bartoń, K. (2018). MuMIn: Multi-Model Inference. R package version 1.42.1. https://CRAN.R-project.org/package=MuMIn.
- Berglund, H., & Jonsson, B. G. (2001). Predictability of plant and fungal species richness of old-growth boreal forest islands. *Journal of Vegetation Science*, 12(6), 857-866.
- Burnham K.P., Anderson D.R. (2002). Model selection and multimodel inference: a practical information theoretic approach, 2nd edn. Springer, New York
- Burrascano, S., Lombardi, F., & Marchetti, M. (2008). Old-growth forest structure and deadwood: Are they indicators of plant species composition? A case study from central Italy. *Plant biosystems*, 142(2), 313-323.
- Climate-Data.ORG (n.D.). Klima Preda. https://de.climate-data.org/europa/schweiz/graubuenden/preda-156091/ (last accessed 23.08.2019).
- Dittrich, S., Jacob, M., Bade, C., Leuschner, C., & Hauck, M. (2014). The significance of deadwood for total bryophyte, lichen, and vascular plant diversity in an old-growth spruce forest. *Plant ecology*, *215*(10), 1123-1137.
- Dufour, A., Gadallah, F., Wagner, H. H., Guisan, A., & Buttler, A. (2006). Plant species richness and environmental heterogeneity in a mountain landscape: effects of variability and spatial configuration. *Ecography*, *29*(4), 573-584.
- Ferreira, L. V., & Stohlgren, T. J. (1999). Effects of river level fluctuation on plant species richness, diversity, and distribution in a floodplain forest in Central Amazonia. *Oecologia*, 120(4), 582-587.
- Fischer, M., Rudmann-Maurer, K., Weyand, A., & Stöcklin, J. (2008). Agricultural land use and biodiversity in the Alps. *Mountain Research and Development*, 28(2), 148-156.
- Foth, H.D. (1990). Fundamentals in Soil Science 8. Wiley, New York.
- Grime, J. P. (1973). Competitive exclusion in herbaceous vegetation. Nature, 242(5396), 344.
- Hothorn, T., Bretz, F. and Westfall, P. (2008). Simultaneous Inference in General Parametric Models. *Biometrical Journal* 50(3), 346--363.
- Kammer, P. M., & Möhl, A. (2002). Factors controlling species richness in alpine plant communities: an assessment of the importance of stress and disturbance. *Arctic, Antarctic, and Alpine Research*, 34(4), 398-407.
- Küffer, N., Gillet, F., Senn-Irlet, B., Job, D., & Aragno, M. (2008). Ecological determinants of fungal diversity on dead wood in European forests.
- Küffer, N., & Senn-Irlet, B. (2005). Diversity and ecology of wood-inhabiting aphyllophoroid basidiomycetes on fallen woody debris in various forest types in Switzerland. *Mycological Progress*, *4*(1), 77-86.
- Kuzemko A.A., Steinbauer M.J., Becker T., Didukh Y.P., Dolnik C., Jeschke M., Naqinezhad A., Ug^{*}urlu E., Vassilev K., Dengler J. (2016). Patterns and drivers of phytodiversity in steppe grasslands of Central Podolia (Ukraine). *Biodivers Conserv*, 25:2233-2250.
- Löbel, S., Dengler, J., & Hobohm, C. (2006). Species richness of vascular plants, bryophytes and lichens in dry grasslands: the effects of environment, landscape structure and competition. Folia Geobotanica, 41(4), 377-393.
- Łuczaj, Ł., & Sadowska, B. (1997). Edge effect in different groups of organisms: vascular plant, bryophyte and fungi species richness across a forest-grassland border. *Folia Geobotanica & Phytotaxonomica*, 32(4), 343-353.
- Mouw, J. E. B., Stanford, J. A., and Alaback, P. B. (2009). Influence of flooding and hyporheic exchange on floodplain plant richness and productivity. *River Research Applications*, 25:929-945.
- Ódor, P., Heilmann-Clausen, J., Christensen, M., Aude, E., Van Dort, K. W., Piltaver, A., ... & Van Hees, A. F. M. (2006). Diversity of dead wood inhabiting fungi and bryophytes in semi-natural beech forests in Europe. *Biological Conservation*, 131(1), 58-71.
- Oehl, F., Sieverding, E., Ineichen, K., Mäder, P., Boller, T., & Wiemken, A. (2003). Impact of land use intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of Central Europe. *Appl. Environ. Microbiol.*, *69*(5), 2816-2824.
- Parc Ela (n.D.). Was ist ein Naturpark? https://www.parc-ela.ch/de/parc-ela/was-ist-ein-naturpark (last accessed 23.08.2019).
- Pouska, M. V. (2011). *The role of wood decay fungi in the dynamics of a mountain spruce forest* (Doctoral dissertation, Institute of Entomology, Academy of Sciences of the Czech Republic).
- R Core Team (2018) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

- Sætersdal, M., Gjerde, I., Blom, H. H., Ihlen, P. G., Myrseth, E. W., Pommeresche, R., ... & Aas, O. (2004). Vascular plants as a surrogate species group in complementary site selection for bryophytes, macrolichens, spiders, carabids, staphylinids, snails, and wood living polypore fungi in a northern forest. *Biological Conservation*, *115*(1), 21-31.
- Schütz, M., Risch, A. C., Leuzinger, E., Krüsi, B. O., & Achermann, G. (2003). Impact of herbivory by red deer (Cervus elaphus L.) on patterns and processes in subalpine grasslands in the Swiss National Park. *Forest Ecology and Management*, 181(1-2), 177-188.
- 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 *Alpine biodiversity in Europe*(pp. 185-193). Springer, Berlin, Heidelberg.
- Turtureanu PD, Palpurina S, Becker T, Dolnik C, Ruprecht E, Sutcliffe LME, Szabo' A, Dengler J (2014). Scale- and taxondependent biodiversity patterns of dry grassland vegetation in Transylvania. *Agriculture, Ecosystems and Environment*, 182:15–24.
- Vittoz, P., Camenisch, M., Mayor, R., Miserere, L., Vust, M., & Theurillat, J. P. (2010). Subalpine-nival gradient of species richness for vascular plants, bryophytes and lichens in the Swiss Inner Alps. *Botanica Helvetica*, *120*(2), 139-149.
- Vonlanthen, C. M., Kammer, P. M., Eugster, W., Bühler, A., & Veit, H. (2006). Alpine vascular plant species richness: the importance of daily maximum temperature and pH. *Plant Ecology*, 184(1), 13-25.
- Wohlgemuth, T., Nobis, M. P., Kienast, F., & Plattner, M. (2008). Modelling vascular plant diversity at the landscape scale using systematic samples. *Journal of Biogeography*, *35*(7), 1226-1240.
- Zechmeister, H. G., Schmitzberger, I., Steurer, B., Peterseil, J., & Wrbka, T. (2003). The influence of land-use practices and economics on plant species richness in meadows. *Biological conservation*, *114*(2), 165-177.

Effects of environmental parameters on canopy height of vascular plants along an altitudinal gradient in alpine grasslands of Val Mulix (canton of Grisons, Switzerland)

Fabien Hiltebrand¹, Durelle Yolande Fossi Mevoutsa² & Urszula Drwęcka³

¹ZHAW Life Sciences und Facility Management Institute for Environment and Natural Resources, Biodiversity & Ecosystems, 8820 Wädenswil, Switzerland, <u>hiltefab@students.zhaw.ch</u>;

²ZHAW Life Sciences und Facility Management Institute for Environment and Natural Resources, Biodiversity & Ecosystems, 8820 Wädenswil, Switzerland, <u>fossidur@students.zhaw.ch</u>;

³University of Warsaw, Międzywydziałowe Studia Ochrony Środowiska, 00-927 Warsaw, Poland, <u>u.drwecka@student.uw.edu.pl</u>

Abstract

This study analysed the influence of environmental factors such as altitude, microrelief, slope aspect and inclination on the development of vascular plant traits, in particular canopy height in alpine grasslands. Topographical factors as well as vascular plant species and their traits were recorded in 18 10-m² plots along a 900 m elevational gradient from c. 1700 to 2600 m a.s.l in the Val Mulix of the Ela Regional Park in the canton Grisons in Switzerland. Both on-site measured and retrieved from LEDA database traits were analysed for comparition. Using data from LEDA database turned out to overestimate canopy height values. The CWM of the canopy height was examined with a multimodel inference approach using the same cover data derived from field sampling for both data sets. In both trait models, sampled traits and LEDA traits based and sampled trait models, elevation appeared as the most successful candidate model. Nevertheless, slope inclination and HLI (Heat Load Index) also showed some influence on canopy height of vascular plants in our study. Results slightly differed depending on data source.

Keywords: Alps, altitude, canopy height, functional diversity, Heat Load Index (HLI), inclination, LEDA database, microrelief, traits, vascular plants

Introduction

The composition of functional traits is increasingly recognized as a key element in better understanding the influence of environmental parameters on plant communities (Wüest et al., 2018). This study, conducted in Val Mulix in Swiss Alps focuses on the influence of some environmental variables such as altitude, microrelief, slope inclination, and Heat Load Index (HLI) on the traits of vascular plants, in particular canopy height. Indeed, most of the studies carried out generally concern the influence of environmental variables on the specific richness in the Alps.

Atlitude is concidered to be one of the most powerful environmental parameters influencing the species richness and dominance of plant species in alpine biotopes (Körner, 2007; Theurillat et al., 2003; Wang et al., 2007). Another parameters studied are the slope inclination which has an influence

on the variation of vegetation, particularly on the richness of species (Bennie et al., 2006; Dearborn and Danby, 2017) and the microrelief, which determines the relationship between the topography of the Alps and the richness of species (Rose and Malanson, 2012).

However, the objective of this study is to show the influence of environmental Parameters on the functional traits of plants (in particular canopy height) in grasslands of the Swiss Alps. To achieve this objective we have worked with our data on the traits of the collected plants and the functional traits of vascular plants obtained from the LEDA database (seelink <u>https://uol.de/en/landeco/download-and-service/databases/biological-traits-of-vascular-plants</u>) to assess functional diversity. The LEDA database is an important international database on plant traits being compiled to share the effort of all researchers in this field since measuring plant traits in site can be very time-consuming (Cordlandwehr et al., 2013). We have therefore extracted for our study the average values of vascular plant traits.

In the light of the literature, so far no one compared the results obtained from their own data on the of the vascular plants sampled and the databases on characteristics for the Alpine regions and assessed the implications for functional diversity studies. Therefore, we are trying to fill this gap by carrying out such a study with the example of canopy height at Val Mulix.

In view of the above, the research question for this study is: How to evaluate the functional diversity of vascular plants in the Val Mulix Alps from the data of the sampling plant traits and those of the LEDA databases?

Methods

Study area and field sampling

Our study was carried out in an alpine area of Switzerland, the Val Mulix in Parc Ela located in the canton of Grisons. Parc Ela is a regional nature park with an area of 548 km². Concerning the geology of the soil, it is made up of silica stones and its vegetation is mainly made up of grassland. Field sampling was conducted in 18 plots representing an elevational gradient in grasslands of Parc Ela in Switzerland (see Figure 1).



Fig. 1. Field sampling locations in Ela Park.

Plots were delimited with about 50 m intervals of altitude, from 1705 to 2592 m a.s.l. Each plot was square-shaped and 10-m² size.

In each plot all vascular plant species present (following the any-part-system) were recorded, as well as the estimated covers of each species and vegetation total. Also the measurements of traits were carried out: canopy height, leaf length and leaf width of one highest individual of each species found.

Additionally, following structural and environmental parameters were noted: elevation, coordinates, slope aspect, slope inclination, microrelief (maximum deviation of the soil surface from an idealised plane cutting through the plot), soil depth, ground layer height. elevation and coordinates of the plots were determined with a handheld GPS device with 4 m precision.

Statistical analysis

The basic approach of our analysis was to apply an identical methodological approach to the Community Weighted Mean (CWM) of the canopy height on the basis of two different trait data sets, namely trait data recorded by us and trait data from the LEDA trait database (Universität Oldenburg, 2019). The LEDA database provides trait data for many vascular plants and is often used as a reference database for calculating the functional diversity of plant communities. For both trait-data sources, the same cover data derived from field sampling was used to calculate the CWM.

The CWM of the canopy height was examined with a multimodel inference approach. Table 1 lists the environmental parameters that were used as model predictors. Soil parameters were not available at the time of analysis.

Predictor	Abbrev.	Unit	Туре	Min	Max
Elevation	Elev	[m.a.S.]		1705	2592
Inclination	slope	[°]		2	34
Aspect	Asp	[°] Northing		14	334
Max. Microrelief	maxMicro	[cm]		4	56.5
Heat Load Index	HLI	[-]		-0-524	0.512

 Table 1. Predictors used for multimodel inference.

All predictors were scaled before analysis. For this reason, the conversion of the slope from degrees to rad was waived. Before beeing scaled, exposure (aspect) was introduced as an ordinal variable by simplifying the increasing orientation to the south with increasing rank. Correlating predictors were removed if they exceeded a Paerson's correlation coefficient of 0.55 and showed lower model performance (measured with AICc).

The multimodel inference was executed with the MuMIn-package (Barton 2019) in R (R Core Team, 2019) and is bder Basisiased on Generalized Linear Models (GLM; Bates et al. 2019) with Gaussian distribution family and using a log-link function instead of commonly used identity because of the higher performance. Generalized Linear Mixed Effect Models were also tested, but caused difficulties due to the small data set (introduction of a random factor).

On the one hand, the Akaike weights (known as relative importance) of the individual predictors within all possible candidate models were of main interest. On the other hand, the estimated effect sizes of the averaged model from within the subset of the most ranked/performant models were also of interest. The model ranking was based on the delta AICc, whereas models with delta AICc ≤ 3 were used for averaging in respect to the law of parsimony especially regarding small datasets as surveyed in this article.

Results

Data

For 23% of the taxa (n=28/122) no trait data on canopy height were available in the LEDA database. On the basis of the remaining matching taxa (n=94), Figure 2 illustrates on the descriptive level an overestimation of canopy height using LEDA data. Figure 3 gives indications on how plots are affected by biases sourcing in missing canopy height data. This finally led to the exclusion of one Plot (C10SE) in further analysis.



Fig. 2. Comparison of the community weighted mean of canopy height between own sampled traits (y-axis) and traits derived from LEDA data-base (x-axis) from 94 species.





Candidate models

Aspect was highly correlated with the Heat Load Index (HLI; r = 0.79) and was therefore excluded from multimodel inferencing. The Maximum Microrelief showed some correlation with elevation (r = 0.59). Even though there seemed to be no evidence being generally correlated with elevation, this variable was excluded from the predictor set in order not to inflate model goodness. Tables 2 and 3 present the most successful candidate models derived from the chosen multimodel inference approach.

