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Research Article

Alpine grassland vegetation at Gornergrat (Canton of Valais, Switzerland): Vegetation mapping for environmental planning

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Abstract: Alpine landscapes are increasingly used by tourism. At the highly frequented Gornergrat in Switzerland there was a need to develop a concept to demerge the paths of hikers and mountain bikers and thus enable a conflict-free use for all user groups. The present study aimed at providing vegetation maps of the sensible areas at Gornergrat to derive recommendations for the planning and restoration of the new trail network. For this purpose, we sampled 32 vegetation plots (10 m²). These were then subjected to TWINSPAN classification, and the derived five units characterized by their diagnostic species based on standardized phi-values. We used ANOVA to test for differences of these units with regard to environmental parameters. The five distinguished vegetation units were assigned to syntaxa down to the alliance level. Finally, a mapping key was derived from the synoptic table to allow the delimitation of units in the field, which resulted in two vegetation maps. We found protected habitats and vascular plant species, as well as a species of the Red List of vascular plants in the study area. Especially at the Riffel Lake, the area has striking disturbances of vegetation due to trampling, which has increased significantly in the last 30 years. For the Gornergrat concept we thus recommend (i) to make the disturbed vegetation at the eastern lake shore inaccessible to visitors, (ii) to restore this part with low-intensity measures and (iii) not to lead the planned new changes through sensitive areas (snow beds and fens).

Keywords: alpine grassland; environmental planning; Gornergrat; hiking trail; mountain bike trail; recreational use; restoration; syntaxonomy; Switzerland; trampling disturbance; Valais; vegetation mapping.

Nomenclature: The nomenclature for vascular plants follows Juillerat et al. (2017).

Abbreviations: ANOVA = analysis of variance; DCA = Detrended Correspondence Analysis.

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Introduction

Alpine vegetation and its harsh site conditions have been important research topics since the beginnings of phytosociological investigations in the early 20th century (Braun-Blanquet 1920; Braun-Blanquet et al. 1954). Phytosociological methods have continued to develop ever since (Dierschke 1994; Glavac 1996; Bruelheide 2000; Dengler et al. 2008). The collection of data and the application of findings from vegetation maps are intended to help steer the cultural and agricultural development as well as the intensity of use of an area (Klötzli 2001). The topicality of alpine ecosystems as objects of investigation, also with regard to climatic fluctuations, is thus unbroken. Phytosociological studies can provide information on the stability and carrying capacity of plant communities. From this, the resilience of areas in terms of (recreational) use can be derived (Klötzli 2001).

Tourism and recreational activities often exert pressure on sensitive landscapes and biocoenoses (Eagles et al. 2002). The type and frequency of use determine the strength of the negative impact on plant diversity and vegetation cover (Pickering & Hill 2007; Mason et al. 2015). In areas with intensive recreational use, damage to habitats and plants can be reduced with planning instruments and regionally adapted visitor management (Rupf 2015). However, coordinated planning and control of recreational use is still lacking in many areas of the densely populated European Alps.

The Gornergrat, a panoramic mountain in the Swiss municipality of Zermatt, is heavily frequented for tourism. The transport frequency through the Gornergrat Railway in 2017 was 1,754,000 persons (BVZ Holding AG 2017). In the summer half-year (May – October), an average of 63,000 people were transported per month (2012–2017), with peaks of over 100,000 people in one month (July 2017; pers. comm. by Gornergrat-Bahn AG pers. comm. 2018). Hikers who walk from the valley to the Riffel Lake are not included in the statistics. In addition, in the summer months 2016/2017 the railway recorded an average of 438 mountain bike transports per month (Gornergrat-Bahn AG pers. comm. 2018). A visit to the Gornergrat is often accompanied by a hike or bicycle ride to the Riffel Lake near the railway station.

The floristic wealth of the Zermatt region and in particular of the Riffel Lake is well documented (Steiner 2002; Käsermann et al. 2003). The lake, together with the Riffelhorn and the Gornergletscher, is under protection (BLN area no. 1707). The aim of the nature reserve is to preserve "the untouched character of natural and wild habitats" and "the mosaic of natural habitats with their characteristic plants" (BAFU 2017). However, the vegetation of mountain lakes with high human activity levels is severely endangered as shown by a study on Grünsee in the Aletsch region (Corrodi 2011). Human trampling causes a strong change of plant communities and can lead to their degradation (Whinam & Chilcott 2003). The more frequented a trail is, the wider it becomes (Wimpey & Marion 2010). This is particularly true in alpine areas, where regeneration takes place much more slowly than in lower altitudes (Reisigl & Keller 1994; Ellenberg & Leuschner 2010). Through the use of informal paths (walking off the beaten track), the quality of the landscape also decreases over time (Barros & Marina Pickering 2017). In the Riffel Lake area, the informal, unapproved network of paths is particularly pronounced (pers. observation).

The project "Gornergrat concept" (*Gesamtkonzept Gornergrat*) strives for improvement of the existing trail network, which then should no longer tempt the users to leave the trails. It is planned (i) to merge several small hiking trails (informal trails) as well as (ii) to design a new separate mountainbike (MTB) trail. Finally, (iii) closed path sections that are no longer used are to be revegetated by means of grass sods (resulting from trail construction) or sowing, and overused areas are to be protected and upgraded (BikePlan AG 2016, unpublished report "Wege des Freizeitverkehrs am Gornergrat - Koordination Gesamtkonzept - Offerte"). The design of the path network is based on the existing topography of the area and can be carried out with low impact and sustainability (little path maintenance), using knowledge of modern path construction (IMBA 2004). However, the effects of this project on the plant communities in the Riffel Lake area were unclear. The detailed route is still in the planning phase and has not yet been reviewed with regard to the vegetation concerned. In view of the planned renewal of the path network in the Riffel Lake area, vegetation-related knowledge about the spatial extent of the habitats and the occurrence of red-listed species was required. This knowledge then should lead to recommendations regarding the course of the path and ecological restoration measures.

The present study examines the following questions in the Riffel Lake area of the "Gornergrat concept":

- Do endangered or protected species and habitats occur within the project perimeter?
- Based on the knowledge gained, can recommendations be derived for the trails and for restoration measures of the "Gornergrat concept"?

Study area

Geographic location

The Gornergrat, with the Riffel Lake lies above Zermatt in the canton of Valais in Switzerland (Fig. 1). The perimeter of the "Gornergrat concept" is located above the current timber line at about 2800 m a.s.l. between the Findel and Gorner glaciers and surrounded by alpine grasslands. It can be reached with the Gornergrat Railway (Rotenboden station).

Climate

The climatic conditions on the Gornergrat and in particular at the Riffel lake are typical for the mountains. At a large scale, the Matter valley is an inner-alpine dry valley with a continental climate. There are large temperature differences between day and night as well as summer and winter, coupled with low precipitation and low humidity. The data from the Gornergrat Station at 3219 m a.s.l. demonstrate this (MeteoSwiss 2018): The mean annual temperature is –2.2 °C and the mean annual precipitation is 603 mm (Fig. 2). The Gornergrat has a mean global radiation of 197 W/m^2 with 2397 hours of sunshine (in comparison: Bern 131 W/m^2). There are 275 days of frost, which shortens the vegetation period to a few months, with frost and snowfall being possible at any time.

Geology and soils

Around the Riffel Lake, on the slightly metamorphic Variscan basement, the Monte-Rosa granite, there are ophiolites. The collective term includes all rocks of the oceanic crust, which were pushed as magma onto the sea floor by the drifting apart of the continental plates. The resulting transformation rocks also belong to the ophiolites, such as the silicate serpentinite, which metamorphosed due to heated, circulating sea water (Gnägi & Labhart 2015). In the project perimeters, antigonite serpentinite [$(Mg,Fe,Ni)_6Si_4O_{10}(OH)_8$] is the main component of serpentinite, which thus forms the main source rock for local soil formation. Windows of calcareous Bündnerschiefer and Kalkglimmerschiefer provide a mixture with basic minerals (swisstopo 2018).

Due to the very slow pedogenesis at high elevations, rankers to brown soils form from the predominantly siliceous bedrock, depending on the stage of development. Solifluc-

Fig. 1. Location of the study area and perimeter of the "Gornergrat concept" in Zermatt, Switzerland. The project perimeter in blue and green is located between 2600 and 3100 m a.s.l. The Rotenboden station (Coordinates CH1903+ / LV95: 2625328 / 1092580) forms the centre of the perimeter and is closest to the Riffel Lake.

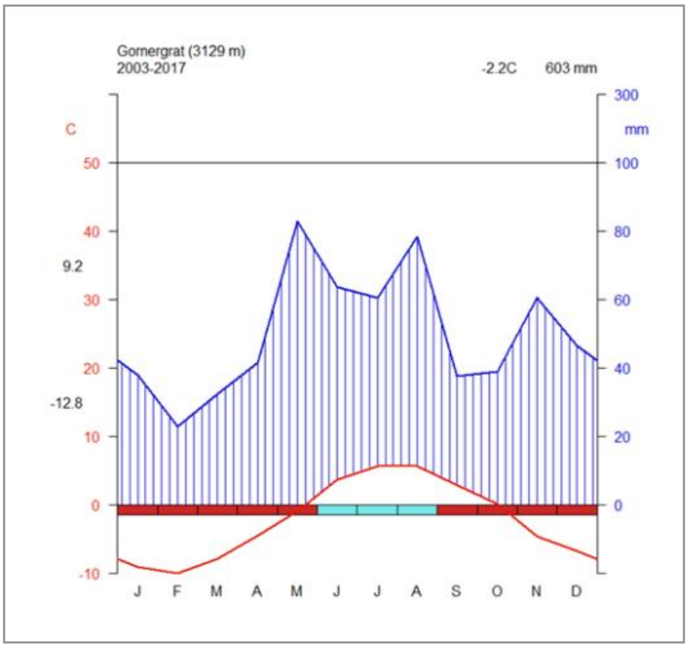


Fig. 2. Climate diagram of the Gornergrat station. Data: MeteoSwiss 2018 (created with R package climatol).

tion on slopes with an inclination of more than 2° and cryoturbation contribute to mixing and loosening of the topsoil as well as to heterogeneous soil characteristics within small areas (Ellenberg & Leuschner 2010). Based on our own measurements, the mean soil pH in the project perimeter is 4.5.