Table 2. Set of best ranked candidate models based on delta AICc <=3 examining the effect of available environmental parameters on the community mean canopy height derived from own sampled cover and trait data. W represents the Akaike weights of the respective models within all models (w full) and within the model subset (w subset). The listed subset of candidate models was used for model averaging based on the weights of w subset. The suffix .sc is for scaled data.

Candidate models	delta	AICc	w full	w subset
Y ~ Elev.sc	0.00	-25.96	0.670	0.80
Y ~ Elev.sc + slope.sc	2.81	-23.15	0.164	0.20

Table 3. Set of best ranked candidate models based on delta AICc <=3 examining the effect of available environmental parameters on the community mean canopy height derived from data base trait data (LEDA data- base). W represents the Akaike weights of the respective models within all models (w full) and within the model subset (w subset). The listed subset of candidate models was used for model averaging based on the weights of w subset. The suffix .sc is for scaled data.

Candidate models		delta	AICc	w full	w subset
Y ~ Elev.sc		0.00	-44.47	0.606	0.64
Y ~ Elev.sc	+ HLI.sc	2.15	-42.33	0.207	0.22
Y ~ Elev.sc + slope.sc		2.97	-41.50	0.137	0.14

Primarily, in both, LEDA based and sampled trait models, elevation appeared as the most successful candidate model and had in both cases a delta AICc of over 2 compared to the next better model (Tables 1 and 2). Their estimated weights (w full) differ about 9 %. Secondly, the most distinguishing difference between the two models is the selection of HLI by the LEDA based model. In terms of Akaike weight, the additional inclusion of inclination (slope.sc) to elevation lead to a 20 % higher weight in the sampled trait based model compared to the LEDA based model.

Relative importance and effect sizes of predictors

Figure 4 demonstrates the overall importance of elevation in the examined candidate models compared to the other considered predictors.



Fig. 4. Cumulated Akaike weights (relative importance) of all considered model predictors that were used for multimodel inference based on own sampled trait and cover data (left) and based on data base traits form LEDA database (right). The horizontal red line is drawn at 0.8, which is used as cut-off to differentiate between important and less important predictors.

The averaged model based on LEDA canopy height data resulted in a comparatively higher (negative) effect size of elevation (Figure 5). The opposite is the case when looking at inclination (slope.sc). Elevation as well as inclination have larger variance when using sampled canopy height data for modelling. Comparing the effect sizes of averaged vs. not-



0.0

-0.6

Effect size: -0.11

-0.4

-0.2

0.0

Heat Load Index (HLI) [-]

0.2

0.4

Adjusted Std. Error: 0.12

0.6

averaged model using the same candidate model, differences can be stated to be of minor amplitude when considering variance.

Discussion

Effect of elevation on the canopy height of vascular plants

From our analyses both approaches, for the sampled data and the traits data from the LEDA database shows that elevation influences the canopy height of vascular plants in Val Mulix. The canopy height decreases with elevation. This phenomenon has already been mentioned in the studies of Körner et al. (1986) and Pellissier et al. (2010) on the study of elevation on the canopy height of plants in the Alps.

These results can be explained by temperature changes. High mountain environments are exposed to faster temperature changes than environments at lower altitudes. This phenomenon leads to the increase of global radiation at low altitude and a decrease in radiation at high altitude (Tudoroiu et al., 2016).

Our results show that elevation superimposes strongly other effects on canopy height. Since an increase in elevation provides major changes in climatic conditions it leads to a conclusion that climate is dominant limiting factor, especially in terms of temperature conditions. Some studies underline the role of large temperature fluctuations, especially when temperature oscillates around 0°C and it leads to repeating freezing and thawing of the soil (Klimes, 2003).

Effect of inclination (slope) on the canopy height of vascular plants

The slope analysis in our study based on the sampled data and the traits data from the LEDA database coincides in both cases. This observation may result in the fact that the slope is not affected by measurement errors in the field.

Our results showing influence of slope inclination on canopy heights correspond with literature. According to Duan et al. (2015) terrain-induced canopy height differences are determined mainly by the slope gradient. Canopy height generally decreases as slope gradient increases. Also Breidenbach et al. (2008) suggested that as the slope gradient increased, models neglecting slopes would overestimate tree height.

Several studies show that slope has a very important role in soil temperature in alpine environments, depending on whether the slope is oriented north or south (Dearborn and Danby, 2017; Scherrer and Körner, 2009). as temperature influences the canopy height of plants, we can say that the slope indirectly influences the canopy height in alpine environments.

Effect of HLI (Heat Load Index) on the canopy height of vascular plants

The influence of the Heat Load Index on the height of the canopy was studied from the data of the traits of the LEDA database. Based on the analysis, we can see that Heat Load Index influences the canopy height. At high altitude the temperatures are low the canopy height decreases and at low altitude the temperatures are elevated and the canopy height increases. This observation is in accordance with the studies by Dalle Fratte et al. (2019) on the sensitivity of the canopy height to different temperature values.

The functional diversity of vascular plants has been measured in Val Mulix by the height of the canopy; it depends on the functioning of the ecosystheme (Goswami et al., 2017). This is the reason why in

alpine environments, with the different environmental variables such as elevation, slope and HLI (Heat Load Index) we can predict the height of the canopy. We can therefore say that the the plants traits extracted from the LEDA database and the traits of the plants harvested in the field made it possible to determine the influence of the environmental variables on the traits of vascular plants, particularly canopy height in the alpine environment in Val the Mulix. It is in function of its environmental variables that the particular trait (canopy height) of vascular plants in alpine environments develops along the altitudinal gradient.

Implications

As, according to our study, elevation seems to be the most powerful abiotic factor affecting canopy height of vascular plants in alpine grasslands it leads to a conclusion that direct reason of these trait differences is climate. Decrease of canopy height with elevation might be concidered as a result of lack of time necessary to built larger organs due to shorter vegetation periods (Bauman et al., 2016) as well as an adaptation to other high mountain climate conditions, for example smaller size provides less exposure for strong wind and rapid run-off of rainwater.

Acknowledgements

We would like to thank all the team that organized International Summer School Biodiversity Monitoring in Alpine Environments. We are grateful to all our teachers for their contribution and their help in field sampling as well as data analysis so it was possible for this study to be conducted successfully.

References

Bartoń, K., 2019. MuMIn: Multi-Model Inference. URL: https://CRAN.R-project.org/package=MuMIn.

- Bates, D., Mächler, M., Bolker, B. and Walker, S. , 2015. Fitting Linear Mixed-Effects Models Using Ime4. Journal of Statistical Software, 67, 1-48.
- Baumann, E., Weiser, F., Chiarucci, A., Jentsch, A., and Dengler, J. (2016). Diversity and functional composition of Scheepens, J.F., Frei, E.S., and Stöcklin, J. (2010). Genotypic and environmental variation in specific leaf area in a widespread Alpine plant after transplantation to different altitudes. Oecologia 164, 141–150.
- Bennie, J., Hill, M.O., Baxter, R., and Huntley, B. (2006). Influence of slope and aspect on long-term vegetation change in British chalk grasslands. J. Ecol. *94*, 355–368.
- Bloor J., Cantarel A., Soussana J.F. (2013). Four years of simulated climate change reduces above- ground productivity and alters functional diversity in a grassland ecosystem. Journal of Vegetation Science 24, 113-126.
- Breidenbach, J., Koch, B., Kändler, G., and Kleusberg, A. (2008). Quantifying the influence of slope, aspect, crown shape and stem density on the estimation of tree height at plot level using lidar and InSAR data. Int. J. Remote Sens. 29, 1511–1536.
- Cordlandwehr, V., Meredith, R.L., Ozinga, W.A., Bekker, R.M., Groenendael, J.M., and Bakker, J.P. (2013). Do plant traits retrieved from a database accurately predict on-site measurements? J. Ecol. *101*, 662–670.
- Dalle Fratte, M., Brusa, G., Pierce, S., Zanzottera, M., and Cerabolini, B.E.L. (2019). Plant trait variation along environmental indicators to infer global change impacts. Flora *254*, 113–121.
- Dearborn, K.D., and Danby, R.K. (2017). Aspect and slope influence plant community composition more than elevation across forest-tundra ecotones in subarctic Canada. J. Veg. Sci. 28, 595–604.
- Duan, Z., Zhao, D., Zeng, Y., Zhao, Y., Wu, B., and Zhu, J. (2015). Assessing and Correcting Topographic Effects on Forest Canopy Height Retrieval Using Airborne LiDAR Data. Sensors *15*, 12133–12155.
- Goswami, M., Bhattacharyya, P., Mukherjee, I., and Tribedi, P. (2017). Functional Diversity: An Important Measure of Ecosystem Functioning. Adv. Microbiol. 07, 82–93.

Klimes, L. (2003). Life-forms and clonality of vascular plants along an altitudinal gradient in E Ladakh (NW Himalayas). Basic Appl. Ecol. *4*, 317–328.

Körner, C. (2007). The use of altitude in ecological Research.html. 6.

- Körner, Ch., Bannister, P., and Mark, A.F. (1986). Altitudinal variation in stomatal conductance, nitrogen content and leaf anatomy in different plant life forms in New Zealand. Oecologia *69*, 577–588.
- Pellissier, L., Fournier, B., Guisan, A., and Vittoz, P. (2010). Plant traits co-vary with altitude in grasslands and forests in the European Alps. Plant Ecol. 211, 351–365.
- R Core Team, 2019.R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. URL: https://www.R-project.org/.
- Rose, J.P., and Malanson, G.P. (2012). Microtopographic heterogeneity constrains alpine plant diversity, Glacier National Park, MT. Plant Ecol. 213, 955–965.
- Scherrer, D., and Körner, C. (2009). Infra-red thermometry of alpine landscapes challenges climatic warming projections: thermometry of alpine landscapes. Glob. Change Biol. no-no.
- Theurillat, J.-P., Schlüssel, A., Geissler, P., Guisan, A., Velluti, C., and Wiget, L. (2003). Vascular Plant and Bryophyte Diversity along Elevation Gradients in the Alps. In Alpine Biodiversity in Europe, L. Nagy, G. Grabherr, C. Körner, and D.B.A. Thompson, eds. (Berlin, Heidelberg: Springer Berlin Heidelberg), pp. 185–193.
- Tudoroiu, M., Eccel, E., Gioli, B., Gianelle, D., Schume, H., Genesio, L., and Miglietta, F. (2016). Negative elevation-dependent warming trend in the Eastern Alps. Environ. Res. Lett. *11*, 044021.
- Universität Oldenburg, 2019. Biological traits of vascular plants. Visited 22.08.19, URL: https://uol.de/en/landeco/download-and-service/databases/biological-traits-of-vascular-plants
- Wang, C.T., Long, R.J., Wang, Q.J., Ding, L.M., and Wang, M.P. (2007). Effects of altitude on plant- species diversity and productivity in an alpine meadow, Qinghai Tibetan plateau. Aust. J. Bot. 55, 110.
- Wüest, R.O., Münkemüller, T., Lavergne, S., Pollock, L.J., and Thuiller, W. (2018). Integrating correlation between traits improves spatial predictions of plant functional composition. Oikos *127*, 472–481.

Appendices

The appendices of this document are in the form of an attached file and contain:

- The set of R-Sckript used for the analysis of our data
- The different buffers
- Exel tables of our data collected in the field
- The different sites from which data on vascular plant traits were collected

Monitoring of small mammals' diversity with Mostela camera trapping along an altitudinal gradient in Val Mulix, Switzerland

Luca Hoppler^{*a*}, Sylwia Budzynska^{*b*} & Szymon Sitek^{*b*}

a Zurich University of Applied Sciences b University of Warsaw

Abstract

The study of diversity and relative abundance of small mammals along the altitudinal gradient has received great attention in recent decades. It turned out that species richness usually peaks at midaltitudes. In the present survey, the diversity of small mammals was studied in Val Mulix (canton of Grisons, Switzerland) along an altitudinal gradient up to over 2600 m a.s.l., in order to close knowledge gaps of small mammals' distribution and habitat use in the alpine zone. For this purpose, 10 new camera traps, so-called Mostela, were used over a one-week period in summer to obtain maximum information with the least possible effort and little intervention in animal welfare. In total 225 visits of 7 different small mammal species could be registered. There was a significant decrease of species richness with increasing altitude. The number of species detected per location was rather low and only a few species could be detected in more than two cases. The most abundant species in our research was *Microtus arvalis* which was only present in open Grassland between 2360 and 2460 m a.s.l. However, the species with the greatest spread along the altitudinal gradient was *Apodemus sp.* Overall, almost all expected species could be recorded with the Mostela with comparably little effort. However, certain restrictions remain, such as the limited determination of closely related species. In addition, many results were limited due to the small sample size.

Keywords: alpine zone, altitudinal distribution, camera traps, Eulipotyphla, habitat preferences, Mostela, Mustelidae, Parc Ela, Rodentia, small mammals

Introduction

Mountains are characterized by strong elevational gradients, which have a direct impact on species richness and therefore received much attention in ecological research (Lomolino 2001, Körner 2007). Elevational gradients are characterized by a sequence of different habitats, which are directly related to climatic factors (McCain 2005). Many studies have demonstrated, that species richness tends to increase with altitude, peaking at mid-altitudes and going down again, creating a hump-shaped picture (McCain 2005, Rickart 2008). However, species richness is not only dependent on elevational gradients, but there is also a complex interaction with other environmental factors (Bertuzzo et al. 2016). The distribution of mountain species is affected by significant environmental restrictions, including extreme temperature conditions including large daily fluctuations, high UV radiation, strong winds, abundant rainfall, long-lasting snow cover, open habitats (Grabherr et al. 1994, Rahbek 2005).

The Alps are the most intensively used mountains in the world. The diverse mosaic of cultural and natural landscape thus provides habitats for numerous endemic species and a high biodiversity (SCNAT 2019). Frequent animals in the Alps are insectivores (Eulipotyphla) and rodents (Rodentia). They are often summarised as small mammals, which include non-flying mammals weighing less than 1 kilogram. Small mammals often differ in their habitat requirements and their distribution (Müller et al. 2010). It has already been shown in different climate zones that elevation gradient has an impact on diversity, distribution and abundance of small mammals (Patterson et al. 1989, Sánchez-Cordero 2001, McCain 2005, Rickart 2008, Sakane 2019). Also in the Alps, the height distribution of small mammals has already been studied several times (Müller 1972, Reiter & Winding 1997, Ladurner & Cazzolli 2003, Milana et al. 2019). However, comparatively few studies exist, which also include altitudes above 2000 m a.s.l. (Marchesi et al., 2014). There is especially a lack of data on the interactions of small mammals with vegetation and other habitat structures in the alpine zone (Marchesi et al., 2014).

Monitoring species is crucial, because information on distribution, population size and population dynamics is the basis for red lists and species protection measures. Traps are a key technique for monitoring the populations of small mammals (Flowerdew et al. 2004). However, traps involve different techniques that vary in performance (Anthony et al. 2005). Combinations of different trap types can be used to get the widest representation of the local mammalian fauna. There are two different approaches for monitoring small mammals: invasive methods and non-invasive methods. With invasive methods, like Longworth or Sherman traps (Hoffmann et al. 2010), the animals are caught and can often directly be recognised. However, there is a relatively large effort to control the traps and the animals are most likely stressed when caught. Non-invasive methods do not catch the animals. Commonly used methods are camera traps, feeding marks, footprint tunnels or hair traps. However, many of the conventional methods for detecting small mammals are still effortful and can only be carried out at certain points. For this reason, the ZHAW is developing methods that require less time and money, offer higher data quality and greater knowledge yield and fulfil animal welfare (ZHAW 2019). The "TubeCam" and "Mostela" are such promising and relatively new methods to detect small mammals, by attracting them into a box and recording them with a camera trap.

The purpose of this work is to investigate, whether it is possible to detect a change in species richness of small mammals along an altitude gradient in the Swiss Alps with the relatively new Mostela trap. The following research questions were formulated: (1) Which small mammal species can be detected with the Mostela in the study area? (2) How does the species spectrum change along the altitudinal gradient? (3) Which habitats are used by each species? (4) What are the activity patterns of each species? (5) Is the Mostela camera trap suitable for capturing the richness and abundance of small mammal species in Swiss Alps?

Methods

Study area

The study area selected was the Val Mulix in the canton of Grisons, Switzerland (Figure 1). Val Mulix is located in the municipality of Bergün Filisur and is part of the nature park "Parc Ela". The valley belongs to the biogeographical region of the eastern Central Alps and extends from an elevation of around 1750 to mountain peaks over 3100 meters above sea level. The area is drained by the Ava da Mulix, which belongs to the river system of the Rhine.



Fig. 5. Location of Val Mulix (red rectangle) in canton of Grisons (orange border), Switzerland. Geodata (swissALTI3D Hillshade) copyright © 2019 by swisstopo.

Field sampling and species determination

To record the species spectrum of the small mammals along the altitudinal gradient in the Val Mulix, socalled Mostela photo traps were used. They consist of a box, 2 tubes, a scent board and a camera, which take colourful pictures (Figure 2). The scent board was rubbed with dirt, peanut butter and dog goodie to attract the animals. After installation, the box was cover with vegetation or branches to prevent extreme heating-up in the sun. The photo traps are triggered as soon as an animal is registered by the passive infrared sensors.



Fig. 6. Interior of the Mostela and cover after setting up the trap.

A total of 10 Mostela traps were set up between approx. 1750 and 2650 m a.s.l. along the hiking path (Figure 3). The vertical distance between the Mostela's was about 100 meters. The traps were installed within a 100 m² square, in which vegetation, cover and topographical parameters were recorded. Traps m01 to m04 were located in the forest, while traps m05 to m10 were set up in shrubs or open grasslands. The Mostela were always placed along or in the most promising structures within the plot. After setting up the Mostela, the coordinates and height of each location were recorded with a GPS. In addition, every location was photographed (Appendix 1).

The traps were set up on 15. (m01 – m05) and 16. (m06 – m10) of August and remained till 22. of August. After the traps were retrieved, all images were manually checked. The animals were determined according to external characteristics as far as possible following the key of determination by Reifler-Bächtiger & Stephani (2019, ZHAW unpublished). If a determination of a species according to external characteristics was not possible, the animals were grouped as "not identifiable individuals" ("nid"). To get a measure of relative abundance, the number of visits was also recorded. It was defined, that if the time between two images of the same species is less than 5 minutes, it is the same individual. In addition, the beginning and the end of each visit were recorded. The end time was defined as the moment when the animal was last seen in the picture.



Fig. 7. Locations of the Mostela photo traps in Val Mulix, canton of Grisons (Switzerland) numbered from lowest (m01) to highest (m10) elevation. Geodata (general plan) copyright © 2019 by canton of Grisons.

Statistical analyses

General data processing

The data processing, analyses and statistical tests were performed using the software R (R Core Team 2019). General data processing steps and plots were done primarily with the "tidyverse" package
(Wickham 2017) and some extra feature from other packages (R-package ggExtra, Attali & Baker2018; R-package: ggfortify, Horikoshi & Tang; R-package: ggpubr, Kassambara 2019; R-package: GGally, Schloerke et al. 2018). In order to examine the temporal aspects of visits of small mammals in the Mostela, the R-package "lubridate" was used (Grolemund & Wickham 2011). To perform statistical test, additional packages like vegan (Oksanen et al. 2019) where used. The associated R script can be found in the supplemented material.

Habitat use

If a species has been detected in more than three Mostela traps, the influence of structural factors on habitat use could be analysed by generalized linear models (GLM) with a binomial error structure (link = logit). For this purpose, the frequency data (number of visits) was converted into presence-absence data.

Starting from an initial set of predictor variables from the vegetation mapping at the same places (Appendix 2), all metric variables were tested for normal distribution (Appendix 3). In a second step, a pairwise correlation between the predictor variables (Spearmans' R) was tested. There was a strong correlation between many variables, especially the elevation correlates strongly with tree layer and stones and dead wood correlates with the tree layer. But due to the small sample size, all variables are retained.

Afterwards a global model with all variables was created. Subsequently, using the "dredge" function (Rpackage MuMin, Barton 2019), all possible combinations of the variables in the global models were tested in order to find the most parsimonious model according to the AIC. From all models that can be considered statistically equivalent (Δ AIC \leq 2, Burnham & Anderson 2002), the one that was most plausible from an ecological point of view was chosen.

To estimate the relative relevance of the predictor variables in the final model, the difference in the AIC (Δ AIC) between the reduced (without corresponding variable) and the final model was calculated for each variable. To determine the model quality, the AUC (Area Under the Curve) under the Receiver Operating Characteristic (ROC) curve (R-package pROC, Robin et al. 2019) and the Kappa statistic (R-package caret, Kuhn 2019) were calculated.

Results

Catch success and species richness

Altogether more than 30'000 single images were evaluated. Based on these pictures, 225 continuous "visits" of animals were determined (counting the same individual several times is possible). No animals could be detected in the two highest traps. The highest number of visits was recorded at an altitude of 2361 m a.s.l. (Trap m07).

Seven different small mammal species could be identified in the 10 installed Mostela traps in the oneweek period (Table 1). The species of the genus *Apodemus* and the *Sorex araneus* group could not be further determined. In addition, the species affiliation in 29 visits were not identifiable in the pictures ("nid").

	Elevation [m a.s.l.]									
Species	1753	1863	1940	2032	2152	2254	2361	2462	2564	2639
Apodemus sp.		24	1	4		1				
Chionymus nivalis					22					
Microtus arvalis							83	38		
Mustela erminea								1		
Myodes glareolus	4			1						
Sorex araneus aggr.	3	2	2							
Sorex minutus	7		3							
"nid"	3	2	2	1	17		3	1		
Species total [n]	3	2	3	2	2	1	2	2	0	0

Table 3. Species list with number of "visits" (as estimation of the abundance) per elevation ("nid" = not identifiable species

From the family of the shrews (Soricidae), two species were detected: The forest shrew (*Sorex araneus aggr.*) and the Eurasien Pigmy Shrew (*Sorex minutus*). The voles (Arvicolidae) were represented by the Bank vole (*Myodes glareolus*), the European snow vole (*Chionymus nivalis*) and the Common vole (*Microtus arvalis*). From the family of Murids (Muridae), only animals of the genus *Apodemus* could be determined. In addition, a representative of the Mustelidae family was recorded with the stoat (*Mustela erminea*) (Figure 4).



Fig. 8. A selection of different pictures of small mammals in the Mostela (top left: Mustela erminea, top right: Apodemus sp., bottom left *Sorex araneus* aggr., bottom right *Microtus arvalis*).

The highest number of species was found on low elevations. Species richness of small mammals very significantly decreased on average by 1 per 350 m of elevation (equation: y = 8 - 0.003x, $F_{1,8} = 18.36$, p = 0.003, $r^2 = 0.697$, Figure 5).



Fig. 9. Linear model of species richness of small mammals depending on the elevation.

Relative abundance and height distribution of the individual species

The two shrew species were only present at an elevation below 2000 m a.s.l. (Figure 6). There were only little differences between the number of visits in the different traps. *Sorex minutus* was not present in the trap m02 at 1863 m a.s.l.

From the three vole species, *Microtus arvalis* and *Chionymus nivalis* were only found in open grass lands above 2100 m a.s.l., while *Myodes glareolus* was only present in two traps below 2100 m a.s.l in the forest. *Microtus arvalis* was the most abundant species in terms of number of visits per trap. On 2361 m a.s.l. twice as many visits of *Microtus arvalis* were detected as on 2462 m a.s.l. The number of visits by *Chionymus nivalis* was slightly lower. Visits of *Myodes glareolus* in a trap were relatively rare (Figure 6).

Apodemus sp. was found between 1860 and 2250 m a.s.l., but was not present in the trap on 2152 m a.s.l. By far the most frequently visited trap by Apodemus sp. was on 1863 m a.s.l. *Mustela erminea* was only recorded by a single individual on 2462 m a.s.l. (Figure 6).



Fig. 10. Comparison of relative abundance (number of visits) of the individual species on different elevations

The percentage share and composition of each species at the different elevation levels (based on the number of visits) are shown in Figure 6 and Figure 7. The first similar group in terms of species composition was between approx. 1700 up to 2000 and 2250 m a.s.l., dominated by *Sorex araneus, Sorex minutus, Myodes glareolus* and *Apodemus sp.* The second similar group was between approx. 2300 and 2500 m a.s.l., dominated by *Microtus arvalis* and *Mustela erminea. Chionymus nivalis* stand alone on 2150 m a.s.l.



Fig. 11. Percentage share of each species at the different elevations.



Fig. 12. Close-up in species composition between individual heights with non-metric direction scaling system (NMDS)

Habitat use

Due to the criteria defined in Chapter 2.3, analysis of habitat use came only into question for *Apodemus sp.* Thus, the presence and absence of *Apodemus sp.* was analysed in relation to environmental variables with GLM. The model selection resulted in 8 statistically equivalent models (Δ AIC \leq 2 models) (Table 2).

Table 4: Result of the model selection for presence-absence of Apodemus sp. using the "dredge" function. Selected model is highlighted in greyish blue.

ID	Intercept	D.wood	elevation	Herb.l	Inclin	Mean_soil	Mean_veg	Shrub.l	Stones	Tree.l	df	logLik	AICc	delta	weight
34	-108.31	10.63	-	-	-	-	6.21	-	-	-	3	-1.5E-10	10.0	0.000	0.132
66	-72.41	11.07	-	-	-	-	-	2.97	-	-	3	-2.1E-10	10.0	0.000	0.132
81	-69.58	-	-	-	-	1.95	-	2.51	-	-	3	-2.4E-10	10.0	0.000	0.132
69	-318.18	-	-	3.65	-	-	-	7.16	-	-	3	-3.2E-10	10.0	0.000	0.132
161	-40.94	-	-	-	-	-	10.10	-	-7.45	-	3	-3.4E-10	10.0	0.000	0.132
289	-384.38	-	-	-	-	-	28.18	-	-	9.84	3	-5.7E-10	10.0	0.000	0.132
49	-694.58	-	-	-	-	9.61	47.89	-	-	-	3	-1.1E-09	10.0	0.000	0.132
65	-2.35	-	-	-	-	-	-	0.33	-	-	2	-2.7E+0	11.0	1.025	0.079

No variable was considered in all models. The proportion of the shrub layer and the mean vegetation height were most often represented in the models, but there was no model which considered both variables. The proportion of dead wood and mean soil depth were taken into account in two models. The remaining variables were only represented in one or no model (elevation and inclination).

Finally, the model that takes the shrub layer and the amount of dead wood into account, has been chosen (ID 66, tab), since these two variables are probably best suited to represent the shelter possibilities from an ecological point of view. The more deadwood present and the higher the share of the shrub layer, the greater the likelihood of the presence of Apodemus sp. (AUC = 1). The shrub layer explains a slightly higher proportion of the variance (Δ AIC = 5.17) than deadwood (Δ AIC = 3.31).

Activity patterns

Differences in the daytime activity patterns were found between the individual species (Figure 9). *Microtus arvalis* was similarly active both during the day and at night. The two shrews were also detected both during the day and at night. However, *Chionymus nivalis* and *Apodemus sp.* showed a preference of the night hours.



Fig. 13. Number of visits of the different species grouped by daytime

Attractivity of the Mostela

Once the animals were in the Mostela, they remained in for different periods of time (Figure 10). There was a significant difference of the duration within the trap among the species (ANOVA, p < 0.001, $F_{5, 189} = 7.94$). Individuals of *Microtus arvalis* and *Chionymus nivalis* remained on average over 5 min in the Mostela. Animals from the genus of *Apodemus* were less long in the trap. *Myodes glareolus* was on average as well only briefly in the Mostela. The two shrews were even shorter in the Mostela. Their stay lasted only a few seconds on average.



Fig. 14. Comparison of the mean duration within the Mostela between the individual species.

If the number of visits per case and day is summed up over the examination period, it can be seen, that only in the cases m07, m05 and m02 a slight saturation was achieved (Figure 11). In the other cases, the number of visits per day remains relatively constant.



Fig. 15. Cumulative sum of visits per trap and time over the study period.

Discussion

Catch success and species richness

With a total of 7 small mammal species, the documented species spectrum was about the expectations. During the same period, catches with life traps of the type "Longworth trap" were carried out on Alp Flix for around one and a half days (Figure 12). During this campaign, a total of 9 small mammal species were detected (unpublished data Dr. J. P. Müller). Neomys fodiens, Pitymys subterraneus, Microtus lavernedii and Mustela nivalis could not be detected in the Val Mulix but were present on the Alp Flix. In contrast, *Chionomys nivalis* and *Mustela herminea* caught in Val Mulix were not detected on Alp Flix.

The proof of small mammal species also depends on the examined habitat types (Marchesi et al. 2014). On Alp Flix, predominantly fens, wetlands and stream banks were surveyed. *Neomys fodiens* and partly also *Pitymys subterraneus* prefer moist habitats along stream banks (Marchesi et al. 2014, Müller et al. 2010). Such habitats have not been studied in the present work, which may explain the absence of these species. On the other hand, *Chionomys nivalis* prefers clefts in stones and screes at higher altitudes (Müller et al. 2010). Such habitats were rather studied in Val Mulix than on Alp Flix. *Microtus agrestis / M. lavernedii* were also missing in the Mostela in the Val Mulix. New genetic studies have shown that *Microtus agrestis* and *Microtus lavernedii* must be considered as separate species (Graf 2019). However, the two species cannot be distinguished morphologically. In comparison with *Microtus arvalis, M. agrestis* doesn't reach the same altitude (Müller et al. 2010), what could be a reason for her missing in Val Mulix. The proof of the two mustelid species, *M. herminea* and *M. nivalis* can be considered as random findings. Both species are still widespread in the canton of Grisons and colonise habitats of almost all altitudes (Müller et al. 2010).