Land use

Since 1942, the summit station has been accessible all year round via the Gornergrat Railway, and has since been used as a skiing area in winter and for hiking in summer. In the course of railway construction and the construction of several mountain hotels, the area was under pressure from construction sites and tourism at an early stage. In recent times, the composition of the vegetation and the soil structure have been changed mainly by ski slope levelling, hiking trail corrections and artificial snow systems.

Marmots (*Marmota marmota*) are present in large numbers on the south-facing slopes. The entire area is grazed with Valais black head sheep. Of lower importance for vegetation is the influence of even-toed ungulates. The sheep's footfall and grazing characterise the landscape in their own way. Excessive recreational use changes the soil structure more severely in this respect (Fig. 3). Leaking paths prevent a

Fig. 3. Left: In steep terrain, deep water grooves form in overused paths and erode the ground. Right: Step loads in the area of the Riffel Lake keep the area vegetation-free. Eroded fine sediments reinforce the effect. Photos: J. Pachlatko, 2018.

closed vegetation cover and cause soil erosion in steep terrain. The sandy to silty components are washed away and displaced by precipitation and melt water. Sometimes deep water grooves or sediment deposits develop, for example in the area of the Riffel Lake. Fine sandy sediments are again compacted by stepping on them, which impedes rapid plant colonisation.

Methods

Vegetation survey

The vegetation surveys were conducted in two previously determined investigation perimeters, which are part of the "Gornergrat concept". They were selected because the current trampling impact was particularly high and at the same time new routes for the trails were being planned (Fig. 1). To characterize the vegetation, 32 circular vegetation plots of 10 m² were recorded in mid-July 2018. The plots were subjectively placed to minimize within-plot heterogeneity and maximize between-plot heterogeneity (Ewald 2003).

In the plots, percentage cover of each vascular plant species was estimated. The field recordings were recorded manually as well as with the software FlorApp for Android (Info Flora 2018) to transmit the recorded data to Info Flora. Species were determined both generatively (Eggenberg et al. 2018; Lauber et al. 2018) and vegetatively (Eggenberg & Möhl 2013). Plant nomenclature follows Juillerat et al. (2017). We also determined a set of important environmental parameters per plot (Table 1). The plot data were managed with the Swiss program VEGEDAZ (WSL 2017) and are now stored in and are available from the emerging Swiss national vegetation database ("Veg.CH"; J. Dengler et al. in prep.).

Table 1. Environmental parameters in the vegetation plots.

Parameter	Unit	Explanation
Coordinates	m	CH 1903+ / LV95
Elevation	m a.s.l.	
Slope aspect	°	
Slope inclination	°	
Mean soil depth	cm	Dengler et al. (2016)
Maximum microrelief	cm	Dengler et al. (2016)
Vegetation-free surface	%	100 – total vegetation cover

Mapping of red list species

Threatened (Bornand et al. 2016) as well as legally protected species (Art. 20 para. 1 Annex 2, NHV 2017) were searched for and mapped within the entire project perimeter and in particular in the two subperimeters. For this purpose, these areas were walked linearly, and the coordinates of the occurrences of target species were recorded with +/- 5 m accuracy. The inspections took place on four days (9, 10, 18 and 19 August 2018) in good weather.

Ordination

The vegetation data were subjected to a Detrended Correspondence Analysis (DCA) with the software "Canoco 5" (version 5.1). Rare species were weighted less (down weighting of rare species). Eight environmental factors were then passively projected into the ordination diagram.

Vegetation classification

The vegetation was classified with the software Juice (Tichý et al. 2018) using modified TWINSPAN Classification (Hill 1979; Roleček et al. 2009; pseudospecies cut level: 1, minimum group size: 3, average Sørensen dissimilarity). Clusters with fewer relevés than three were merged at the next-higher level of the dendrogram. For the final clusters, we determined diagnostic species based on standardised phi-values (Chytrý et al. 2002; Tichy & Chytrý 2006). Species with phi ≥ 0.5 were regarded as highly diagnostic, those with phi ≥ 0.25 as diagnostic for a vegetation unit (Chytrý 2007). The resulting clusters were then interpreted syntax-


Fig. 4. Left: *Thlaspi sylvium* (Matterhorn pennycress). Photo: J. Dengler 2018; right: *Nigritella rhellicani* (Alpine vanilla orchid). Photo: J. Pachlatko 2018.

onomically through comparison with the diagnostic species lists and descriptions in Grabherr & Mucina (1993); Theurillat et al. (1995), Landolt et al. (2010), Schubert et al. (2010), Pignatti & Pignatti (2014) and Delarze et al. (2015).

Characterisation and comparison of vegetation units

The distinguished vegetation units were characterised with mean topographic parameters, mean species richness and mean indicator values according to Landolt et al. (2010). We used analysis of variance (ANOVA) to test for differences in means of these parameters between the distinguished vegetation types, followed by Tukey's post-hoc test (at α = 0.05) implemented in R. Based on a visual inspection of the residuals we concluded that deviations from the requirements of linear models were small enough to allow the application of ANOVAs.

Vegetation mapping

A mapping key derived from the diagnostic species determined in the vegetation classification served as the tool for vegetation mapping. On 6 September 2018, vegetation units were delimited in the field and transferred into digital maps using ArcMap Version 10.5 (ESRI) and overlaid with the information from the route planning.

Results

Flora

A total of 109 vascular plant species were found in 32 vegetation plots. In the project perimeter, *Thlaspi sylvium* (Matterhorn pennycress) was found, which is listed as Vulnerable in the Red List 2016 (Bornand et al. 2016). Also found around the Riffel Lake were some individuals of *Nigritella rhellicani*, an orchid species which is not endangered but protected according to Art. 20 para. 1 Appendix 2 (NHV 2017) (Fig. 4). A list of the coordinates (CH1903+ / LV95) of the Red List species mapped in the project perimeter is available in Pachlatko (2018).

Ordination

Axes 1 and 2 in Figure 5 explain most of the variation in species composition with 15.88% and 6.52% respectively (eigenvalues: 0.79 and 0.32). The gradient length for the first axis is 7.21 SD, which indicates an almost double species change along the gradient (prerequisite for TWINSPAN given). The underlying gradient thus shows a high ecological significance. It is positively related to moisture and negatively to soil reaction and slope aspect. The second axis has a length of 3.45 SD (there are almost no common species at the top and bottom). Here, the underlying gradient can also be assumed to be important for the species occurrence, but there was no strong correlation with any of the seven displayed environmental factors.

Vegetation classification

Figure 6 shows the dendrogram with six groups from the TWINSPAN classification (maximum Sorensen dissimilarity: 0.576). Cluster 4 consisted of only one relevé and was thus merged with cluster 5.

The result of the summarized TWINSPAN calculation led to the synoptic table (Table 2). The complete vegetation table shows that the five resulting vegetation units are floristically well characterised (for their syntaxonomic interpretation, see Discussion). A selection of their diagnostic species (Table 2) was then used to prepare the mapping key (Pachlatko 2018).

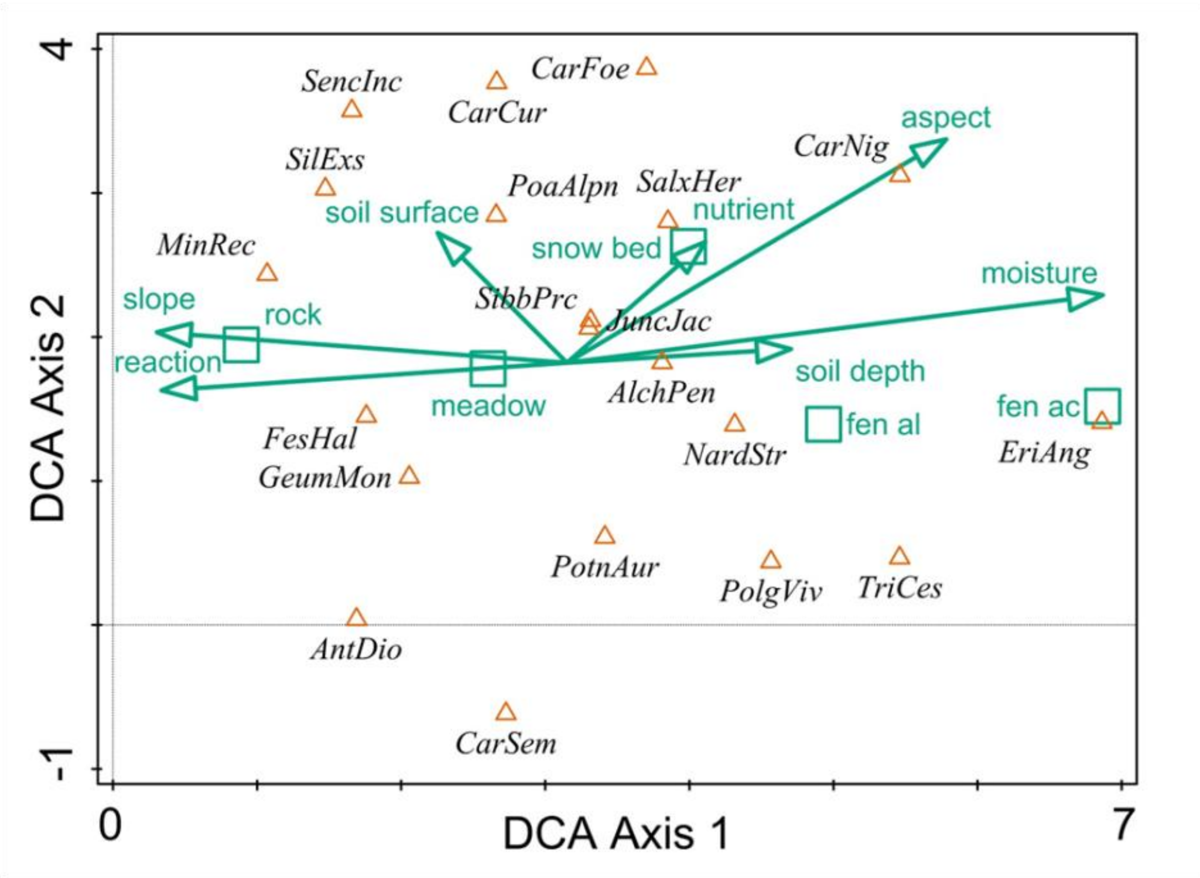


Fig. 5. DCA Ordination of 32 vegetation plots with a total of 109 species. Axis 1 (horizontal) explains 15.9% of the distribution, axis 2 (vertical) 6.5%. Eigenvalues of the first/second axis: 0.79 and 0.32; gradient length: 7.2 and 3.5 SD. The position of the 20 most common species are shown by triangles (*CarSem: Carex sempervirens, AntDio: Antennaria dioica, TriCes: Trichophorum cespitosum, PolgViv: Polygonum viviparum, PotnAur: Potentilla aurea, GeumMon: Geum montanum, NardStr: Nardus stricta, EriAng: Eriophorum angustifolium, AlchPen: Alchemilla pentaphyllea, FesHal: Festuca halleri, SibbPrc: Sibbaldia procumbens, JunJac: Juncus jacquinii, PoaAlpn: Poa alpina, SalxHer: Salix herbacea, MinRec: Minuartia recurva, SilExs: Silene exscapa, CarCur: Carex curvula, CarNig: Carex nigra, SencInc: Senecio incanus, CarFoe: Carex foetida*). The distribution of the five distinguished vegetation types is shown by their centroids (fen ac = fen acidic, fen al = fen alkaline, meadow, rock, snow bed). Finally, the correlation of the mean indicator values (moisture, nutrients, reaction) and of the measured environmental/structural parameters (aspect = slope aspect, slope = slope inclination, soil depth = mean soil depth, soil surface = vegetation-free surface) with the two ordination axes is visualised via arrows.

Comparison of vegetation units

The five distinguished vegetation units significantly differed in inclination ($p < 0.001$) and vegetation-free surface ($p < 0.001$) and marginally significantly differed ($p = 0.054$) in soil depth (Fig. 7). The vegetation types “meadow” and “rock” inhabited the slopes, while fens and snow beds were found in nearly level areas. However, “meadow” and “rock” strongly differed in open soil, which was high in the rock communities and low (i.e. relatively dense vegetation) in the meadow communities.

Species richness in 10 m² varied considerably between the vegetation units, being about 10 times higher in the meadow type compared to the acidic fens, with all other units showing intermediate values ($p < 0.001$; Fig. 8). The vegetation units also differed significantly in the means of the ecological indicator values for moisture ($p < 0.001$), nutrients ($p < 0.025$) and reaction ($p < 0.001$) (Fig. 9). The biggest differences occurred for the moisture values, being high in the two fen types and the snow beds, medium in the meadows and lowest in the rocky communities. The mean nutrient values were generally low, but slightly higher in the snow beds than in the other communities. Reaction values generally indicated acidic conditions, with lowest values in the acidic fens and highest values in the rocky communities, while the three other types were intermediate.

Vegetation mapping

According to the vegetation mapping (Fig. 10), meadow (“*Caricion curvulae*”) and rocky communities (“*Caricion curvulae*, rocky”) cover most of the area, while the two fen types and snow beds occur only locally in flat areas, mainly around the Riffel Lake.

Table 2. Complete vegetation table ordered by TWINSPAN clusters with informal names (columns). To the left, the individual relevés are shown, to the right the % constancies for the five distinguished vegetation units. Diagnostic species are ordered by decreasing phi-values within the clusters. The superscript symbols represent the phi-values (phi ≥ 0.50, * phi ≥ 0.25, ° phi > 0.00), but without checking for significant concentration. Diagnostic species and joint diagnostic species of vegetation units are marked with frames.**

Vegetation ID	%	A				B				C					D					E														A	B	C	D	E
Plot ID		9	19	20	24	10	11	28	32	4	21	22	23	29	2	5	25	27	31	1	3	6	7	8	12	13	14	15	16	17	18	26	30	*n* = 4	*n* = 4	*n* = 5	*n* = 5	*n* = 14
Vegetation type		fen acidic				snow bed				fen alkaline					rock					meadow														%	%	%	%	%
Diagnostic species fen ac																																						
Eriophorum angustifolium	28	50	35	50	18	.	.	0.1	.	.	12	2	8	42	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100**	25	80*	.	.
Eriophorum scheuchzeri	3	.	25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25*	.	.	.	.
Diagnostic species snow bed	0																																					
Carex foetida	19	.	.	.	.	10	0.5	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	.	.	.	2	.	3	.	.	.	75**	.	.	21
Taraxacum alpinum aggr.	34	.	.	.	.	1	15	0.1	0.1	.	.	0.1	0.1	.	.	.	.	.	.	.	.	.	.	0.5	1.5	.	0.1	0.1	.	.	.	.	0.1	.	100**	40°	.	36°
Alchemilla pentaphyllea	41	.	.	.	.	20	20	2	0.1	1	0.5	1	0.1	.	.	.	.	.	.	.	.	.	.	.	60	35	.	25	0.3	.	.	.	15	.	100**	80*	.	36
Salix herbacea	50	.	.	.	.	5	0.1	10	0.5	0.5	0.3	1	0.5	.	.	0.5	.	0.1	.	.	.	.	.	.	5	35	20	35	.	.	.	2	20	.	100*	80*	40	43
Eleocharis quinqueflora	3	.	.	.	.	.	.	.	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25*	.	.	.
Cerastium cerastoides	6	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	.	.	.	.	.	.	.	.	.	25*	.	.	7°
Phleum alpinum aggr.	19	.	.	.	.	.	.	0.1	0.3	.	.	.	0.2	0.1	.	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	3	.	.	.	50*	40°	.	14
Sibbaldia procumbens	50	.	.	.	.	.	1	2	0.1	.	.	0.1	0.3	.	.	0.2	.	.	.	.	.	5	.	0.1	7	15	.	10	1	0.1	0.1	0.1	2	.	75*	40	20	71*
Cerastium alpinum	9	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	0.2	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	25*	.	.	14°
Carex lachenalii	9	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	0.1	.	.	.	.	.	.	25*	.	.	14°
Gnaphalium supinum	28	.	.	.	.	1	0.2	.	.	0	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	0.2	.	0.2	0.1	.	.	.	0.1	.	50*	40°	.	36°
Deschampsia cespitosa	6	.	.	.	.	.	.	.	2	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25*	20°	.	.
Diagnostic species fen al																																						
Trichophorum cespitosum	16	.	.	.	.	.	.	.	.	6	8	3	12	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100**	.	.
Primula farinosa	16	.	.	.	.	.	.	0.1	.	5	0.2	0.2	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25°	80**	.	.
Carex nigra	25	.	.	.	2	.	.	65	20	0.1	35	30	32	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25	50°	100**	.	.
Pinguicula spec.	6	.	.	.	.	.	.	.	.	.	0.1	0.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40**	.	.
Viola biflora	6	.	.	.	.	.	.	.	.	.	.	0.3	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40**	.	.
Loiseleuria procumbens	9	.	.	.	.	.	.	.	.	.	1	.	0.3	.	.	.	.	.	.	.	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40**	.	7
Homogyne alpina	9	.	.	.	.	.	.	.	.	3	1	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40**	.	7
Polygonum viviparum	47	.	.	.	.	.	0.1	2	0.1	7	3	.	0.1	0	.	0.1	.	1	.	0.5	.	5	.	.	.	0.1	.	0.3	0.5	.	.	.	0.2	.	75*	80*	40	43
Leontodon helveticus	41	.	.	.	.	.	.	.	0.2	2	.	0.1	0.1	.	.	0	.	.	.	0.1	0.2	0.1	0.1	.	0.1	0.2	.	0.3	.	.	.	0.1	.	.	25	60*	20	57*
Joint diagnostic species rock and meadow																																						
Minuartia recurva	59	.	.	.	.	.	0.1	.	.	.	0	.	.	.	4	1.5	5	4	0.3	2	.	0.5	1	0.5	0.5	0.3	1	0.2	2	2	1	1	.	.	25	20	100**	86*
Ligusticum mutellinoides	59	.	.	.	.	.	.	.	.	.	0.1	0.1	0.1	.	.	0.5	0.1	0.1	0.1	0.2	0	0.1	0	.	0.1	0.1	0.2	0.3	0.1	0.2	.	0.1	0.2	.	.	60°	80*	86*
Festuca halleri aggr.	53	.	.	.	.	.	.	.	.	.	.	.	.	.	8	15	1	.	.	30	10	30	25	25	1	1	0.3	5	7	15	30	3	15	.	.	.	60*	100**
Sempervivum arachnoideum	28	.	.	.	.	.	.	.	.	.	.	.	.	.	5	0	.	.	2	0.1	.	.	0.1	0.5	.	.	.	.	0.1	8	.	0.1	.	.	.	.	60*	43*
Draba aizoides	28	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0.1	.	.	0	.	.	.	0.1	.	.	0.5	0.1	.	0.1	.	.	0.1	.	.	.	60*	43*
Sempervivum montanum	28	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	0	.	0.2	.	0.2	0.1	.	2	0.5	.	.	.	.	.	3	1	.	.	.	.	.	60*	43*
Hieracium piliferum aggr.	25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	0.5	.	.	0.2	.	0.5	.	0	0.1	0.1	.	.	.	.	0.1	.	.	.	.	40*	43*
Cardamine resedifolia	28	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	0.1	.	.	.	0	.	0.1	.	.	0.1	.	.	0.1	0.1	0.1	.	0.1	.	.	.	40*	50*
Diagnostic species rock																																						
Thlaspi sylvium	22	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	0.1	0.1	0	.	0	.	.	.	0.5	.	.	.	.	0	.	.	.	.	.	.	.	80**	21°
Thymus praecox subsp. *polytrichus*	22	.	.	.	.	.	.	.	.	.	.	.	.	.	2	0.5	3	.	1	0.5	.	.	.	0.5	.	.	.	.	.	.	.	0.3	.	.	.	.	80**	21°
Festuca intercedens	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	4	3	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60**	7
Phyteuma hemisphaericum	6	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40**	.
Salix retusa	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40**	.
Campanula scheuchzeri	31	.	.	.	.	.	.	.	.	0	0	.	.	.	0	0.1	.	0.1	0.1	0	.	.	.	0	.	.	.	.	.	.	.	0.1	0.1	.	.	40°	80**	29
Phyteuma globulariifolium	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	40*	7
Erigeron uniflorus	13	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	0.1	.	.	.	.	.	0.1	.	.	.	.	.	0.2	.	.	.	.	.	.	40*	14°
Diagnostic species meadow																																						
Leucanthemopsis minima	41	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	0.2	0	0.1	.	0.3	0.3	0.1	0.1	.	0.3	0.2	1	0.1	0.3	.	25°	.	.	86**
Senecio incanus subsp. *incanus*	44	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0.1	.	.	.	.	.	1	0.1	1	0.1	0.1	0.1	0.1	0.3	4	1	2	0.5	.	.	.	40°	86**
Luzula spicata	34	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	.	.	.	.	0.5	.	1	0.5	0.5	0.2	0.1	.	0.1	1	.	0.3	.	0.4	.	.	.	20	71**
Geum montanum	34	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	17	1	7	5	5	.	.	.	1	1	7	5	.	4	.	.	20°	.	71**
Gentiana brachyphylla	38	.	.	.	.	.	.	.	.	0.1	.	.	.	.	0	.	.	.	.	0.1	0	0.3	0.1	0.1	0.1	.	.	0.1	.	0.2	0.3	.	0.3	.	.	20	20	71**
Lotus alpinus	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	1	0.1	0.5	0.1	.	.	.	.	.	.	.	.	.	.	.	.	36**
Carex curvula	28	.	.	.	.	.	.	.	15	.	.	.	.	.	.	.	.	.	.	.	.	3	2	0.5	.	.	.	1	15	10	25	.	3	.	25°	.	.	57**
Silene exscapa	41	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	0.4	.	5	.	.	.	2	.	0.5	0.2	0.3	1	1	0.3	8	0.1	.	2	.	25	.	40°	71*
Veronica alpina	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	0.1	0.1	.	0	.	.	.	.	.	.	.	.	.	29*
Myosotis alpestris	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	0.1	.	.	.	.	.	.	0.1	.	.	0.1	.	.	.	.	29*
Pedicularis kerneri	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	0.1	.	0.1	.	.	0.1	.	.	.	.	.	29*
Poa alpina	41	.	.	.	.	7	0.5	.	.	.	.	.	.	.	.	0.1	.	.	.	0.2	.	1	0.1	0.3	0.5	.	0.3	1	1	.	.	0.1	0.5	.	50°	.	20	71*