Fig. 16. Life trap of the type "Longworth trap" which was used on Alp Flix.

Another species which is widespread in the investigated altitudes and whose occurrence in the canton of Grisons is proven, is *Sorex alpinus* (Marchesi et al. 2014, Müller et al. 2010). She may not have been detected because her rare occurrence in larger populations (Müller et al. 2010). Also not documented were the dormice (Gliridae). With exception of the Garden dormouse, dormice like to climb on trees and shrubs (Müller et al. 2010) and are therefore rarely detected with bottom traps like the Mostela.

One problem was the determination of species based on morphological criteria. In almost every Mostela, some individuals could not be assigned to a species due to insufficient image capture. However, the proportion of unidentifiable individuals was rather small at around 13% of all visits. Another problem was the determination of closely related species. Animals of the genus *Apodemus*, of which potentially three species can occur in the area, and the *Sorex araneus* group, also with three potential species, cannot be identified by external characteristics (Müller et al. 2010). The only way to determine these species is the removal of tissue samples and subsequent genetic analysis (Figure 13).



However, the animals would have to be caught and slightly anesthetized. The implementation of such an intervention also requires an animal test permit from the cantonal authorities.

Fig. 17. Sampling of tissue for genetic analysis, which is often necessary for species determination.

In the present study, a significant decrease in the species richness of small mammals was detected with increasing altitude. A peak of species richness on mid-level elevation, as often found in other studies (McCain 2005, Rickart 2008), could not be detected. Marchesi et al. (2014) found in a comprehensive study on Alp Flix only a small difference in the diversity of small mammal species between the subalpine and alpine stages. But the authors were able to detect a change in dominance ratios of the individual species and a tendency of a decline in catch success with increasing altitude. As the abundance of a species decreases, the likelihood of detecting a species also decreases. It can therefore be assumed, that due to the very small number of Mostela traps, the range of species in the current study was not recorded in a representative manner, especially at higher altitudes. In addition, the sites were mostly selected for vegetation ecology. Therefore, especially at higher altitudes, optimal habitats for small mammals have not always been studied. Especially riverbanks and screes, which attract several species (Marchesi et al. 2014, Müller et al. 2010), were not considered in the present study. In order to reliably record the species richness of small mammals over the altitudinal gradient, the use of more traps is necessary. Also, all different habitat types on each altitude should be investigated. Thus, the influence of

Relative abundance and height distribution of the individual species

The densities and distribution of the individual species in the Val Mulix are compared below with the cantonal distribution (Müller et al. 2010) and the results of Marchesi et al. (2014), which examined the small mammal fauna at a comparable altitude on the nearby Alp Flix, where also long-term observation series of small mammals are available.

Shrews

The two species of shrews (*Sorex araneus aggr. & S. minutus*) were detected in the Val Mulix only at the lowest elevations and in rather low densities. On Alp Flix, however, these two species colonise almost the entire altitudinal gradient up to the highest level (Marchesi et al. 2014). In the canton of Grisons, both species are widespread, with the highest densities in the area of the tree line (Müller et al. 2010).

Voles

Microtus arvalis was by far the most common species in Val Mulix in terms of total number of visits. However, she was only detected in the two Mostela's on 2360 and 2460 m a.s.l. On Alp Flix she was found over the entire altitudinal gradient but reached the highest densities in the same altitude as in Val Mulix on heavily grazed areas (Marchesi et al. 2014). By far the most common species in the study on Alp Flix by Marchesi et al. (2014) was *Chionomys nivalis*, which became more and more frequent with increasing altitude. In Val Mulix she was detected only in one Mostela at 2150 m a.s.l. *Chionomys nivalis* is widespread in the canton of Grisons above the tree line up to 3000 m a.s.l (Müller et al. 2010). Their occurrence was therefore expected in the Val Mulix up to the topmost Mostela. The third vole in the Val Mulix was *Myodes glareolus*. It was detected in 2 out of 4 forest locations below 2100 m. She typically lives in forests, hedges and shrubbery. In the canton of Grisons, she also extends beyond the tree line, provided that enough cover is available (Müller et al. 2010). On Alp Flix, the species also reaches the potential tree line where dwarf shrubs still grow (Marchesi et al., 2014). *Pitymys subterraneus*, which was first detected 2008 in the Albula Valley during of the GEO day of biodiversity (Schmid & Müller 2010), could not be documented in this study.

Murids

The only murid species in Val Mulix was *Apodemus sp*. She was present in 4 Mostelas up to 2250 m a.s.l. The highest densities were recorded on 1860 m a.s.l. There are three species of *Apodemus* in the canton of Grisons: *Apodemus sylvaticus*, *A. flavicolis* and *A. alpicola*. All three species are often sympatric. But *A.* sylvaticus and *A. flavicolis* are more likely in the forest or near settlements and *A. alpicola* is often more abundant at higher altitudes. It is therefore probable that in Val Mulix at least two different *Apodemus* species have been detected: In the forest rather *A. sylvaticus* or *A. flavicolis* and above the tree line rather *A. alpicola*. Also on Alp Flix, *A. alpicola* is the only *Apodemus* species at higher elevations (Marchesi et al., 2014).

In the present study, the number of visits was used as a measure of abundance. In total 225 visits were recorded. It must be considered, that the number of visits is not necessarily equal to the number of individuals. On the one hand, it should be remembered that the number of visits depends on the time limit between two images that has been defined and it cannot be verified when the same individual returns to the Mostela. On the other hand, it was observed that the single species behaved differently in the Mostela. For instance, relatively many visits of *Microtus arvalis* in Mostela 07 and 08 have been recorded. Due to the long stay, the shifting of nesting material and the recurring observations of "pairs" (Figure 14), it is possible that the same individuals tested the Mostela as a nesting site and thus kept returning. In that case, the number of individuals would be significantly overestimated. In contrast, the Shrew species only last for short time in the Mostela. A comparison of the abundances between the species is thus hardly possible.





Fig. 18. Shifted nesting material in Mostela 07 by Microtus arvalis (top right and left) and probably a "couple" of Microtus arvalis.

Furthermore, technical problems cannot be excluded. For instance, the very few pictures in the Mostela m06 and the absence of animals in two highest Mostela's (m09 and m10) are difficult to explain based on our data.

Habitat use

The habitat use was studied only with presence absence data for *Apodemus sp.*, as it was the only species present in more than 4 Mostela. It turned out that in particular the average vegetation height, the share of the shrub layer and the deadwood had a strong positive influence on the habitat choice. These factors well reflect the three-dimensional structure of the habitat, which seems to be important for *Apodemus sp.* (Müller et al. 2010). Mean soil depth was also positively associated with *Apodemus sp.* occurrence. However, since *Apodemus* does not dig corridors, this factor seems less important from an ecological point of view. The proportion of stones was the only variable that was negatively associated with the occurrence of *Apodemus sp.* Marchesi et al. (2014) also found that *Apodemus alpicola* tends to avoid boulders. On the other hand, the authors found a positive correlation with the structure type "pasture" and the *Apodemus alpicola* occurrence.

The habitat choice of *Apodemus* was correctly predicted in the studied area with the final model in all 10 Mostela traps (AUC = 1, Kappa statistic = 1). However, the coefficients of the final model showed very high standard errors and no significance. This is probably due to the very small sampling size and the large variance in the data.

Activity patterns

In the present study we found that the different small mammal species showed different patterns of activity. The shrew species were active both during day and during night. Ivanter and Makarov (2002)

found, that the activity of *Sorex araneus* is characterized by two peaks of activity, in the morning and in the evening and that the season plays a role in the distribution of animal activity over the day. Also, in the present work there seems to be a tendency towards activity in the early morning and again in the afternoon to evening. Due to the small sample size, however, this cannot be conclusively assessed. Also *Microtus arvalis* was active more or less 24 hours. Similar has already been observed in other studies, but there were pronounced seasonal changes in vole activity patterns with less nocturnal behaviour in winter than in summer (Hoogenboom et al. 1984). In contrast, *Apodemus sp.* showed a preference for nighttime hours. The same has been observed with *Apodemus flavicolis* (Wójcik & Wołk 1985). But differences in the pattern of activity are not only known for different species, but also for the different sexes and age groups (Wójcik & Wołk 1985).

Attractivity of the Mostela

As already discussed above, there was a significantly difference in the duration of a stay between the species. This could be an indication that the Mostela is different attractive for the individual species and therefore the probability of a proof is not the same for all species. In order to test this thesis, however, additional investigations would have to be carried out. For example, small mammals could be tagged with a transponder and the Mostela equipped with an antenna that registers the tagged animals. On the one hand, this could be used to investigate the probability of detecting a species with the Mostela and, on the other hand, make a comparison between the abundance (capture-recapture) and the number of visits by individuals would become possible.

In addition, the investigation period of one week is probably rather short, since not in all Mostela a saturation in the number of visits was observed.

Overall, the functionality of the Mostela can be regarded as very positive. It was possible to detect a comparable species spectrum as with live traps on the Alp Flix. Compared to the classic live traps, the Mostela has the advantage that the traps do not have to be checked every few hours and the animals are not stressed or killed. On the other hand, species identification is limited by morphological features in cryptic species. Here, a combination with hair traps could be a possibility to subsequently perform genetic analyses for species identification.

References

- Anthony, N. M., Ribic, C. A., Bautz, R. & Garland Jr, T. (2005) Comparative effectiveness of Longworth and Sherman live traps. *Wildlife Society Bulletin*, **33**(3), 1018-1026.
- Attali, D. & Baker C. (2018) ggExtra: Add Marginal Histograms to 'ggplot2', and More 'ggplot2' Enhancements. R package version 0.8. URL: <u>https://CRAN.R-project.org/package=ggExtra</u> (accessed: 1. September 2019).
- Barton, K. (2019) MuMIn: Multi-Model Inference. R package version 1.43.6. URL: <u>https://CRAN.R-project.org/package=MuMIn</u> (accessed: 1. September 2019).
- Bertuzzo, E., Carrara, F., Mari, L., Altermatt, F., Rodriguez-Iturbe, I., & Rinaldo, A. (2016). Geomorphic controls on elevational gradients of species richness. *Proceedings of the National Academy of Sciences*, **113**(7), 1737-1742.
- Burnham, K.P., Anderson, D.R. (2002) *Model selection and multimodel inference: a practical information-theoretic approach*. Springer Science & Business Media, New York.
- Flowerdew, J. R., Shore, R. F., Poulton, S. M. & Sparks, T. H. (2004) Live trapping to monitor small mammals in Britain. *Mammal review*, **34**(1-2), 31-50.
- Fox, J. & Weisberg, S. (2019) An R Companion to Applied Regression, 3. Edition. Thousand Oaks CA: Sage. URL: https://socialsciences.mcmaster.ca/ifox/Books/Companion/ (accessed: 1. September 2019).
- Graf, R.F. (2019) *Neuer Säugetieratlas der Schweiz und Liechtensteins Jahresbericht 2018*. Tätigkeitsbericht des Projekts der Schweizerischen Gesellschaft für Wildtierbiologie SGW-SSBF, Wädenswil.

- Grolemund, G. & Wickham H. (2011) Dates and Times Made Easy with lubridate. Journal of Statistical Software, 40(3), 1-25. URL: <u>http://www.jstatsoft.org/v40/i03/</u> (accessed: 1. September 2019).
- Hoffmann, A., Decher, J., Rovero, F., Schaer, J., Voigt, C. & Wibbelt, G. (2010) Field methods and techniques for monitoring mammals. Manual on field recording techniques and protocols for All Taxa Biodiversity Inventories and Monitoring (eds. J. Eymann, J. Degreef, C. Häuser, J. C. Monje, Y. Samyn, & D. VandenSpiegel), pp. 482-529. Abc Taxa.
- Hoogenboom, I., Daan, S., Dallinga, J. H. & Schoenmakers, M. (1984) Seasonal change in the daily timing of behaviour of the common vole, *Microtus arvalis*. *Oecologia*, **61**(1), 18-31.
- Horikoshi, M. & Tang, Y. (2016) ggfortify: Data Visualization Tools for Statistical Analysis Results. <u>https://CRAN.R-project.org/package=ggfortify</u> (accessed: 1. September 2019).
- Ivanter, E. V. & Makarov, A. M. (2002) Daily activity and mobility of the common shrew (Sorex araneus L.). Russian Journal of Ecology, 33(4), 280-285.
- Kassambara, A. (2019) ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.2.2. URL: <u>https://CRAN.R-project.org/package=ggpubr</u> (accessed: 1. September 2019).
- Körner, C. (2007) The use of 'altitude' in ecological research. Trends in ecology & evolution, 22(11), 569-574.
- Kuhn, M. (2019) caret: Classification and Regression Training. R package version 6.0-84. URL: <u>https://CRAN.R-project.org/package=caret</u> (accessed: 1. September 2019).
- Ladurner, E. & Cazzolli N. (2003) Die Kleinsäugerfauna im Unterland und Überetsch (Südtirol, Italien), unter besonderer Berücksichtigung des Montiggler Waldes. *Gredleriana*, **3**, 313 332.
- Lomolino, M. V. (2001) Elevation gradients of species-density: historical and prospective views. *Global Ecology and biogeography*, **10**(1), 3-13.
- Marchesi, C., Müller, J.P. & Briner T. (2014) Die Kleinsäugerfauna eines alpinen Lebensraumes in den Schweizer Alpen (Alp Flix, Sur, Graubünden). Jahresbericht der Naturforschenden Gesellschaft Graubünden, **118**, 143-157.
- McCain, C. M. (2005) Elevational gradients in diversity of small mammals. *Ecology*, 86(2), 366-372.
- 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.
- Müller, J. P. (1972) Die Verteilung der Kleinsäuger auf die Lebensräume an einem Nordhang im Churer Rheintal. Zeitschrift für Säugetierkunde, **37** (5), 257–286.
- Müller, J.P., Jenny, H., Lutz, M., Mühlethaler, E. & Briner T. (2010) Die Säugetiere Graubündens eine Übersicht. Stiftung Sammlung Bündner Naturmuseum und Verlag Desertina, Chur.
- 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. Henry, M.H., Stevens, H., Szoecs, E. & Wagner, H. (2019) vegan: Community Ecology Package. R package version 2.5-5. URL: <u>https://CRAN.R-project.org/package=vegan</u> (accessed: 1. September 2019).
- Patterson, B. D., Meserve, P. L. & Lang, B. K. (1989) Distribution and abundance of small mammals along an elevational transect in temperate rainforests of Chile. *Journal of Mammalogy*, **70**(1), 67-78.
- R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: <u>https://www.R-project.org/</u> (accessed: 1. September 2019).
- Rahbek, C. (2005). The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology letters*, **8**(2), 224-239.
- Reiter, G. & Winding, N. (1997) Verbreitung und Ökologie alpiner Kleinsäuger (Insectivora, Rodentia) an der Südseite der Hohen Tauern, Österreich. *Wissenschaftliche Mitteilungen aus dem Nationalpark Hohe Tauern*, **3**, 97–135.
- Rickart, E. A. (2008) Elevational diversity gradients, biogeography and the structure of montane mammal communities in the intermountain region of North America. *Global Ecology and Biogeography*, **10**(1), 77-100.
- Robin, X., Turck, N., Hainard, A., Tiberti, N., Lisacek, F., Sanchez, J-C. & Müller, M. (2019) pROC: Display and Analyze ROC Curves. R package version 1.15.3. URL: <u>https://cran.r-project.org/web/packages/pROC/index.html</u> (accessed: 1. September 2019).
- 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*.
- Sánchez-Cordero, V. (2001) Small mammal diversity along elevational gradients in Oaxaca, Mexico. *Global Ecology and Biogeography*, **10**(1), 63-76.
- Schloerke, B., Crowley, J., Cook, D., Briatte, F., Marbach, M., Thoen, E., Elberg, A. & Larmarange, J. (2018) GGally: Extension to 'ggplot2'. R package version 1.4.0. URL: <u>https://CRAN.R-project.org/package=GGally</u> (accessed: 1. September 2019).