Table 2. Continuation.

Vegetation ID	%	A				B				C					D					E														A	B	C	D	E
Plot ID		9	19	20	24	10	11	28	32	4	21	22	23	29	2	5	25	27	31	1	3	6	7	8	12	13	14	15	16	17	18	26	30	n = 4	n = 4	n = 5	n = 5	n = 14
Vegetation type		fen acidic				snow bed				fen alkaline					rock					meadow														%	%	%	%	%
Androsace obtusifolia	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	0	0.1	.	.	.	.	.	.	.	.	21*
Hippocrepis comosa	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	0.5	3	.	.	.	.	.	.	.	.	.	.	.	.	.	21*
Salix serpyllifolia	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20	20	0.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21*
Ranunculus kuepferi	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	0.1	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	21*
Galium anisophyllon	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	.	0.1	.	0.2	.	.	.	.	.	.	.	.	.	.	.	.	.	21*
Potentilla aurea	34	.	.	.	.	.	.	.	.	2	2	.	.	.	.	0	.	.	.	1	1.5	5	1	0.5	.	.	.	.	.	.	15	0.1	2	.	.	40	20	57*
Antennaria dioica	19	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	25	2	5	0.1	1	.	.	.	.	.	.	.	.	.	.	.	.	20°	36*
Nardus stricta	53	.	.	.	.	15	3	3	.	12	.	25	10	.	.	.	.	.	.	7	0.3	5	15	0.5	4	1	.	1	25	.	15	.	5	.	75*	60°	.	79*
Juncus jacquinii	47	.	.	.	.	.	0.1	.	5	3	0.2	1	.	.	.	.	.	.	.	1	0.1	5	8	0.1	5	10	.	.	2	.	10	.	5	.	50°	60*	.	71*
Potentilla crantzii	16	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	0.5	.	8	.	1	.	.	.	.	.	0.2	.	.	.	.	.	.	20°	29*
Sedum alpestre	16	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	0.2	.	0.1	0.2	0.1	.	.	.	.	.	.	.	20°	29*
Helictotrichon versicolor	16	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	1	4	.	5	.	.	.	.	.	.	.	.	.	0.1	.	.	20°	.	29*
Hieracium alpinum	16	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	0.3	2	.	0.2	.	.	20°	.	29*
Companion species																																						
Carex sempervirens	19	.	.	.	.	.	.	.	.	15	.	.	.	.	0.1	.	.	.	.	8	15	.	.	.	.	.	.	.	1	.	.	.	3	.	.	20°	20°	29°
Botrychium lunaria	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	0.2	.	0.2	.	0.2	.	.	.	.	.	.	.	.	.	.	.	.	20°	21°
Erigeron alpinus	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	0.5	.	0.5	.	2	.	.	.	.	.	.	.	.	.	.	.	.	20°	21°
Minuartia sedoides	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	.	.	.	0.2	.	.	.	.	.	.	.	.	4	6	.	.	.	.	.	.	20°	7°
Salix foetida	9	.	.	.	.	.	.	1	.	.	.	.	0.2	0.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	25	40*	.	.
Veronica aphylla	9	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	3	0.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	14°
Alchemilla cf. *helvetica* aggr.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	14*
Anthyllis vulneraria subsp. *valesiaca*	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	14*
Cardamine alpina	6	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	20*	7°
Carex caryophyllea	6	.	.	.	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	7°
Luzula alpinopilosa	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	0.1	.	.	.	.	14*
Thesium alpinum	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	14*
Achillea nana	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	7°
Agrostis cf. *rupestris*	3	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.
Androsace vitaliana	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.5	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Carex cf. *pulicaris*	3	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	.
Carex dioica	3	.	.	.	.	.	.	.	.	.	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	.
Carex flava	3	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.
Carex rupestris	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.
Festuca rubra aggr.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Gentiana clusii	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Gentiana spec.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	.	.	.	.	.	.	7°
Hieracium angustifolium	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Juncus trifidus	3	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.
Juniperus communis subsp. *alpina*	3	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.
Leontodon cf. *crispus*	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Ligusticum mutellina	3	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	.
Luzula lutea	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Nigritella rhellicani aggr.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Oxytropis helvetica	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	7°
Polygala alpina	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Potentilla frigida	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.
Pulsatilla vernalis	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Ranunculus platanifolius	3	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	.
Rumex acetosella	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Saxifraga androsacea	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	7°
Saxifraga oppositifolia aggr.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	7°
Senecio doronicum	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Silene rupestris	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Soldanella alpina	3	.	.	.	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	.
Soldanella spec.	3	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.	.
Thlaspi rotundifolium subsp. *corymbosum*	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	.	.	.	.	.	.	.	.	.	.	7°
Trifolium alpinum	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7°
Trisetum cf. *distichophyllum*	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	7°
Veronica fruticans	3	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20*	.

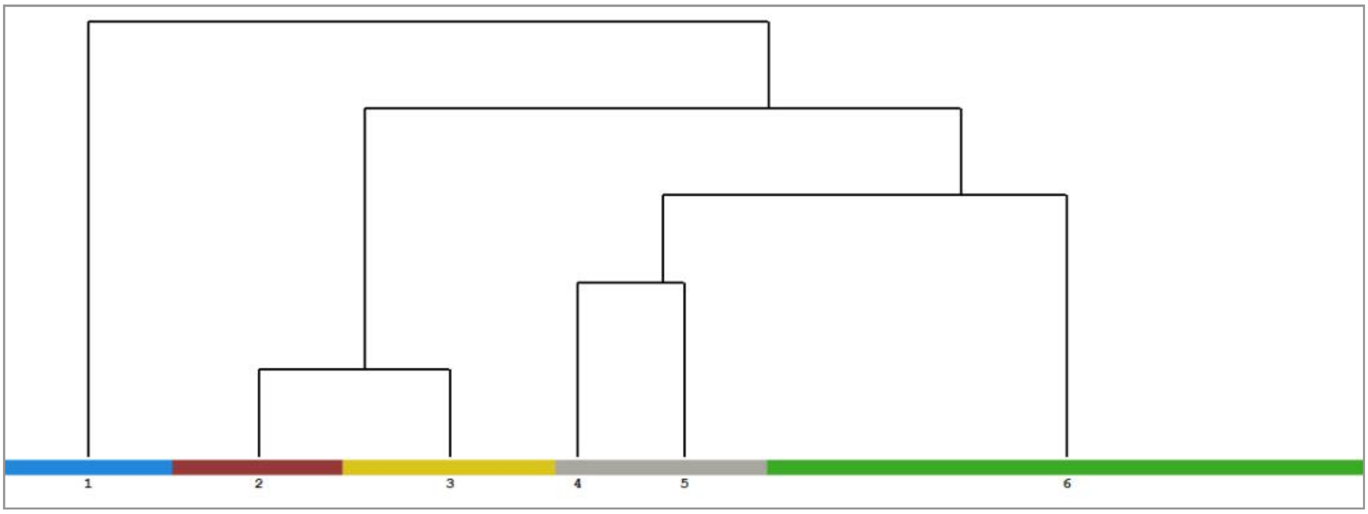


Fig. 6. Dendrogram from Juice with 6 clusters (maximum Sorensen dissimilarity: 0.576) Cluster 4 and 5 were merged into one cluster. The informal names used in this work are as follows: 1 – "fen acidic", 2 – "snow bed", 3 – "fen alkaline", 4 and 5 – "rock", 6 – "meadow".

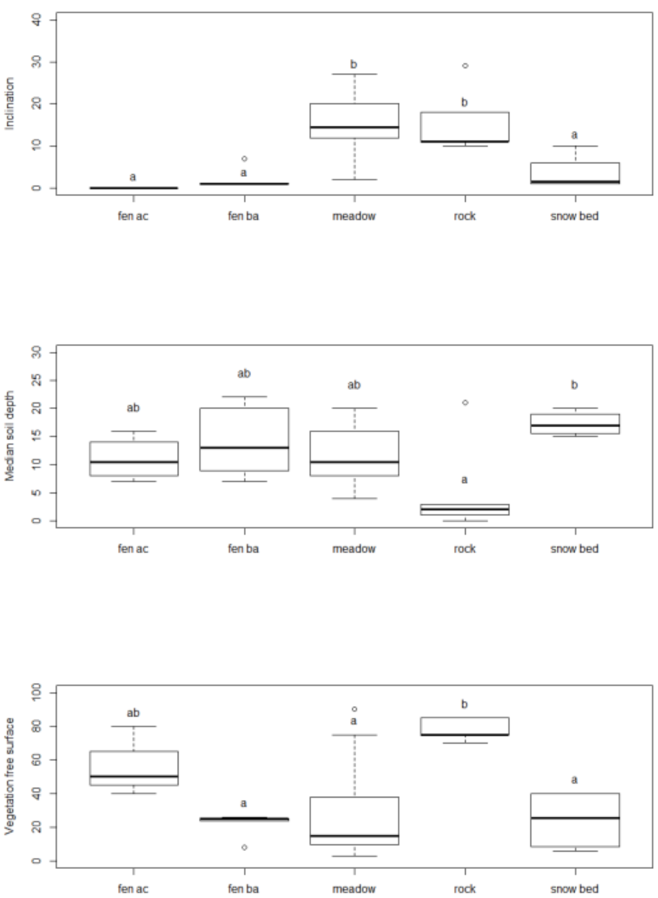


Fig. 7. Boxplots of topographic and soil parameters in comparison between the five distinguished vegetation types (fen acidic, fen alkaline, meadow, rock and snow bed). The superscript letters indicate homogeneous groups according to Tukey's post-hoc test.

Discussion

Species and their distribution

The species found are typical and well-known for the siliceous Alps at the given elevation (Info Flora 2018); *Thlaspi sylvium* (Matterhorn pennycress) was the only Red List species. In all of Switzerland, this species only occurs in a small territory around the study area (< 20 km^2) and is listed as Vulnerable according to IUCN criterion D2 (Bornand et al. 2016). Accordingly it has a high national priority (BAFU 2011). Due to further distribution areas in the Italian/French Cottian and Grajan Alps (Sauerbier & Langer 2017), the species is not listed on the international list of endangered species (Bilz 2011). Category D2 stands for a very small distribution area in which a species can disappear in a very short time due to the effects of human activity or accidental events. On the Gornergrat and in the wider surroundings of Zermatt, the plant species must therefore be given increased attention, as these areas are used heavily for recreation and tourism.

The species list of the current study reflects a large part of the local vegetation but cannot be considered complete due to the fact that sampling took place only during part of the season. According to Info Flora (2018) six additional nationally red-listed species occur or occurred in the project perimeter (Table 3).

The orchid *Nigritella rhellicani* (Alpine vanilla orchid) found in the project perimeter is protected according to the Nature and Cultural Heritage Ordinance of Switzerland. However, this species is distributed widely in the entire Swiss Alps and Jura Mts. and not endangered (Info Flora 2018).

The marsh plants *Eriophorum scheuchzeri* and *Carex nigra* were found at the Riffel Lake at 2770 m a.s.l. These occurrences, which are regarded as elevational records

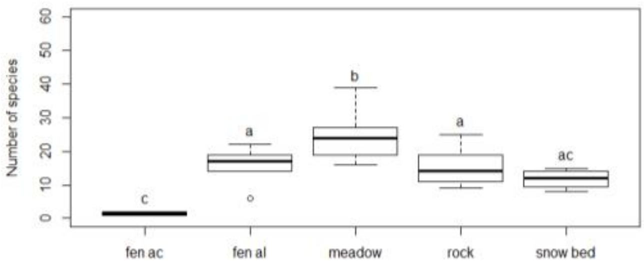


Fig. 8. Boxplots for species richness of vascular plants in 10 m² in comparison between the five distinguished vegetation types (fen acidic, fen alkaline, meadow, rock and snow bed). The superscript letters indicate homogeneous groups according to Tukey's post-hoc test.

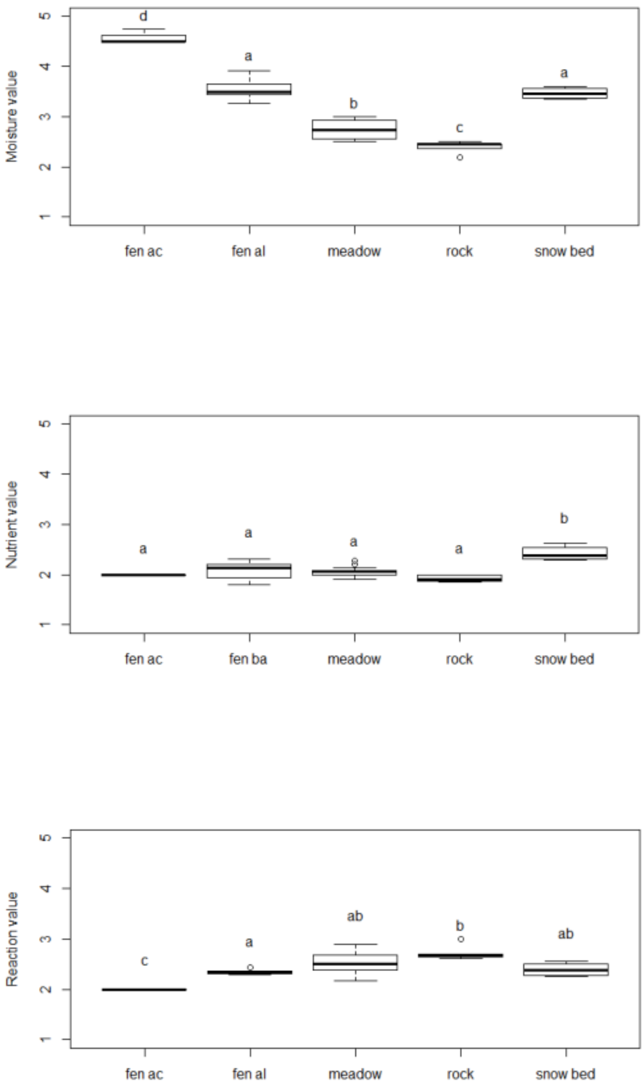


Fig. 9. Boxplots of mean indicator values for soil properties in comparison between the five distinguished vegetation types (fen acidic, fen alkaline, meadow, rock and snow bed). The superscript letters indicate homogeneous groups according to Tukey's post-hoc test.

Table 3. Red List Species of the Info Flora database for the study area Gornergrat (project perimeter). The finds were reported by various persons, including explicit Red List inspections. The endangerment criteria (including subcategories) stand for A: decrease in population size and C: general population size.