- Schmid, M. & Müller, J. P. (2010) Der GEO-Tag der Artenvielfalt 2008 am Albulapass: eine 24-Stunden-Aktion zur Erfassung der Biodiversität: Methoden und Resultate. *Jahresbericht der Naturforschenden Gesellschaft Graubünden*, **116**, 5-58.
- SCNAT
 (2019)
 Alpen.
 SCNAT
 Akademie
 der
 Naturwissenschaften
 Schweiz.
 URL:

 https://naturwissenschaften.ch/topics/biodiversity/about biodiversity/zustand und entwicklung/gebirge
 (accessed:

 01
 September 2019).
- Wickham, H. (2017). tidyverse: Easily Install and Load the 'Tidyverse'. R package version 1.2.1. URL: <u>https://CRAN.R-project.org/package=tidyverse</u> (accessed: 1. September 2019).
- Wójcik, J. M. & Wołk, K. (1985) The daily activity rhythm of two competitive rodents: *Clethrionomys glareolus* and *Apodemus flavicollis. Acta theriol*, **30**(14), 241-258.
- Zeileis, A. & Grothendieck, G. (2005) zoo: S3 Infrastructure for Regular and Irregular Time Series. Journal of Statistical Software, 14(6), 1-27. doi:10.18637/jss.v014.i06
- ZHAW (2019) Project TubeCam. ZHAW Zurich University of Applied Sciences. URL: https://www.zhaw.ch/en/lsfm/institutes-centres/iunr/ecosystems-and-biodiversity/wild-animalmanagement/referenzprojekte/project-tubecam/ (accessed: 01 September 2019).

Appendix

Appendix 1. Mostela sites





Coordinates: 778094 / 162715 Elevation [m a.s.l]: 1753 Vegetation type: Forest



Coordinates: 777851 / 162344 Elevation [m a.s.l]: 1863 Vegetation type: Forest



Coordinates: 777508 / 162029 Elevation [m a.s.l]: 1940 Vegetation type: Forest



Coordinates: 777065 / 161582 Elevation [m a.s.l]: 2032 Vegetation type: Forest



Coordinates: 777071 / 160609 Elevation [m a.s.l]: 2152 Vegetation type: Shrubs



Coordinates: 776992 / 160060 Elevation [m a.s.l]: 2254 Vegetation type: Shrubs



Coordinates: 777349 / 159862 Elevation [m a.s.l]: 2361 Vegetation type: Grassland



Coordinates: 776568 / 159619 Elevation [m a.s.l]: 2462 Vegetation type: Grassland



Coordinates: 775953 / 159714 Elevation [m a.s.l]: 2564 Vegetation type: Grassland

Mostela 10



Coordinates: 775778 / 159718 Elevation [m a.s.l]: 2639 Vegetation type: Grassland **Appendix 2.** Predictor variables which were recorded on the 10 m x 10 m plots and which were used to analyse habitat preference of small mammals

Тур	Variables	Description (unit)	Scale
Landscape and topography	elevation	elevation in m a.s.l	interval
	Inclination	Inclination in °	interval
Soil and vegetation structure	Mean_soil	mean soil depth in cm	interval
	Mean_veg	mean vegetation height (with disc) in cm	interval
	Tree.layer	proportion of the tree layer	ratio
	Shrub.layer	proportion of the shrub layer	ratio
	Herb.layer	proportion of the herb layer	ratio
Cover	Dead.wood	proportion of dead wood	ratio
	Stones	proportion of stones	ratio

0.00400	elevation	Inclination	Mean_soil	Mean_veg	Tree.layer	Shrub.layer	Herb.layer	Dead.wood	Stones	
0.00075	\bigcap	Corr:	Corr:	Corr	Corr:	Corr:	Corr:	Corr:	Corr:	eleva
0.00025 -		-0.173	-0.24	-0.139	-0.794	-0.468	0.326	-0.642	0.952	ation
50 - 40 -	•	. Λ	Corr:	Corr:	Corr:	Corr:	Corr:	Corr:	Corr:	Inclin
30 - 20 -		V M	-0.168	0.845	-0.236	0.2	0.223	0.334	-0.275	hation
40 - 30 -	•	•		Corr	Corr	Corr	Corr	Corr	Corr	Mea
20 - 10 -				-0.249	0.606	-0.133	0.293	0.503	-0.372	n_soil
20 -			•	\frown	Corr	Corr	Corr	Corr	Corr	Mea
10 - 5 -					-0.267	0.614	-0.161	0.298	-0.285	In_veg
20 -			/	•••	Ν	Corr	Corr	Corr	Corr	Tree
10 - 0 -						0.0418	-0.265	0.566	-0.79	e.layer
40 -						\square	Corr	Corr	Corr	Shru
20 -				/			-0.44	0.482	-0.435	ıb.layer
90 - 80 - 70 -	_		· · · · · ·			:	\sim	Corr	Corr	Her
60 - 50 - 40 -							ſ	-0.284	0.264	b.layer
30 - 10 -								\square	Corri	Dea
5-			/		/	/			-0.752	ld.wood
30 -			·					:	\frown	co.
20 - 10 -										tones
0-	5020002502500	20 30 40 50	10 20 30 40	5 10 15 20	0 10 20	0 10 20 30 40 50 3	30 40 50 60 70 80 9	00 4 8 120	10 20 3	

Appendix 3. Scatterplot matrix of predictor variables for habitat use of Apodemus sp.



Appendix 4. Density plot with presence – absence information of Apodemus sp.

Appendix 5. ROC-curve for final GLM for Apodemus presence absence data



Plant biodiversity in an alluvial plain in Preda in the Swiss Alps: A modelling approach to determine driving factors influencing species richness

Adrian Hochreutener, Anna Dębska & Carmen Isaak

Hochreutener Adrian: <u>adrian hochreutener@hotmail.com</u> Dębska Anna: <u>ae.debska@student.uw.edu.pl</u> Isaak Carmen: isaakcar@students.zhaw.ch

Abstract

Alluvial plains are among the richest in plant species habitats. In this study, we aim to determine the most important driving factors on species richness. We set up twenty 1 m² plots on a transect across the Alvra river in Preda in the Swiss Alps. On each plot, we determined all the plant species and collected numerous environmental data, including measurements of elevation to produce a cross-section profile of our transect. We programmed a multiple linear regression model where species richness within our plots was predicted. We added some quadratic terms to the model, since the intermediate disturbance hypothesis states that diversity is the highest on intermediate disturbance level. Further, we calculated Shannon index and Evenness to estimate the biodiversity in our plots. There was a high diversity in both environmental conditions and vascular plant richness (109 species in total). The most important factors determining species richness were grazing intensity squared, soil type (sand content squared) and heat index (aspect and inclination). While biodiversity was the highest at intermediate sand content and grazing intensity, the heat index was negatively correlated. We assume that species richness decreasing with a higher heat index is just a coincidence of our study design and that heat index was overridden by factors such as different kind of habitats.

Introduction

Biodiversity is a complex ecological concept, which includes species richness as well as genetic and functional diversity and diversity of habitats (DeLong 1996). There have been several factors proposed as determinants of biodiversity, with most important habitat heterogeneity, disturbance frequency and productivity. Huston (1979) proposed a dynamic equilibrium model, combining intermediate disturbance (Connell 1978) and intermediate productivity (Grime 1973) hypotheses. According to this model, a stable level of biodiversity is achieved by a dynamic balance between competition and frequency of the population reduction. Alluvial plain ecosystems are characterised by frequent occurrence of disturbances, which lead to high levels of spatial and temporal habitat heterogeneity. The most important driving factor influencing the habitat is flood pulse, which range from unpredictable to predictable and from short to long duration (Junk et al. 1989). As alluvial plain water bodies include often a main stream and side arms of the stream, many ecotones (e.g. between aquatic and terrestrial zone) are formed. These factors make floodplains one of the most species-rich habitats known (Ward et

al. 1999). Therefore, it is important for the authorities and habitat managers to know the diversity of species and ecotones within alluvial plains to justify protection and conservation of these habitats.

Our investigated alluvial plain is characterised by reoccurring fluvial processes, such as the annual high waters in the months from May till August caused by melting snow in the catchment area of the Alvra river (BAFU 2017). Further, small side streams and springs, which arise from the foot of the surrounding mountains, are found. So, fluvial processes cause disturbance (Junk et al. 1989) and intermediate disturbance promotes biodiversity (Connell 1978). However, it is not known, how diverse the habitats within the investigated plain are and how biodiversity changes along a transect through the alluvial plain in Preda, Switzerland. Therefore, this alluvial plain provides an interesting research area to measure plant diversity and environmental factors, which can be seen in relation to the intermediate disturbance theory.

The goal of this project is to define the most important driving factors on species richness in an alluvial plain in Preda. Firstly, we describe fluvial processes with help of the visualised transect across the plain. Secondly, we show the distribution of red list vascular plant species in our plots. Then, we use environmental data such as pH or soil texture type to provide a model predicting species richness in relation to the different environmental factors. Finally, we compare and discuss two indices of biodiversity.

This paper aims to investigate four different research questions:

- How is the landscape along a transect across the alluvial plain shaped?
- What are the significant environmental factors determining species richness in the alluvial plain in Preda?
- What influence do factors such as grazing intensity or soil type have on the plant diversity and how can this be linked with the intermediate disturbance hypothesis?
- How biodiverse are the investigated plots?

Methods

Study area

The study site is located in Preda, Switzerland, at the alluvial plain of the Alvra River (2'778'423, 1'162'482).

The mean annual temperature in Bergün (the nearest automatic weather station) between 2016 and 2018 was 5.8 °C. This station got a mean annual precipitation sum of 962 mm between 2000 and 2018 (Meteo Schweiz 2019). The southern slopes in Preda consist of granite, granodiorite or quartz diorites, while the northern slopes are mostly classified as dolomites. This means that the southern side is mainly acidic while the northern slopes have calcareous properties. Surroundings of our study site are classified as slope debris, which indicates a mixture of different rock types (swisstopo 2019). The whole alluvial plain with the name "Puntschiala da Tschoff, Chagiosch" is nationally protected and contains the main vegetation types: pioneer plane ("Pionierfluren"), small sedge reed ("Kleinseggenried") and areas with coniferous trees ("Nadelwaldflächen") (GeoGR 2019).

We selected twenty plots of 1 m^2 on both sides of the river, which were set along a 105-meter-long transect, perpendicularly to river flow. The exact locations of the plots were chosen subjectively, to avoid side arms of the stream and to cover most of the habitats. The location of the plots is shown in the appendix.

Field sampling

We collected samples from 20th to 22nd of August 2019. At every plot we determined vascular plant species in 3 vegetation layers (herb, shrub and tree) and estimated their cover in percentage. Additionally, we estimated the coverage of the whole vascular plant vegetation, mosses and lichen (in one group) as well as the coverage of litter and dead wood in percent. Further, to define surface cover, we estimated percentage of water, stones (>63 mm in diameter), gravel (2 - 63 mm) and fine soil (< 2 mm) covering the plot. We estimated grazing intensity in a pseudo metric scale, ranging from 0 - 3, with 0 standing for no grazing and 3 for intense grazing. This scale only refers to the site of this study and may not be directly compared with other studies.

Secondly, we measured with a water level device the elevation at each meter along the transect for calculating the vertical profile of it. The difference in elevation to a reference point (starting point or last measuring point) provided the needed information.

We then measured the maximum microrelief with a penetrometer. For this, we placed it in our plots in such a way, that the highest distance from the penetrometer to ground could be measured in a right angle. Using the "Precise Level" mobile application, we measured the inclination; a mobile phone was placed on the penetrometer, which remained in the same position as when measuring microrelief. Additionally, we measured aspect (along the penetrometer) with a compass.

We measured the height of the vegetation at five random points in the plot with a standardised method, where a circular plastic plate with a central borehole was dropped along a penetrometer from onemeter height onto vegetation. The height where the disc stopped was measured and set as vegetation height. For analysis, we calculated per plot the mean and standard deviation of these measurements. We measured soil depth with a penetrometer as well at 5 points per plot. However, this time we measured at the corners and in the middle of the plot. We pushed the penetrometer in the ground until it met an impassable object and noted this distance.

Finally, we took soil samples, prefering the south-western corner of the plot. If there was no vegetation or soil at all, the sample was taken at the south-eastern corner of the plot (sample at plot no. 4). We also sampled water from the spring, side arm of the stream and the main stream (water bodies between plots no. 1 and 2, 7 and 8, 10 and 11). We used these samples to measure pH and conductivity with a waterproof pH/EC/TDS/Temperature Meter (HI991300, HANNA instruments). We also used the soil samples to determine the soil texture types and then define the percentage of sand, silt and clay with a soil identification sheet (following Projektgruppe Kulturlandschaft Hohenlohe 2002).

Data preparation

For calculating species richness and further analysis with the species list, the collected data needed to be cleaned up. For that, we created a pivot-table in Microsoft Excel. We checked if there were any entries with wrong names or spellings and joined same species with different names into one entry. The collected environmental data we tidied up, standardised and merged them into one Excel sheet. There, we calculated the mean and the standard deviation for the soil depth and herb layer height as well as the heat index (Equation 1).

Equation 1: Calculation of the heat index. The higher the resulting values, the steeper and more south-east facing the plot is.