Red List species	Red List category	IUCN criteria
Artemisia borealis	VU	C2a(i)
Carex atrofusca	VU	C2a(i)
Carex maritima	VU	A2c, A3c
Phyteuma humile	VU	C1, C2a(i)
Taraxacum pacheri	VU	A2c, C1, C2a(i)
Trifolium saxatile	VU	C1, C2a(i)

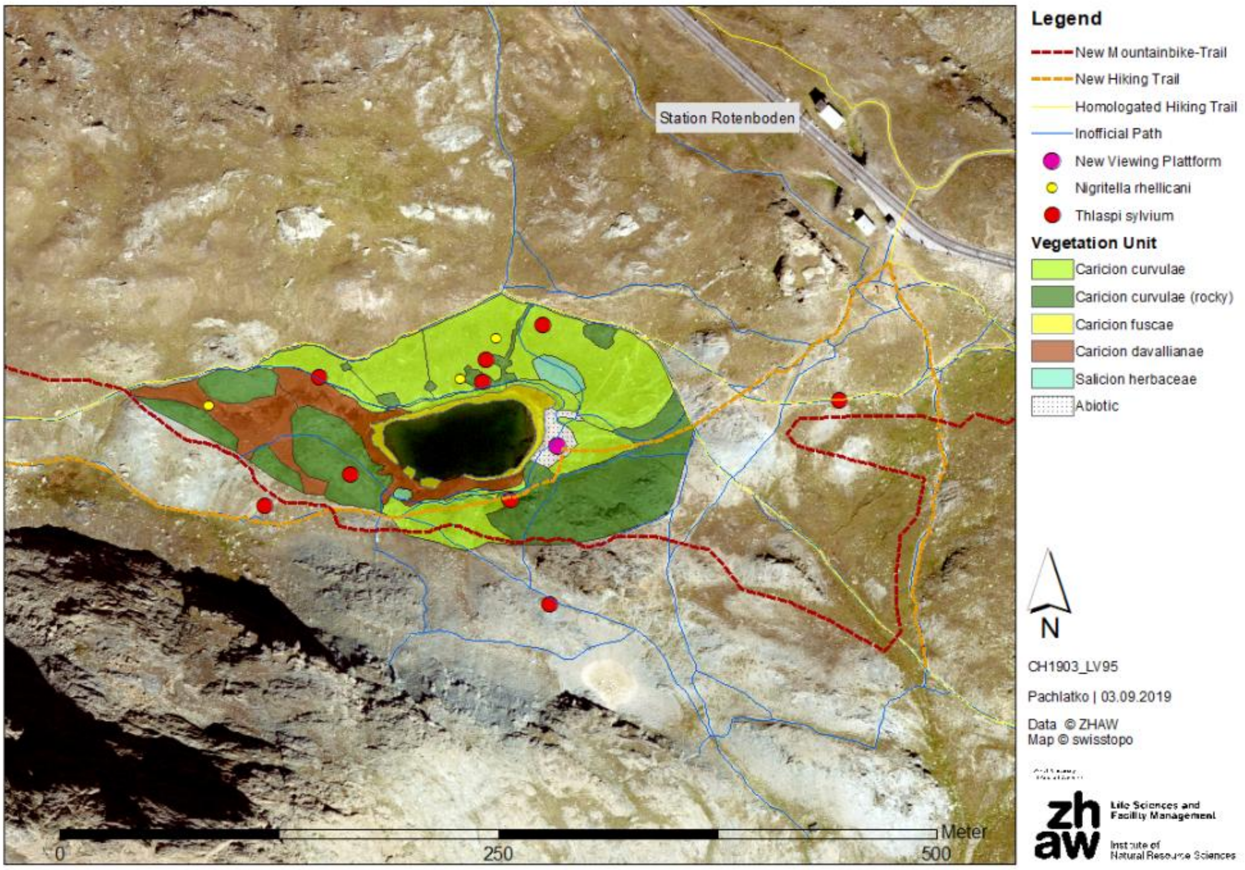
(Käsermann et al. 2003), are due to the protected location of the lake. Here a total of eleven marsh and aquatic plants have their alpine elevation record (among others also *Sparganium angustifolium*, *Ranunculus trichophyllus* subsp. *eradicatus*, *Potamogeton berchtoldii*, *Carex davalliana*, *Juncus triglumis*) (Käsermann et al. 2003).

Ordination

The length of the first ordination axis shows the high importance of the underlying factors. The distribution of species along this axis (left: *Minuartia recurva*; right: *Eriophorum angustifolium*) together with the relative length and the angle of the arrow "weighted moisture number" indicate that this axis mainly reflects a moisture gradient. In the diverse mosaic structure of the investigated landscape, this seems plausible, particularly under the dry climate of the Gornergrat: depressions with higher humidity represent a blatant contrast to the exposed hilltop location (Käsermann et al. 2003). For the second ordination axis, we did not find strong correlation with any of the measured or inferred parameters, so likely a non-measured parameter (or a combination of several parameters) is responsible for the differentiation along this axis.

Syntaxonomic assignment

The acidophilous snowbeds could readily be assigned to the *Salicetum herbaceae* (class *Salicetea herbaceae*), which was already described in the early days of phytosociology by Rübel in 1911 (Grabherr & Mucina 1993; Pignatti & Pignatti 2014). The cluster "fen acidic" could equally well be assigned to the alliance *Caricion fuscae* (order *Caricetalia fuscae*, class *Scheuchzerio palustris-Caricetea fuscae*). In the area it is represented by two extremely species-poor communities in the shallow waters of the Riffel lake: the well-known *Eriophoretum scheuchzeri* and one-species stands of *Eriophorum angustifolium*. The cluster "fen alkaline" actually forms a transition between the orders *Caricetalia fuscae* and *Caricetalia davallianae*, of acidic and base-rich fens respectively, which also is reflected by the mean reaction values that were only slightly higher than in "fen acidic". Based on the presence of *Primula farinosa* with a constancy of 80% and a phi-value of 0.72, we placed it preliminarily into



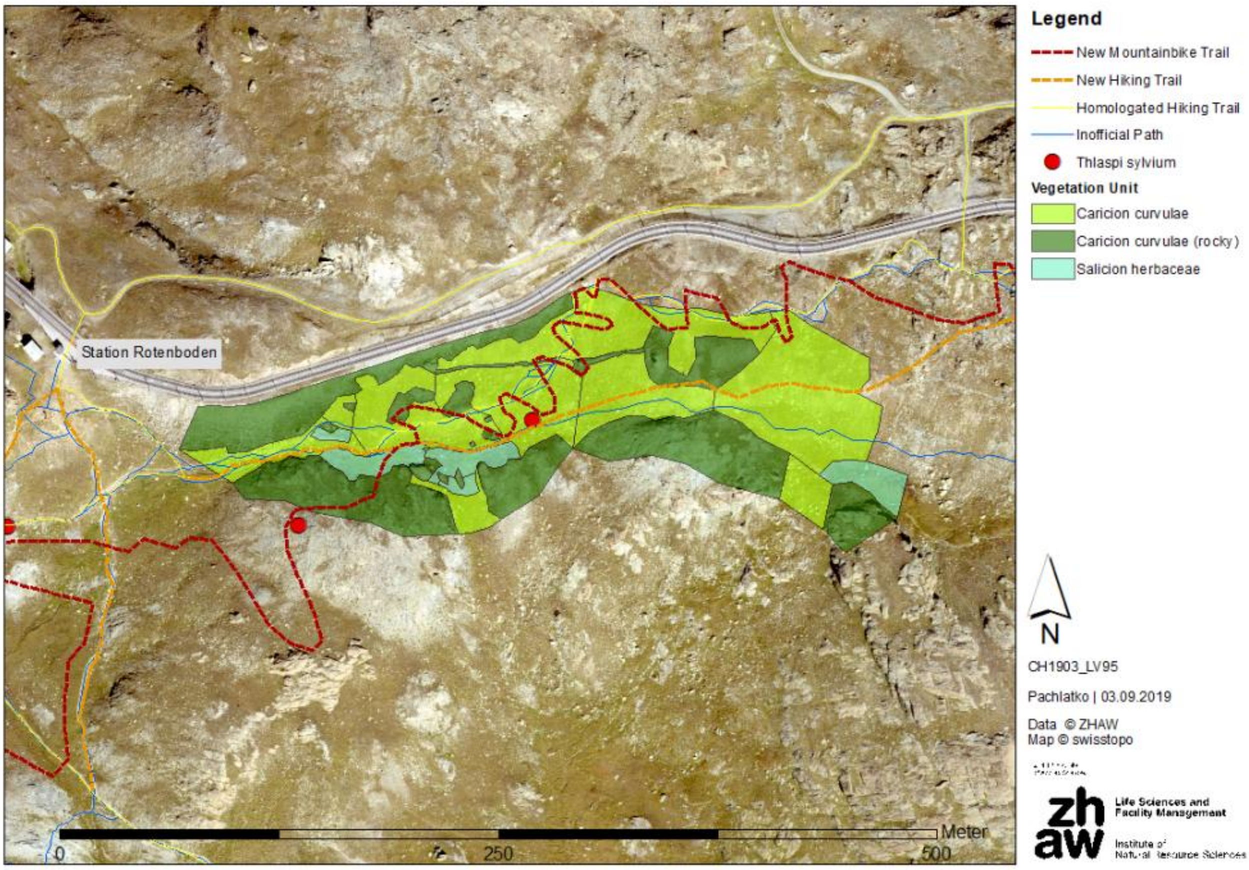


Fig. 10. Detailed vegetation maps of the two parts of the study perimeter. The vegetation units are shown with the names according to the assignment in the Discussion: fen acidic = *Caricion fuscae*; fen alkalilne = *Caricion davallianae*; meadow = *Caricion curvulae*; rock = *Caricion cuvulae* (rocky); snow bed = *Salicion herbaceae*.

the *Caricetalia davallianae*/*Caricion davallianae*, where this species is considered a character species (Grabherr & Mucina 1993; Theurillat et al. 1995; Delarze et al. 2015). The two dominating graminoids, *Carex nigra* and *Trichophorum cespitosum*, are generally considered as diagnostic species of the class, thus occurring in both acidic and base-rich fens (Grabherr & Mucina 1993; Theurillat et al. 1995). Therefore, the rather low mean indicator values for soil reaction in the case of "fen alkaline" might be due to the fact that the indicator values of Landolt et al. (2010: both 2, corresponding to acidic = pH 3.5–6.5) underestimate the true amplitude of the species.

The two remaining vegetation types, "meadow" and "rock", share many diagnostic species, in particular *Minuatria recurva*, *Ligusticum mutellinoides* and *Festuca halleri* ("Joint diagnostic species" in Table 2), which have their main occurrences in the order *Caricetalia curvulae* (class: *Juncetea trifidi*) (Landolt et al. 2010). The "meadows" with their relatively close sward (Fig. 7) and further diagnostic species of the *Caricetalia curvulae*, e.g. *Leucanthemopsis minima*, *Senecio incanus*, *Geum montanum* and *Carex curvula* (Table 2), clearly fall into this order. They can be readily identified with the *Festucetum halleri*, which Grabherr & Mucina (1993) characterise as a community of the central Alps on warm and dry slopes occurring at 2100–2600 m a.s.l. in Austria. With 2800 m a.s.l. the occurrences at Gornergrat are even higher up. The syntaxonomic placement of the "rock" unit is a challenge. While it shares numerous species with the "meadow" unit, it has a much more open vegetation structure (approx. 20% cover vs. 80% cover; Fig. 7). The local diagnostic species *Festuca intercedens* and *Phyteuma hemisphaericum* point into the direction of the class *Carici rupestris-Kobresietea bellardii*, while *Thlaspi sylvium* and *Salix retusa* point to the class *Thlaspietea rotundifolii*. The open, rocky character together with the frequent occurrence of *Sempervivum arachnoideum* and *S. montanum* would suggest that the unit could also belong to the alliance *Sedo-Scleranthion* of the class *Sedo-Scleranthetea* (Grabherr & Mucina 1993; Delarze et al. 2015). We could not find any association in the literature that matches our type, which occurs frequently and rather homogeneously throughout the study area. Therefore, we treat it here as informal *Sempervivum arachnoideum-Minuartia recurva* community, which we place preliminarily in the *Caricion curvulae*.

Proposed syntaxonomic scheme (higher ranks according to Mucina et al. 2016)

Class *Salicetea herbaceae* Br.-Bl. 1948

Order *Salicetalia herbaceae* Br.-Bl. in Br.-Bl. & Jenny 1926

Alliance: *Salicion herbaceae* Br.-Bl. in Br.-Bl. & Jenny 1926

"Snow bed": *Salicetum herbaceae* Rübel 1911 (Fig. 11)

Class *Scheuchzerio palustris-Caricetea fuscae* Tx. 1937

Order *Caricetalia fuscae* Koch 1926

Alliance: *Caricion fuscae* Koch 1926 *nom. conserv. propos.*

"Fen acidic": *Eriophoretum scheuchzeri* (Rübel 1911) Fries 1913 and *Eriophorum angustifolium* community (Fig. 12)

Order *Caricetalia davallianae* Br.-Bl. 1950 *nom. conserv. propos.*

Alliance: *Caricion davallianae* Klika 1934

"Fen alkaline": *Primula farinosa-Trichophorum cespitosum* community (Fig. 13)

Class *Juncetea trifidi* Hadač in Klika & Hadač 1944

Order *Caricetalia curvulae* Br.-Bl. in Br.-Bl. & Jenny 1926

Alliance: *Caricion curvulae* Br.-Bl. 1925

"Meadow": *Festucetum halleri* Br.-Bl. in Br.-Bl. & Jenny 1926 (Fig. 14)

"Rock": *Sempervivum arachnoideum-Minuartia recurva* community (Fig. 15)

Vegetation map

The vegetation map of Steiner (2002) at the alliance level at large scale agrees with our study, but comes to different conclusions at small scales in the area of the Riffel Lake (Fig. 10). Specifically, Steiner classified the shores and fens of subarea 1 (Riffel Lake) differently and did not distinguish snow bed communities at all. With regard to the riparian vegetation, Steiner describes the situation as alluvial bank (TypoCH: 2.2.5), while we divided them into two alliances. On the one hand the non-calcareous fen (*Caricion fuscae*) with interspersed *Eriophorum scheucherzi* as character species, on the other hand the calcareous fen (*Caricion davallianae*) with *Primula farinosa* as character species. In the course of our study, *Carex bicolor* and *Carex maritima* could not be detected, despite multiple inspections. According to Steiner (2002) and Info Flora (2018), these character species (*C. bicolor*: dominant, *C. maritima*: rare) of the alluvial banks should occur at the Riffel Lake. This would have made a small-scale assignment to the *Caricion bicolori-atrofuscae* Nordhagen 1937 (alluvial bank) possible. It is not clear whether the absence of the species in the surveys and inspections of this work is subject to an observer bias or is due to an actual change in the vegetation during the 1.5 decades. The complete absence of snow bed communities in Steiner's (2002) work is probably due to the generalization in the mapping process. The abundance of snow beds in the perimeter, with *Alchemilla pentaphyllea* (character species) as well as *Salix herbacea* and *Sibbaldia procumbens* (characteristic species), can be assumed also for 2002.

Conservation value

With the above described assignment of the two fen types and the snow bed to the alliance *Salicion herbaceae* (*Carex foetida* and *Alchemilla pentaphyllea*), the question of protected habitats in the study area can be answered positively (Delarze et al. 2015). According to the Red List of Habitats (Delarze et al. 2016), both fen types are vulnerable (VU), while the other three vegetation units fall into the category LC (least concern). According to the Swiss Nature and Cul-

Fig. 11. Stand of the *Salicion herbacae* with typical carpet-like growth of the low *Salix herbacea*. Photo: J. Pachlatko 2018.

Fig. 12. Shore vegetation with *Eriophorum angustifolium* at the Riffel lake. The vegetation unit coded as "fen acid" was assigned to the *Caricion fuscae.* Photo: J. Dengler 2018.

Fig. 13. Example of an area coded as "fen alkaline" in the discharge of the Riffel lake. The assignment to the alliance *Caricion davallianae* was based on the species *Primula farinosa.* Photo: J. Dengler 2018.

tural Heritage Ordinance, both the fens and the snow beds are all protected (Art. 14, para. 3, Annex 1, NHV 2017). As described in the Results, also a few protected and endangered species can be found in the study area. The diversity and rarity of the plants in this area, concentrated in a small area, is of great floristic value (Käsermann et al. 2003) and conflicts with the high visitor frequency (Whinam & Chilcott 2003; Mason et al. 2015). The overuse of nature as a tourist resource often results in the loss of local biodiversity and landscape quality (Holden 2016).

The analyses of orthophoto series of the Riffel Lake (years 1882–2015) show a continuous degradation of the shore and fen vegetation (for details, see Pachlatko 2018). The integration into a BLN protected area and the floristic values surveyed raise the question of appropriate protection. The Swiss Federal Inventory of Landscapes and Natural Monuments (BLN) calls for the preservation of the untouched character of natural and wild habitats (BAFU 2017). The Swiss Federal Ordinance on Nature and Cultural Heritage also makes it clear that biotopes are protected among other things by "design measures that can achieve the protection objective, repair existing damage and prevent future damage" (Art. 14, Para. 2c, NHV 2017). Due to the situation (deterioration of the vegetation condition, visitor frequency), the authors therefore recommend a visitor management system with measures such as user-specific trails that does justice to the protection objectives of the area.

Recommendations for the "Gornergrat concept"

For the "Gornergrat concept", it is recommended to adapt the planned route changes in the study area based on the vegetation mapping of our study (for details, see Pachlatko 2018). In particular, the routing in subarea 2 (path section) should be shifted because the planned mountain bike trail leads through a stand of the *Salicion herbaceae* (snow bed, protected according to NHV 2017), and the planned new hiking trail to be approved would be very close to it (Pachlatko 2018). The strong tourist attraction of the eastern lake shore (very scenic point for photographers with lake in the foreground and Matterhorn in the background) was included in the project with the planned construction of a viewing platform. Our findings support such a solution. A landscape-friendly viewing platform on the lake shore, combined with attractive visitor information, could greatly reduce the pressure of use on the shore vegetation. Also recommended are the path changes planned by the project around the Riffel Lake, as they take into account the sensitive fens that occur here. Throughout the project area, it is also recommended to restore the informal paths in order to avoid further erosion.

In order to reduce the pressure of use on the flora and vegetation of the area, steering measures are required to keep the flow of visitors on the paths and give the habitats around the Riffel Lake a chance to regenerate. Sensitive areas are to be bypassed with lead structures. Due to the strong degradation of the eastern shore of the Riffel lake, it is recommended that visitors be kept away and that the shore be restored during the project. Here, the roughening

Fig. 14. Example of the vegetation type coded as "meadow" with dominating *Festuca halleri*. It belongs to the alliance *Caricion curvulae.* Photo: J. Dengler 2018.

Fig. 15. Rocky subtype of the alliance *Caricion curvulae* with *Erigeron alpinus*, *Sempervivum arachnoideum* and *Festuca halleri*. It inhabits the driest sites of the study area. Photo: J. Pachlatko 2018.

of the most disturbed areas in the shore area is superficially necessary in order to make plant growth possible again. By preserving the area from trampling, the Riffel Lake shore could regain its original character.

Author contributions

This publication is based on the Bachelor thesis of J.P., which was supervised by J.D. and M.W. J.P. sampled the data, ran the analyses, planned the paper and led the writing, while J.D. and M.W. revised and approved the text.

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References

BAFU 2011. *Liste der National Prioritären Arten. Arten mit nationaler Priorität für die Erhaltung und Förderung, Stand 2010*. Bundesamt für Umwelt [Umwelt-Vollzug Nr. 1103], Bern, CH.