=IF(Inclination=0;0;COS(RADIANS (Aspect-225))*TAN(RADIANS (Inclination)))

The data we read into R with the package "data.table" (Dowle & Srinivasan 2018). Firstly, with the package "reshape2" (Wickham, H. 2007), we calculated species richness per plot. Here, we also created a subset of the data frame, which was suitable for calculating biodiversity indexes. Then we visually explored the data. For example, the species richness, as the dependant variable, was plotted as a boxplot. The homogeneity of the variances was not strongly violated, so we started the analysis without any transformations.

Analysis

General remarks

We conducted the statistical analysis with the program R (R Core Team 2019). All details concerning the analysis are provided in the commented R Skript, which is available on request as digital file.

Calculation and visualisation of the cross-section of the transect

With the digitalised data concerning the elevation along the transect with the height difference for each measurement in respect of the starting point calculated. This data we read into R with the package "readxl" (Wickham & Bryan 2018) and plotted it using the package "tidyverse" (Wickham 2018). We added the positions of our plots as vertical lines; water bodies we marked as well.

Analysis of soil texture type and pH

The data covering the soil texture and the pH measurements we read into R with the package "readxl" (Wickham & Bryan 2018). Data had to be cleaned up (Wickham & Henry 2018). In the next step, we visualised this data as a stacked barplot, where each vertical bar is subdivided into the different soil fractions. Further, the pH values were visually displayed with the same package as a scatterplot ("tidyverse" Wickham 2018).

Identification of red list species and grouping of vegetation

In a next step, we compared the species in our plots to the red species list of Switzerland (Infoflora 2016) and identified threatened species. Further, we divided our plots into different vegetation groups. For this, we conducted a kmeans analysis, integrated in base R. The best number of groups in a span between 2 and 6 was, according to the SSi-Citerion, 4. The assigned groups we manually tested for plausibility.

Preparation of the multiple linear regression model

We excluded rows with not available values (one measurement concerning the coverage in plot 19) and tested the predictor variables with Pearson's Correlations coefficient for correlations among them. We plotted the results with the package GGally (Schloerke et al. 2018). From pairs with a |r| > 0.6 only the one which was easier to explain or had a higher ecological importance remained in the model selection (Table 1).

Parameter name	Scale	min	max	Corr.	Corr.	Remain?
					strength	
Species name	character	-	-	-	-	-
Species richness	numeric	7	28	-	-	+
Sand	numeric [%]	0	90	Silt	-0.69	+
				Gravel	0.63	
				Fine Soil	-0.67	
Silt	numeric [%]	5	85	Sand	-0.69	-
Clay	numeric [%]	5	85	-	-	+
Grazing intensity	numeric	0	3	Mean soil	-0.62	+
				depth		
Litter	numeric [%]	1	25	Dead Wood	0.66	+
Dear Wood	numeric [%]	0	10	Litter	0.66	-
Stones	numeric [%]	0	20	-	-	+
Gravel	numeric [%]	0	87.5	Sand	0.63	-
Fine Soil	numeric [%]	0	100	Sand	-0.68	-
Water	numeric [0 /	0	1	-	-	+
	1]					
Mean soil depth	numeric [cm]	3.1	77.6	Grazing	-0.62	-
SD soil depth	numeric [cm]	1.04	33.8	-	-	+
			9			
Maximum	numeric [cm]	1.5	21	-	-	+
microrelief						
рН	numeric	4.8	7.88	-	-	+
Conductivity	numeric [µS]	56	620	-	-	+
Heat Index	numeric	-0.42	0.89	-	-	+
Elevation above	numeric [cm]	-8	1271	-	-	-
water						
Coverage tree layer	numeric [%]	0	80	SD soil depth	0.63	-
(E-S-W)						

Table 1. Investigated parameters, their scale as well as their range and correlation values (min = minimum value of the parameter, max = maximum value of the parameter, Corr. = to the parameter correlating parameter, Corr. Strength = strength and direction of correlation, Remain = parameter remained in the model [+] or dropped [-]).

After this procedure no more correlations were present. Still, because of the limited number of plots, our model did not produce valid results. Therefore, we further reduced the number of parameters. For this, we grouped the remaining variables into 4 groups. In each group the ecologically most important variable or the easiest to measure was chosen for the final model (Table 2).

.

Matter	Grazing	Surroundings	Chemistry
Clay	Grazing intensity	Maximum microrelief	рН
Sand		Heat index	Conductivity
Litter			
Stones			
Water			
SD soil depth			

Table 2. Grouping of the not correlating parameters into similar groups. The parameters in bold have been selected for the final model. The heading of the table shows the name of the group.

With the remaining parameters we created a linear global model including the species richness as the dependant variable. We did not investigate interactions among parameters. Further, we followed the multimodel Inference approach "dredge", which is provided by the package MuMIn (Barton 2018), to select models. The fit of the models we tested with the AICc; models with a delta AICc < 2 we treated as statistically equivalent and so we averaged them. To estimate the importance of the variables in the model, we calculated the importance values (sum of the akaike weights in all models which include the parameter). Then, a model containing parameters weighted with the akaike weights was calculated for the estimations of the effect seizes. Finally, we visually inspected the model and found that normal distribution was not given. Therefore, we tried a logarithmic transformation of the dependant variable. The result was not satisfying and so we further used the non-transformed data. However, to test the intermediate disturbance hypothesis, we added for the remaining four parameters a quadratic term to the formula (Equation 2).

Equation 2: Species richness described by the formula provided in the quadratic model.

Im (Species richness ~ Sand + I(Sand^2) + Grazing intensity + I(Grazing intensity^2) + Heat index + (Heat index^2) + pH + I(pH^2))

Again, we did a model selection as described above (Barton 2018). The deviation from normal distribution was still quite strong. Since these models are robust and non-transformed data is easier to interpret, we still decided to use the original data. The significant parameters in the final model we visualised with the package "tidyverse" (Wickham 2018) and plotted them in one frame ("gridExtra", Auguie 2017).

How to measure biodiversity?

Finally, we described biodiversity within our plots. For this, we first calculated the Shannon index. We used the coverage in percentage of a given species divided by the total species richness. The basis of exp (1) was used in the formula of the function "diversity" in the package "vegan" (Oksanen et al. 2018). We presented the results of this procedure with the package "tidyverse" (Wickham 2018) as a barplot.

Using the Shannon index we calculated Evenness. For this, we divided the Shannon index by the logarithm of the number of species per plot. Evenness shows the balance of the number of species found in one plot in dependence to the total number of species in the transect. The higher the value, the higher the balance of the species in the plot. We showed the result in the same way as the Shannon index.

Results

Cross-section of the transect

The cross-section of our transect shows some major differences in height. For example, the difference between the highest and the lowest point of the transect was 1409 cm. The water bodies were on the lower end of our vertical scale with exception of one small stream between plot nos. 12 and 13 (Figure 1).



Fig. 1. Transect elevation profile. Water bodies are marked with blue colour. Note that the x- and y-axis have different scales.

Soil texture type and pH

In some plots the distribution of soil texture types was even (nos. 1, 5, 12, 13, 16), while in plot no. 15 sand was the main content (Figure 2).



Fig. 2. Percentage of different grain sizes in the soil samples of our plots.

Water in the river was alkaline, soil was alkaline, neutral or acidic (Figure 3). Although plots 1-16 highly varied in both soil type and pH, plots 17-20 were much more homogenic, with acidic reaction and low sand content.



Fig. 3. pH of soil samples from each plot and water from one spring (blue dot at plot no. 1.5), one side arm (blue dot at plot no. 7.5) and the main stream (blue dot at plot no. 10.5) in the line of our transect.

Red list species and grouping of vegetation

In total, we identified 109 different species in our plots. We found some, according to the red species list of the flora in Switzerland, near threatened or vulnerable species (Table 3). Half of the plots contained one or two species from the red species list of the flora in Switzerland. *Helianthemum nummularium* has five subspecies from which are three potentially in danger and two not. A list of all found species is available in the appendix.

Plot No.	Species	Red list status
4	Dactylorhiza maculata	VU
5	Helianthemum nummularium	NT
6	Helianthemum nummularium	NT
	Sanguisorba officinalis	NT
7	Helianthemum nummularium	NT
9	Helianthemum nummularium	NT
	Sanguisorba officinalis	NT
12	Pinguicula vulgaris	NT
13	Helianthemum nummularium	NT
18	Vaccinium uliginosum	NT
19	Vaccinium uliginosum	NT
20	Vaccinium uliginosum	NT

Table 3. Potentially endangered and vulnerable plants found in our plots. NT= near threatened, VU= vulnerable

The first 6 plots, as well as the plots found between the main river and its side stream, are being said to belong to the same vegetation group while the plots on the northern end of the transect belong to a different group (Table 4).

Table 4. The plots and their corresponding vegetation group based on a kmeans analysis, subdivided in 4 different groups.

Plot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Group	2	2	2	2	2	2	3	2	3	2	4	4	2	2	2	1	1	1	1	1

Multiple linear regression model

The minimal adequate model and according to the AICc-values the best model includes only some of the investigated quadratic terms; it was simplified by "dredge" from the package "MuMIn (Barton 2018). The multiple linear regression was calculated as an average over all 64 investigated models. For the assessment of the model, the akaike weights were consulted. With an importance values of 100% the parameters Grazing intensity squared, Heat Index and Sand content squared were the most important variables. The pH remained with an importance above 50% as well in the statistic relevant models (Table 5).

Table 5. Parameters, which remained after the multimodel inference in the final model. The variables are sorted decreasing according to their importance values. The estimate only reflects models where the corresponding variable is included and is weighted according to the akaike weights.

	Estimate	Standard	p-Value	Significance	Importance
		Deviation			Value
Intercept	-0.5286582	10.9972635	0.962		-
Grazing	14.6870231	1.0131973	<0.001	* * *	1.00
Grazing^2	-4.2368411	0.3067124	<0.001	***	1.00
Heat Index	7.8756192	1.0413837	<0.001	***	1.00
Sand	0.2063503	0.0330079	<0.001	* * *	1.00
Sand^2	-0.0022022	0.0003398	<0.001	* * *	1.00
рН	0.6626704	4.7642604	0.890		0.60
pH^2	0.2043888	0.3297430	0.537		0.56

Finally, species richness in our plots can be described best by the following equation:

Equation 3: Species richness described by variables and their estimate according to the final model.

Species richness = -0.53 - 4.24 * Grazing^2 + 7.88 * Heat Index + 0.66 * pH -0.00 * Sand^2

The visualisation of the significant variables shows that species richness is, according to our model, the highest when soil has an intermediate sand content and grazing intensity is intermediate as well. Species richness seems to decrease with a higher heat index (Figure 4).



Fig. 4. Plotted formula, provided by the model, which best describes species richness depending on the investigated, significant parameters and their levels in the investigated area.

Shannon Index and Evenness

The plot with the highest biodiversity, according to the Shannon index, was plot no. 8; the one with the lowest biodiversity plot no. 15 (Figure 5).



Fig. 5. Shannon Index in the investigated plots. A higher number represents a higher biodiversity.

The highest values for Evenness were found among plots nos. 4, 8, 14, 19 and 20. Evenness was the lowest in the plot no. 15 (Figure 6).



Fig. 6. Species evenness on each plot, calculated out from Shannon diversity index. The numbers are between 0 and 1. Higher number represents a higher biodiversity.

Discussion

Our study showed that the landscape across the alluvial plain is shaped with a lot of heterogeneity. The left bank of the main stream is rather flat and fragmented with little watercourses. At the right bank the terrain rises fast and strongly. The alluvial processes there probably have no impact at all; greater distance from the river evokes better soil development (Walker 1976). This is reflected by a dramatic change of the soil content. The percentage of silt rises quite strongly, which indicates old soil and therefore a stable system (Brzęczyszczykiewicz et al. 2014). The pH supports this finding as well, since well developed soils, originating from acidic bed rock, which can be found in this region (swisstopo 2019), tend to be acidic as well (in this case probably acid brown earth "saure Braunerde") (based on own surveys and following Bodenkundliche Gesellschaft der Schweiz 1996). Although acidic rocks predominate, the values of soil pH in the rest of the plots are surprisingly high. Plant species composition in our first 3 plots did not match the pH values as well (Landolt et al. 2010). We assume that the pH of the soil might be altered by alkaline water. However, we do not know why water pH is so high; this question requires further studies.

The drastic change of soil texture type across our transect is well reflected in the vegetation found in our plots. The vegetation at the end of our transect next to the main stream (plot nos. 16 - 20) was classified as one group, which nicely reflects the change in soil texture and pH. This group could be called "forest". However, plot 16 was also considered to be in the same group, which is not consistent with soil texture and pH. Another group, which we named "grassland", included plots 2 - 5, 8 and 13, and had similar properties concerning soil texture type and pH. On the other hand, the vegetation in plots 6, 10, 14 and 15 was grouped in the same category. Here, soil texture doesn't show any similarities. All in all, we found that these 4 groups quite well reflect the actual plant composition in the field.

We found few species in our plots, which are listed on the red species list of the flora in Switzerland (Infoflora 2016). Since we only had two plots with more than one red list species and half of our plots contained just one, we had not enough data to do further analysis covering this issue. Further, for some of the found plants only specific subspecies are potentially endangered (Infoflora 2016). Since we did not determine subspecies, we are not able to define the grade of endangerment of the found plants. However, we still think that a diversity of 109 different species in a 105-meter-long transect on the

investigated altitude is quite remarkable (Girel & Manneville 1998) and it shows the necessity of protection of such pristine environments.

Both species richness and environmental conditions highly vary along the transect. From all examined factors, which may influence the plant biodiversity, the most important are grazing intensity, soil type (expressed as sand content in the soil) and heat index (aspect and inclination). Biodiversity is the highest at intermediate sand content, which was found within the plain in the zones where water disturbances are probable. Therefore, we conclude that reoccurring transportation of material and therefore deposition of sand promotes biodiversity. Effects of grazing on plant biodiversity depend on a variety of environmental factors and may be either positive or negative (Olff & Ritchie, 1998). In our research, species richness is the highest at intermediate grazing intensity. We assume that grazing increases plants diversity by (1) increasing environment heterogeneity at local scale, (2) decreasing dominance of best resource competitors and (3) promoting higher dispersal of seeds of external species. However, very intensive grazing decreases plant species richness, as it leads to extinction of less resistant species and dominance of very few tolerant species. However, one has to mention that grazing level described as "3" in our research area is still quite extensive.

Negative correlation between species richness and heat index have been explained by higher drought stress (Polyakova et al. 2016). However, as our study area is characterised by high wetness, this explanation is probably not correct in our case. We suppose that this correlation is altered by other, unexamined in this study factors (for example limited by tree layer sunlight). However, to answer this question, further research in the study area is necessary.