BAFU 2017. BLN Nr. 1707 Dent Blanche, Matterhorn, Monte Rosa. URL: https://data.geo.admin.ch/ch.bafu.bundesinventare-bln/objectsheets/2017revision/nr1707.pdf [accessed 27 July 2018].

Barros, A. & Marina Pickering, C. 2017. How networks of informal trails cause landscape level damage to vegetation. *Environmental Management* 60: 57–68.

Bilz, M., IUCN Regional Office for Europe & IUCN Species Survival Commission (eds.) 2011. *European red list of vascular plants*. Publications Office of the European Union. Luxembourg, LU.

Bornand, C., Gygax, A., Juillerat, P., Jutzi, M., Möhl, A. & Rometsch, S. 2016. *Rote Liste Gefässpflanzen. Gefährdete Arten der Schweiz*. BAFU and InfoFlora, Bern and Geneva, CH.

Braun-Blanquet, J. 1920. Observations sur la végétation et sur la flore des environs de Zermatt (1919-1920). *Bulletin de la Murithienne* 41: 18–55.

Braun-Blanquet, J., Pallman, H. & Bach, R. 1954. *Pflanzensoziologische und bodenkundliche Untersuchungen im schweizerischen Nationalpark und seinen Nachbargebieten*. Lüdin, Liestal, CH.

Bruelheide, H. 2000. A new measure of fidelity and its application to defining species groups. *Journal of Vegetation Science* 11: 167–178.

BVZ Holding AG 2017. *BVZ Holding annual report. 2017*. URL: https://www.bvzholding.ch/de/investoren/berichterstattung/geschaeftsberichte [accessed 20 September 2018].

Chytrý, M. 2007. Project vegetation of the Czech Republic: Preface and summary of methods. In: Chytrý, M. (ed.) *Vegetation of the Czech Republic 1. Grassland and heathland vegetation*, pp. 35–52. Academia, Prague, CZ.

Chytrý, M., Tichý, L., Holt, J. & Botta-Dukát, Z. 2002. Determination of diagnostic species with statistical fidelity measures. *Journal of Vegetation Science* 13: 79–90.

Corrodi, D. 2011. *Einfluss der touristischen Nutzung auf die Pioniervegetation am Grünsee im Gletschervorfeld des Grossen Aletschgletschers – Analyse des Trittfaktors und Vorschläge für die Besucherlenkung.* Master thesis, Geographical Institute, University of Zurich, Zurich, CH.

Delarze, R., Gonseth, Y., Eggenberg, S. & Vust, M. 2015. *Lebensräume der Schweiz: Ökologie – Gefährdung – Kennarten*. 3rd ed. Ott, Bern, CH.

Delarze, R., Eggenberg, S., Steiger, P., Bergamini, A., Fivaz, F. & Gonseth, Y. 2016. *Rote Liste der Lebensräume der Schweiz. Updated Summary of the Technical Report 2013 on behalf of the Federal Office for the Environment (BAFU)*. BAFU, Bern, CH.

Dengler, J., Chytrý, M. & Ewald, J. 2008. Phytosociology. In: Jørgensen, S.E. & Fath, B.D. (eds.) *Encyclopedia of ecology*, pp. 2767–2779. Elsevier, Oxford, UK.

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 Grassland Group* 32: 13–30.

Dierschke, H. 1994. *Pflanzensoziologie – Grundlagen und Methoden*. Ulmer, Stuttgart, DE.

Eagles, P.F.J., McCool, S.F. & Haynes, C.D. 2002. *Sustainable tourism in protected areas: guidelines for planning and management*. IUCN, Gland, CH.

Eggenberg, S. & Möhl, A. 2013. *Flora Vegetativa*. 3rd ed. Haupt, Bern, CH.

Eggenberg, S., Bornand, C., Juillerat, P., Jutzi, M., Möhl, A., Nyffeler, R. & Santiago, H. 2018. *Flora Helvetica – Exkursionsführer*. Haupt, Bern, CH.

Ellenberg, H. & Leuschner, C. 2010. *Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht*. 6th ed. Ulmer, Stuttgart, DE.

Ewald, J. 2003. A critique for phytosociology. *Journal of Vegetation Science* 14: 291–296.

Glavac, V. 1996. *Vegetationsökologie - Grundfragen, Aufgaben, Methoden*. Fischer, Jena, DE.

Gnägi, C. & Labhart, T.P. 2015. *Geologie der Schweiz.* 9th ed. Ott, Bern, CH.

Grabherr, G. & Mucina, L. (eds.) 1993. *Die Pflanzengesellschaften Österreichs. Teil 2: Natürliche waldfreie Vegetation.* Fischer, Jena, DE.

Hill, M.O. 1979. *TWINSPAN – A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes*. Cornell University, New York, US.

Holden, A. 2016. *Environment and tourism*. 3rd ed. Routledge, New York, US.

IMBA 2004. *Trail solutions IMBA's guide to building sweet singletrack – International Mountain Bicycling Association*. Publication Printers Corp., Boulder, US.

Info Flora 2018. *Das nationale Daten- und Informationszentrum der Schweizer Flora*. URL: https://www.infoflora.ch/en/ [accessed 20 September 2018].

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.

Käsermann, C., Meyer, F. & Steiner, A. 2003. *Die Pflanzenwelt von Zermatt*. Rotten, Visp, CH.

Klötzli, F. 2001. Zur Biotopkartierung der Bergregionen – Eine vegetationskundliche Betrachtung. *Sauteria* 11: 9–25.

Landolt, E., Bäumler, B., Erhardt, A., Hegg, O., Klötzli, F., Lämmler, W., Nobis, M., Rudmann-Maurer, K., Schweingruber, F.H., (…) & Wohlgemuth, T. 2010. *Flora indicativa – Ökologische Zeiterwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen*. 2nd ed. Haupt, Bern, CH.

Lauber, K., Wagner, G. & Gygax, A. 2018. *Flora Helvetica.* 6th ed. Haupt, Bern, CH.

Mason, S., Newsome, D., Moore, S. & Admiraal, R. 2015. Recreational trampling negatively impacts vegetation structure of an Australian biodiversity hotspot. *Biodiversity and Conservation* 24: 2685–2707.

MeteoSwiss. 2018. *Bundesamt für Meteorologie und Klimatologie – Messwerte Gornergrat / Zermatt*. URL: https://shop.meteoswiss.ch/productView.html?type=psc&id=17 [accessed 25 August 2018].

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J.-P., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, J., (…) & Tichý, L. 2016. Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Applied Vegetation Science* 19, Suppl. 1: 3–264.

NHV 2017. *Verordnung über den Natur- und Heimatschutz (NHV) vom 16. Januar 1991 (Stand am 1. Juni 2017)*. URL: https://www.admin.ch/opc/de/classified-compilation/19910005/201706010000/451.1.pdf.

Pachlatko, J. 2018. *Vegetationskartierung am Gornergrat*. Bachelor thesis, IUNR, Zurich University of Applied Sciences, Wädenswil, CH. DOI: 10.21256/zhaw-2364.

Pickering, C.M. & Hill, W. 2007. Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia. *Journal of Environmental Management* 85: 791–800.

Pignatti, E. & Pignatti, S. 2014. *Plant Life of the Dolomites - Vegetation Structure and Ecology.* Springer, Heidelberg, DE.

Reisigl, H. & Keller, R. 1994. *Alpenpflanzen im Lebensraum – Alpine Rasen, Schutt- und Felsvegetation.* 2nd ed. G. Fischer, Jena, DE.

Roleček, J., Tichỳ, L., Zelenỳ, D. & Chytrỳ, M. 2009. Modified Twinspan classification in which the hierarchy respects cluster heterogeneity. *Journal of Vegetation Science* 20: 596–602.

Rupf, R. 2015. *Planungsinstrumente für Wandern und Mountainbiking in Berggebieten – unter besonderer Berücksichtigung der Biosfera Val Müstair. Nationalpark-Forschung in der Schweiz*. Haupt, Bern, CH.

Sauerbier, H. & Langer, W. 2017. *Endemische Alpenpflanzen.* Margraf Publishers, Weikersheim, DE.

Schubert, R., Hilbig, W. & Klotz, S. 2010. *Bestimmungsbuch der Pflanzengesellschaften Deutschlands.* 2nd ed. Spektrum, Heidelberg, DE.

Steiner, A. 2002. *Die Vegetation der Gemeinde Zermatt*. Hochschulverlag AG ETH, Zürich, CH.

swisstopo. 2018. *Bundesamt für Landestopographie. GeoCover Vektordaten*. URL: https://map.geo.admin.ch [accessed 27 July 2018].

Theurillat, J.-P., Aeschimann, D., Küpper, P., Spichinger, R. 1995. The higher vegetation units of the Alps. *Colloques Phytosociologiques* 23: 189–239.

Tichy, L. & Chytry, M. 2006. Statistical determination of diagnostic species for site groups of unequal size. *Journal of Vegetation Science* 17: 809–818.

Tichý, L., Chytrý, M. & Zelený, D. 2018. *Juice Version 7.0.102.* URL: http://www.sci.muni.cz/botany/juice/ [accessed 09 September 2018].

Whinam, J. & Chilcott, N. M. 2003. Impacts after four years of experimental trampling on alpine / sub-alpine environments in western Tasmania. *Journal of Environmental Management* 67: 339–351.

Wimpey, J. F. & Marion, J. L. 2010. The influence of use, environmental and managerial factors on the width of recreational trails. *Journal of Environmental Management* 91: 2028–2037.

WSL. 2017. *VEGEDAZ*. URL: https://www.wsl.ch/de/services-und-produkte/software-websites-und-apps/vegedaz-version-2017.html [accessed 09 September 2018].