Finally, different approaches of measuring biodiversity can be compared. It seems that Shannon index and Evenness well correspond to each other and did not produce opposite findings. For example, plot no. 15, which had the lowest Shannon index, is also the one with the lowest Evenness value. Shannon Index indicates a high biodiversity in the plots nos. 8 and 14. This is supported by Evenness. However, Evenness has high values as well in the plots nos. 4, 18, 19 and 20. The last three plots have obviously a quite low biodiversity, since they are mainly dominated by grasses and shrubs. For the big picture it is therefore necessary to calculate both indexes for different aspects.

The dynamic character of the Alvra River provides high habitat heterogeneity, which increases vascular plant biodiversity. In compliance with intermediate disturbance theory, the highest species richness is found at zones with extensive pasture or intermediate sand content in the soil. We assume that sand content may be correlated with the frequency of fluvial processes. We believe that this paper adds to the understanding of driving factors of biodiversity, the strong impact of alluvial processes and highlights the importance of protection of natural, pristine environments.

References

- Auguie, B. (2017) gridExtra: Miscellaneous Functions for "Grid" Graphics. R package version 2.3. URL: https://CRAN.R-project.org/package=gridExtra (accesed 22.08.2019).
- BAFU, Bundesamt für Umwelt. (2017) Hochwasserstatistik. Stationsbericht. Albula Tiefencastel. URL: https://www.hydrodaten.admin.ch/de/2141.html (accesed 30.08.2019)
- Barton, K. (2018) MuMIn: Multi-Model Inference. R package version 1.42.1. URL: https://CRAN.R-project.org/package=MuMIn (accesed 22.08.2019).
- Bodenkundliche Gesellschaft der Schweiz. Arbeitsgruppe Bodenklassifikation und Nomenklatur. (1996). Schlüssel zur Klassifikation der Bodentypen der Schweiz.

Brzęczyszczykiewicz, G., Kowalski, J. Pradera, J. (2014) Zależność układu przestrzennego, wykształcenia litologicznego oraz struktury trzeciorzędowej od budowy geomorfologicznej doliny zalewowej rzeki Łękołody w powiecie Chrząszczyrzewoszyce. Roczniki Gleboznawcze, 56, 34-49.

Connell, J.H. (1978) Diversity in Tropical Rain Forests and Coral Reef. Science (New York, N.Y.), 199, 1302-10.

DeLong, D. (1996) Defining Biodiversity. Wildlife Society Bulletin, 24(4), 738-749.

Dowle, M., Srinivasan, A. (2018) data.table: Extension of `data.frame`. R package version 1.11.8. URL: https://CRAN.R-project.org/package=data.tabl (accesed 22.08.2019).

GeoGR (2019) Map type: "Auen". URL: https://www.geogr.ch/de/portait-geogr.html (accesed 26.08.2019).

- Girel, J., Manneville, O. (1998) Present species richness of plant communities in alpine stream corridors in relation to historical river management. Biological Conservation, 85, 21-33.
- Grime, J. P. (1973) Control of species density in herbaceous vegetation. Journal of Environmental Management, 1, 151-167.
- Huston, M. (1979) The general hypothesis of species diversity. American Naturalist, 113, 81-101.
- Infoflora. (2016) URL: https://www.infoflora.ch/de/flora/artenschutz/rote-liste.html (accesed 22.08.2019).
- Junk, W. J., Bayley, P. B., Sparks, R. E. (1989) The flood pulse concept in river-floodplain systems. Canadian special publication of fisheries and aquatic sciences, 106(1), 110-127.
- Landolt, E., Bäumler, B., Ehrhardt, A., Hegg, O., Klötzli, F., Lämmler, W., Nobis, M., Rudmann-Maurer, K., Schweingruber, F H., Theurillat, J-P., Urmi, E., Vust, M., Wohlgemuth, T. (2010). Flora indicativa: Ökologische Zeigerwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen. Bern: Haupt.
- MeteoSchweiz, Bundesamt für Meteorologie und Klimatologie. (2019). URL: https://gate.meteoswiss.ch/idaweb/system/welcome.do (accesed 26.08.2019).
- 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. (2018). vegan: Community Ecology Package. R package version 2.5-3. URL: https://CRAN.R-project.org/package=vegan (accesed 23.08.2019).
- Olff, H., Ritchie, M. E. (1998) Effects of herbivores on grassland plant diversity. Trends in Ecology & Evolution, 13(7), 261–265.
- Polyakova, M. A., Dembicz, I., Becker, T., Becker, U., Demina, O. N., Ermakov, N., Filibeck, G., Guarino, R., Janišová, M., Jaunatre, R., Kozub Ł., Steinbauer, M. J., Suzuki, K., Dengler, J. (2016) Scale-and taxon-dependent patterns of plant diversity in steppes of Khakassia, South Siberia (Russia). Biodiversity and Conservation, 25(12), 2251-2273.

Projektgruppe Kulturlandschaft Hohenlohe. (2002) Fühlprobe mit Koernungsdreieck. Unpublished.

- R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/ (accesed 22.08.2019).
- Schloerke, B., Crowley, J., Cook, D., Briatte, F., Marbach, M., Thoen, E., Elberg, A., Larmarange, J. (2018) GGally: Extension to 'ggplot2'. R package version 1.4.0. https://CRAN.R-project.org/package=GGally (accesed 22.08.2019).
- swisstopo, Bundesamt für Landestopografie (2019) Map type: "Geologie 500". URL: https://map.geo.admin.ch (accesed 26.08.2019).
- Walker, P.H., Coventry, R.J. (1976) Soil profile development in some alluvial deposits of eastern New South Wales. Soil Research, 14, 305-317.
- Ward, J. V., Tockner, K., & Schiemer, F. (1999) Biodiversity of floodplain river ecosystems: ecotones and connectivity. River Research and Applications, 15(1-3), 125-139.
- Wickham, H. (2007) Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL: http://www.jstatsoft.org/v21/i12/ (accesed 22.08.2019).
- Wickham, H. (2017) tidyverse: Easily Install and Load the 'Tidyverse'. R package version 1.2.1. URL: https://CRAN.R-project.org/package=tidyverse (accesed 22.08.2019).
- Wickham, H., Bryan, J. (2018) readxl: Read Excel Files. R package version 1.1.0. URL: https://CRAN.R-project.org/package=readxl (accesed 23.08.2019).
- Wickham, H., Henry, L. (2018). tidyr: Easily Tidy Data with 'spread()' and 'gather()' Functions. R package version 0.8.1. URL: https://CRAN.R-project.org/package=tidyr (accesed 22.08.2019).
Appendix

Appendix 1. Transect and positions of the plots.



W = plot is on the western side of the transect, E = plot is on the eastern side of the transect.

m_Start	m_End	Middle
0.3	1.3	0.8
3	4	3.5
10.2	11.2	10.7
12.9	13.9	13.4
18.2	19.2	18.7
22.9	23.9	23.4
28	29	28.5
31.9	32.9	32.4
37	38	37.5
42.8	43.8	43.3
53	54	53.5
56.6	57.6	57.1
60	61	60.5
68.6	69.6	69.1
73.8	74.8	74.3
80	81	80.5
85	86	85.5
90.5	91.5	91
95.3	96.3	95.8
100	101	100.5

Appendix 2. Positions of plots (m_Start = southern end of the plot, m_End = northern end of the plot, Middle = arithmetic middle of the plot on the transect)

Shannon		Evenness	
Plot	Shannon	Plot	Evenness
1	1.93953596	1	0.63705753
2	1.32863463	2	0.55408368
3	1.34844807	3	0.45012303
4	1.89091421	4	0.82121361
5	1.65965245	5	0.52222289
6	2.13620853	6	0.6481536
7	1.37614815	7	0.46737194
8	2.66162265	8	0.79875729
9	1.81516563	9	0.62800421
10	1.76790376	10	0.61165272
11	1.38419405	11	0.44145961
12	1.54547372	12	0.48012841
13	1.60483085	13	0.5357057
14	2.56692377	14	0.83043951
15	0.75996089	15	0.39054264
16	1.97673071	16	0.65984892
17	1.2188013	17	0.52931868
18	1.50127725	18	0.72196175
19	1.96458382	19	0.79060669
20	1.56435536	20	0.80391963

Appendix 2. Biodiversity Indeces.

Appendix 4. Species per plot.

Plot	Species per plot
1	21
2	11
3	20
4	10
5	24
6	27
7	19
8	28
9	18
10	18
11	23
12	25
13	20
14	22
15	7
16	20
17	10
18	8
19	12
20	7

Appendix I: List of all observed species

Compiled by Jürgen Dengler, Jamyra Gehler, Julia Pawłowska,Piotr Tykarski & Marta Wrzosek

In the following, we provide a list of all species that have been recorded in the permanent plots, in the other student research projects plus some observations from along the trails. The species are grouped into vascular plants (nomenclature according to Juillerat et al. 2017), orthoptera, amphibians, mammals and fungi (nomenclature according to Index Fungorum Partnerniship 2020). They are arranged into three geographical units "Arround Sonnenhof", Val Mulix below and above tree line. Additionally there are fungi observations from the trail to Lai Palpuegna and data from the mammal live trapping on Alp Flix. Very few species could not be assigned post hoc to one of the sites. In total we recorded 296 vascular plant, 8 orthoptera, 1 amphibian, 7 mammal and 202 fungi taxa.

References

Index Fungorum Partnership 2020. *Index Fungorum*. Royal Botanic Gardens, Kew. URL: http://www.indexfungorum.org/Index.htm [accessed on 2020-07-27].

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.

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Vascular plants						
Achillea millefolium aggr.		х	х	х		
Achillea nana				х		
Aconitum lycoctonum subsp. neapolitanum				х		
Aconitum lycoctonum subsp. vulparia				х		
Aconitum napellus			x			
Aconitum variegatum subsp. paniculatum				x		
Adenostyles alliariae				x		
Adenostyles leucophylla				x		
Agrostis capillaris		x	х	x		
Agrostis rupestris				x		
Agrostis schleicheri				x		
Agrostis schraderiana			х	x		

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Agrostis stolonifera		х	х			
Ajuga pyramidalis			х	x		
Alchemilla alpina aggr. s.l.		х	х	x		
Alchemilla vulgaris aggr. s.l.		х	х	x		
- Alchemilla splendens aggr.				x		
Alnus viridis			х			
Androsace chamaejasme				x		
Androsace obtusifolia				x		
Anthoxanthum odoratum aggr.			х	x		
- Anthoxanthum alpinum				cf.		
- Anthoxanthum odoratum		x				
Anthyllis vulneraria			x			
- Anthyllis vulneraria subsp. alpestris		cf.		x		
Aquilegia atrata	x					
Arabis caerulea			х			
Arabis subcoriacea		x				
Arctostaphylos alpina	x					
Arctostaphylos uva-ursi			х			
Arnica montana		x		x		
Arrhenatherum elatius			х			
Asplenium viride			cf.			
Aster bellidiastrum		x	х	x		
Astragalus alpinus			х			
Avenella flexuosa		x	х	x		
Bartsia alpina		x	х	x		
Biscutella laevigata				x		
Botrychium lunaria				x		
Briza media		х	х	x		
Calamagrostis varia		х	х			
Calamagrostis villosa		х	х	x		
Calluna vulgaris		х				
Caltha palustris		х	х			
Campanula barbata			х	x		
Campanula rotundifolia			х	x		
Campanula scheuchzeri		х		x		
Cardamine amara		х				
Carduus defloratus		х	х	х		
Carex curvula				х		
Carex davalliana		x	х			

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Carex digitata				х		
Carex elata		x				
Carex flacca		x	х			
Carex flava			х			
Carex lepidocarpa		x	х			
Carex montana		x				
Carex nigra		x		х		
Carex ornithopoda		x				
Carex pallescens				х		
Carex panicea		x				
Carex pilulifera				cf.		
Carex sempervirens		x	х	х		
Carlina acaulis		x				
Centaurea nervosa		x				
Centaurea scabiosa			х			
Cerastium arvense				х		
Cerastium fontanum		х		х		
- Cerastium fontanum subsp. fontanum				х		
Chaerophyllum hirsutum		x	х			
Chaerophyllum villarsii			х	cf.		
Cirsium helenioides		х	х			
Cirsium oleraceum		х				
Cirsium spinosissimum				х		
Coeloglossum viride				х		
Corallorhiza trifida		х				
Cotoneaster integerrimus			х			
Crepis aurea	х					
Crepis paludosa		x	х			
Cystopteris alpina		x				
Cystopteris fragilis aggr.			х	х		
Dactylis glomerata		x	х	х		
Dactylorhiza incarnata			х			
Dactylorhiza maculata		x	х			
- Dactylorhiza maculata subsp. fuchsii			х			
Dactylorhiza majalis			х			
Daphne mezereum			x			
Daphne striata				x		
Deschampsia cespitosa		x	x	x		
Dianthus superbus	х					

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Diphasiastrum alpinum				x		
Doronicum clusii				x		
Dryas octopetala		x	х			
Dryopteris dilatata aggr.			х			
Empetrum nigrum		x	х	x		
- Empetrum nigrum subsp. hermaphroditum				x		
Epilobium alsinifolium		х				
Epilobium angustifolium			х			
Epilobium fleischeri		x	х			
Equisetum palustre		x				
Equisetum variegatum		x	х			
Erica carnea		x	х			
Eriophorum angustifolium		x				
Euphorbia cyparissias		x	х			
Euphrasia minima aggr.				x		
Euphrasia rostkoviana		x	х	cf.		
Festuca pulchella		x	х			
Festuca rubra aggr.			х	x		
- Festuca rubra		x	х	x		
- Festuca nigrescens		x		x		
Festuca violacea aggr.				x		
Fragaria vesca			х			
Galium album		х				
Galium boreale		х	х			
Galium pumilum aggr.			х	x		
- Galium pumilum		x				
- Galium anisophyllon		х	х	x		
Gentiana acaulis				x		
Gentiana asclepiadea		х	х			
Gentiana campestris		х	х	x		
Gentiana clusii		х				
Gentiana germanica				x		
Gentiana lutea				x		
Gentiana nivalis			х	x		
Gentiana punctata				x		
Gentiana ramosa				x		
Geranium sylvaticum		x	x	x		
Geum montanum			x	x		
Geum rivale				x		

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Gnaphalium supinum				х		
Gymnadenia conopsea		x	x			
Gymnadenia odoratissima			х			
Gypsophila repens		x	x			
Hedysarum hedysaroides				x		
Helianthemum nummularium		x	x	x		
Helictotrichon pubescens		x				
Helictotrichon versicolor		x		x		
Heracleum sphondylium		x	x			
Hieracium alpinum				x		
Hieracium lactucella				x		
Hieracium murorum aggr.		x	x	x		
Hieracium villosum aggr.				x		
Homogyne alpina		x	х	x		
Huperzia selago				x		
Hypochaeris uniflora				x		
Juncus articulatus aggr.			х			
Juncus triglumis			х			
Juniperus communis subsp. alpina		x	x	x		
Knautia arvensis		x				
Knautia dipsacifolia		x	x			
Koeleria pyramidata	x					
Larix decidua		x	x			
Laserpitium latifolium		x	x			
Lathyrus pratensis		x				
Leontodon helveticus		x	x	x		
Leontodon hispidus		x	x	x		
- Leontodon hispidus subsp. danubialis			x			
Leontodon incanus				x		
Leucanthemopsis alpina				x		
- Leucanthemopsis alpina subsp. alpina				x		
Leucanthemum vulgare aggr.			x	x		
- Leucanthemum adustum		x				
Ligusticum mutellina				x		
Ligusticum mutellinoides				х		
Linaria alpina		x				
Linum catharticum		x	х	х		
Listera ovata		x	х			
Loiseleuria procumbens				х		

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Lonicera xylosteum			х			
Lotus alpinus		х		x		
Lotus corniculatus		х	х	x		
Luzula alpina		х		x		
Luzula alpinopilosa				х		
Luzula luzulina			х			
Luzula luzuloides subsp. rubella		х				
Luzula multiflora				х		
Luzula sieberi		х	х			
Luzula spicata				х		
Luzula sudetica		х				
Luzula sylvatica			х			
Melampyrum pratense			х	х		
Melampyrum sylvaticum		х	х	x		
Melica nutans		х				
Moehringia trinervia			х			
Molinea caerulea		х	х			
Moneses uniflora		х	х			
Myosotis alpestris				x		
Myosotis alpina				x		
Myosoton aquaticum		х				
Nardus stricta		х	х	x		
Oxalis acetosella			х			
Oxytropis campestris		х	х			
Parnassia palustris		х	х			
Pedicularis rostratospicata subsp. helvetica				х		
Petasites paradoxus		х	х			
Peucedanum ostruthium				х		
Phleum alpinum aggr.				x		
- Phleum rhaeticum		х				
Phyteuma betonicifolium		х	х	х		
Phyteuma hemisphaericum				х		
Phyteuma orbiculare			х			
Phyteuma scheuchzeri			х			
Picea abies		х	х			
Pimpinella major		х	х			
Pinguicula alpina			х			
Pinguicula vulgaris		х				
Pinus cembra		х	х			

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Pinus mugo subsp. mugo			x			
Pinus mugo subsp. uncinata		х	x			
Plantago atrata				х		
Plantago lanceolata		х				
Plantago serpentina aggr.				х		
- Plantago alpina		x				
Poa alpina			x	х		
Poa pratensis		х	x			
Poa trivialis		x				
Polygala alpestris		x	cf.			
Polygala amara aggr.				х		
Polygala vulgaris			x			
Polygonum viviparum		x	x	х		
Potentilla aurea			x	х		
Potentilla crantzii			x	х		
Potentilla erecta		x	x			
Prenanthes purpurea			x			
Primula farinosa		x	x			
Primula hirsuta				х		
Primula integrifolia				х		
Primula latifolia				х		
Prunella grandiflora		x				
Pseudorchis albida				x		
Pulmonaria australis			x			
Pulsatilla alpina subsp. apiifolia				x		
Pyrola minor		x		x		
Pyrola rotundifolia			x	x		
Ranunculus montanus aggr.		x	x	x		
- Ranunculus villarsii				x		
Rhinanthus alectorolophus		x				
Rhinanthus minor		x	x	х		
Rhododendron ferrugineum			x	х		
Rosa pendulina		x	x			
Rubus caesius			x			
Rubus idaeus			x			
Rubus saxatilis		x	x			
Rumex scutatus				x		
Salix appendiculata		x	x	x		
Salix caesia			x			

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Salix foetida		х	х			
Salix herbacea				x		
Salix myrsinifolia		x	x	x		
Salix purpurea			x			
Salix retusa				x		
Salix waldsteiniana				x		
Sanguisorba officinalis		x	x			
Saussurea alpina			x	x		
Saxifraga aizoides		x	x			
Saxifraga bryoides				x		
Saxifraga paniculata				x		
Saxifraga rotundifolia			x			
Saxifraga stellaris		x				
Scabiosa columbaria aggr.			x			
- Scabiosa lucida		x				
Sedum villosum				cf.		
Selaginella selaginoides		х	х	x		
Sempervivum montanum				x		
Senecio doronicum				x		
Senecio incanus				x		
Senecio ovatus aggr.			х			
Sesleria caerulea		х	х	x		
Silene nutans	х					
Silene rupestris				x		
Silene vulgaris subsp. vulgaris		х	х	x		
Soldanella pusilla			х	x		
Solidago virgaurea		х	х	x		
Sorbus aucuparia			х			
Stellaria nemorum			х			
Taraxacum officinale aggr.		х	х	х		
Thalictrum aquilegiifolium				х		
Thesium alpinum		х	х	х		
Thesium pyrenaicum			х	х		
Thymus alpestris		х	х	х		
Thymus praecox subsp. polytrichus			х			
Thymus praecox subsp. praecox				х		
Thymus pulegioides		х				
- Thymus pulegioides subsp. pulegioides			х			
Tofieldia calyculata		x	x			

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Trichophorum cespitosum		х	х	х		
Trifolium alpinum				x		
Trifolium badium				х		
Trifolium medium		х				
Trifolium pratense			х			
- Trifolium pratense subsp. nivale				х		
- Trifolium pratense subsp. pratense				х		
Trifolium thalii				х		
Trollius europaeus		х		х		
Tussilago farfara		х	х	х		
Vaccinium myrtillus		х	х	х		
Vaccinium uliginosum aggr.		х	х	х		
Vaccinium vitis-idaea		х	x	х		
Valeriana diversifolia		v	x			
		X	x	x		
				x		
				×		
Veronica officinalis			x	~		
Vicia cracca		x	x			
Viola biflora		x	x	x		
Viola palustris		x				
Viola sylvestris aggr.			x	х		
Orthoptera						
Chorthippus apricarius			x			
Chorthippus parallelus			х	х		
Gomphocerus sibiricus				х		
Metrioptera brachyptera			х			
Miramella alpina			х	x		
Omocestus viridulus			х	х		
Stethophyma grossum			х			
Tetrix bipunctata			х			
Amphibians						
Rana temporaria				x		
Mammals						
Apodemus sp.			x	x		x

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Chionymus nivalis				x		х
Microtus arvalis				x		х
Mustela erminea				x		х
Myodes glareolus			x			x
Sorex araneus aggr.			x			x
Sorex minutus			x			x
Fungi						
Agaricus comtulus				х		
Agaricus langei					x	
Agaricus porphyrocephalus				x		
Albatrellus ovinus					x	
Amanita muscaria		х	х			
Amanita submembranacea			х		x	
Amanita vaginata				х		
Ampulloclitocybe clavipes					x	
Amylostereum areolatum			х			
Armillaria ostoyae/borealis			х			
Arrhenia griseopallida	х					
Arrhenia oniscus			х			
Arrhenia velutipes				х		
Ascobolus sp.				х		
Atheniella flavoalba			х	х		
Atractosporocybe inornata					x	
Bankera violascens				х		
Bisporella citrina			х			
Boletus edulis			х			
Bovista plumbea				x		
Bovistella utriformis			х			
Bryoglossum gracile				x		
Calocera viscosa					x	
Calocybe carnea				x		
Cantharellus cibarius		х				
Cerocorticium sp.			x			
Chalciporus piperatus		x	x			
Cheilymenia stercorea			х	x		
Chroogomphus helveticus		x	x			
Clavaria fragilis				x		
Clitopilus scyphoides			x			

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Clitopilus sp.				x		
Collybia cookei					x	
Conocybe fuscimarginata			x			
Conocybe ochrostriata				x		
Coprinopsis nivea			x	x		
Coprinopsis patouillardii				x		
Coprinopsis sp.				x		
Coprinopsis tigrinella				x		
Coprobia granulata			x	x		
Cortinarius distans			x			
Cortinarius crassifolius			x			
Cortinarius sect. Phlegmacium					x	
Cudonia confusa			x			
Cuphophyllus virgineus			x			
Dacrymyces stillatus					x	
Deconica montana			x	x		
Entoloma longistriatum				х		
Entoloma mougeotii			х			
Entoloma serrulatum			x			
Entoloma sodale				x		
Exidia nigricans			х			
Exobasidium juelianum				x		
Exobasidium myrtilli			х			
Exobasidium rhododendri	х					
Exobasidium vaccinii			х	x		
Fayodia gracilipes			х	x	х	
Fomes fomentarius					х	
Fomitopsis pinicola					х	
Galerina marginata					х	
Gliophorus irrigatus		x				
Gliophorus psittacinus			x			
Gloeocystidiellum leucoxanthum					х	
Gloeophyllum abietinum			x			
Gomphidius glutinosus		х			х	
Gymnopilus junonius					х	
Gymnopus androsaceus				х		
Gymnopus dryophilus			x	х	x	
Gymnosporangium cornutum			x			
Hebeloma mesophaeum					x	

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Hemimycena sp.				х		
Hydnellum caeruleum			х			
Hydnellum concrescens			х			
Hydnum repandum		x				
Hygrocybe chlorophana		x				
Hygrocybe conica			х	x		
Hygrocybe flavescens			х			
Hygrocybe miniata				х		
Hygrocybe nigrescens				х		
Hygrocybe punicea		х				
Hygrophorus atramentosus					х	
Hygrophorus chrysodon		х				
Hymenoscyphus sp.				х		
Infundibulicybe gibba					х	
Inocybe geophylla			х			
Inocybe mixtilis			х			
Inocybe sp.				х		
Laccaria montana				x		
Lachenllula suecica			х			
Lactarius badiosanguineus			х			
Lactarius deterrimus		х				
Lactarius pseudouvidus				x		
Lactarius rufus			х		x	
Lactarius scrobiculatus					x	
Lactarius semisanguifluus		х			x	
Lactarius trivialis					х	
Lactarius turpis					х	
Lactarius zonarioides					х	
Lasiobotrys lonicerae				x		
Leccinum scabrum					х	
Lepista nuda					х	
Leucocybe connata					х	
Lichenomphalia umbellifera		х				
Lophodermium pinastri			х			
Lycoperdon molle					x	
Lycoperdon lividum			х			
Lycoperdon perlatum			х			
Lycoperdon pratense			х			
Mallocybe fulvipes		х				

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Mallocybe leucoblema			x			
Marasmiellus ramealis					х	
Marasmius androsaceus			х	х		
Melampsora epitea				х		
Melanoleuca melaleuca			х			
Melanoleuca subalpina		х		х		
Mensularia radiata			х			
Mollisia sp.			х			
Mucronella calva			х			
Mycena abramsii			х			
Mycena aetites				х		
Mycena alcalina			х			
Mycena amicta			х			
Mycena aurantiomarginata			х			
Mycena capillaripes				х		
Mycena epipterygia			х			
Mycena filopes			х			
Mycena galericulata			х			
Mycena galopus			x			
Mycena laevigata			x			
Mycena leaiana			x			
Mycena maculata			x			
Mycena metata			x			
Mycena olivaceomarginata				x		
Mycena pura					x	
Mycena sp.				x		
Mycena strobilicola			x			
Mycena xantholeuca			x			
Mycocentrodochium curvisporum				x		
Neolentinus lepideus			x			
Panaeolina foenisecii			x			
Panaeolus papilionaceus			x			
Panaeolus semiovatus			x			
Parasola misera				x		
Peniophora aurantiaca			х	x		
Phaeoclavulina flaccida		x			х	
Phaeolus schweinitzii			х		х	
Phloeomana alba			x			
Phloeomana clavata				x		

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Pholiota scamba			х			
Pilobolus sp.				x		
Protostropharia semiglobata			x	x		
Pseudosperma rimosum					х	
Puccinia bistortae				x		
Puccinia festucae			x	x		
Pyxidiophora sp.				x		
Ramaria largentii			x			
Rhizopogon odoratus			x			
Rickenella mellea		х				
Rickenella sp.			x			
Roridomyces roridus			x			
Russula acrifolia			x			
Russula adusta			x			
Russula alutacea			x			
Russula consobrina					х	
Russula decolorans					х	
Russula densifolia					х	
Russula laccata				x		
Russula montana				x		
Russula nana				x		
Russula nauseosa			x			
Russula rhodopus					х	
Russula sp.			x			
Russula subrubens				x		
Russula viscida			x			
Rutstroemia bolaris			x			
Scutellinia scutellata				x		
Spathularia flavida			x		х	
Steccherinum ochraceum			x			
Stereum sanguinolentum				x	х	
Suillus cavipes			x			
Suillus granulatus			x			
Suillus grevillei			x			
Suillus placidus			х			
Suillus plorans			х			
Suillus variegatus			х		х	
Suillus viscidus		x	х			
Trichaptum abietinum			x			

Species	Without site information	Arround Sonnenhof (alluvial plain, mires, grasslands, woodlands)	Val Mulix below treeline	Val Mulix above treeline	Trail to Lai Palpuogna	Alp Flix
Tricholoma atrosquamosum					x	
Tricholoma inamoenum			х			
Tricholoma psammopus					x	
Tricholoma scalpturatum			х			
Tricholoma sulphureum			х			
Tricholoma terreum			х			
Tricholomopsis decora			х			
Tricholomopsis rutilans					x	
Tubaria conspersa			х			
Tubulicrinis glebulosus			х			
Uromyces cacaliae				х		
Uromyces solidaginis				х		
Uromyces trifolii-repentis			х	х		
Uromyces veratri				x		
Xerocomellus chrysenteron					x	

Appendix II: Photo plates

Photos and compilation by Jürgen Dengler

The venue



The group house "Sonnenhof" in Preda, predominantly with good weather, but not always...



Habitats and species in Preda

Diverse habitat mosaic of the Albula alluvial plain close to Sonnenhof with gravel bars (C) and Molinion meadows (D).



Habitats of the subalpine zone of Val Mulix.



Habitats of the alpine zone on our permanent transect from Val Mulix (overview in A) to Lai Negr.



Two typical animals of the alpine zone: the grasshopper Miramella alpina (A) and the Common frog (Rana temporaria).



Some typical plants of the alpine zone: *Eriophorum scheuchzeri* (A), *Polygonum vivivparum* (B), *Senecio incanus* (C) and *Hypochoeris uniflora* (D).



Activities of the Summer School

In the field...



The permanent transect: plot C04 (A), plot C08 (B), plot C09 (C), plot C10 (D), modified Mostela (camera trap for small mammals) (E) and installed temperature logger (F).



Special sampling in the student projects: "Plant functional traits in grasslands" (A) and "Transect through the Albula flood plain" (B).



Scientific work in the group house.



Good food is half the rent for the success of a field class.