University of Bayreuth
Department of Plant Ecology
M.Sc. Biodiversity and Ecology

Resurvey of a GLORIA Target Region in the Swiss National Park

Master Thesis

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1 Summary

There is no doubt that recent global climate change is in process and affects life on earth. Especially mountain ecosystems are supposed to be highly sensitive to climate change due to the vertical compression of life zones, rough abiotic environment and limiting ecological factors. Therefore, the European Alps are one of the best observed ecosystems where many studies figured out how climate change is affecting biodiversity. One of the biggest and most well-known projects is the GLORIA-Europe initiative established by Prof. Dr. Georg Grabherr from University of Vienna. The aim of this project is to establish a world-wide long-term monitoring network in alpine ecosystems to detect effects of climate change on the vegetation of mountain summits using standardised methods.

This study is involved in the GLORIA initiative to resurvey four calcareous and four siliceous summits at Swiss National Park in summer 2009/10. The aim of this study is to answer the questions if there are changes between the first (2002/03) and second survey in plant species number, species frequency and in heterogeneity between plots. Furthermore, is altitude, cardinal direction and bedrock influencing changes or are there species groups reacting different and what are the reasons behind it?

In total 226 species were found in 2009 and 2010 with almost 80% more species on the siliceous summits. Species turnover rate between the two surveys is relatively high (15-30%) and also frequency is increasing for several species. But, there are no effects of bedrock or exposition and no differences for species groups. This study shows that fluctuation of species turnover is due to phenological development. Furthermore, differences in plot heterogeneity can be explained by phenological fluctuation. However, there are hints for initiating effects of climate change. The occurrence of *L. decidua* on three lower summits and the high content of new found species with a lower distribution limit at the montane belt on Piz Murter as well as general increase in plant frequency could be caused by climate change. Hence, these hints of climate change should be focused on in future investigations as long-term effects of climate change are expected.

2 Zusammenfassung

Der Einfluss des Klimawandels auf die Erde ist mittlerweile unbestritten. Vor allem auf Bergregionen hat der Klimawandel großen Einfluss, da hier Vegetationszonen vertikal sehr dicht aufeinander folgen und raue Lebensbedingungen sowie begrenzende ökologische Faktoren stark angepasste Pflanzenarten voraussetzen. Aus diesem Grund sind die Europäischen Alpen eines der am Besten untersuchten Naturräume weltweit. Eines der größten und bekanntesten Forschungsprojekte ist das GLORIA-Europe Projekt, das die Einrichtung eines weltweiten Dauermonitoring Netzwerkes in alpinen Ökosystemen zum Ziel hat um die Auswirkungen des Klimawandels auf die Berggipfelflora unter Verwendung standardisierter Methoden zu erfassen.

Diese Studie ist in das GLORIA-Europe Projekt eingegliedert und untersucht die erste Wiederholungsaufnahme im Schweizer Nationalpark auf vier Kalk und vier Silikatgipfeln. Dabei wird den Fragen nachgegangen ob es zwischen der ersten (2002/03) und zweiten (2009/10) Aufnahme zu Änderungen in der Artenzahl, der Artfrequenz und in der Heterogenität zwischen den Aufnahmeflächen gekommen ist. Darüber hinaus wurde untersucht ob Höhe, Exposition und Ausgangsgestein der Aufnahmeflächen einen Einfluss auf die Änderungen haben und ob es Pflanzenartengruppen gibt, die unterschiedliche Reaktionen zeigen. Zudem sollen mögliche Gründe erörtert werden.

Insgesamt wurden in dieser Studie 226 Pflanzenarten aufgenommen, wobei 80% der Arten auf Silikatgipfeln auftreten. Der Artumsatz ist mit 15-30% relativ hoch und auch die Frequenz einzelner Arten nimmt zwischen beiden Aufnahmezeitpunkten stark zu. Dabei gibt es kaum Unterschiede zwischen Art- oder Plotgruppen. Es spricht einiges dafür, dass die hohe Fluktuation des Artumsatzes durch phänologische Unterschiede beider Aufnahmejahre begründet ist. Auch die Änderungen der Plot Heterogenität können durch die Fluktuation erklärt werden. Trotzdem gibt es Hinweise auf beginnende Auswirkungen des Klimawandels. So tritt *L. decidua* das erste Mal auf 3 niedrigeren Gipfeln auf und es gibt einige neue Arten mit montanem Verbreitungsschwerpunkt auf einem der höheren Gipfel. Auch die allgemeine Zunahme der Artfrequenzen sprechen für Auswirkungen des Klimawandels. Diese Hinweise sollten in zukünftigen Wiederholungsaufnahmen berücksichtigt und genauer untersucht werden.

3 Introduction

In the last 10 years evidence has accumulated that recent climate change has substantial influence on various ecosystems and causes ecological and biological responses (Hughes, 2000; Walther et al., 2002; Root et al., 2003; Parmesan & Yohe, 2003; Walther et al., 2005a and Parmesan, 2006). Especially mountain ecosystems will be, and already have been, strongly affected (Sala et al., 2000; Theurillat & Guisan, 2001; Beniston, 2003; Pauli et al., 2003; Krajick, 2004; Kullman, 2004 and Nogués-Bravo et al., 2007) not only because species are finely adapted to temperature, but also because alpine biodiversity is very high due to heterogeneous site conditions, vertical compression of live zones, high rates of endemism caused by isolation and few competitive dominance through limiting ecological factors like the lack of organic substrate, short growing season or rough winds (Jentsch & Beierkuhnlein, 2003).

As a consequence of temperature increase with climate change, plant species are expected to shift towards the top of mountains (Grabherr *et al.*, 1994; Walther *et al.*, 2005b; Vittoz P., 2006; Cannone *et al.*, 2007; Pauli *et al.*, 2007; Holzinger *et al.*, 2008; Lenoir *et al.*, 2008; Erschbamer *et al.*, 2009). Not only vascular plant species will shift, but also other life forms like bryophytes and butterfly species (Bergamini *et al.*, 2009; Wilson *et al.*, 2007). Upward movements of plant species will lead to the reduction of available space and thus, the size of populations, because the area in higher altitudinal ranges is smaller than at lower altitudes (Theurillat & Guisan, 2001; Jentsch & Beierkuhnlein, 2003).

As different species will likely move with different speed vegetation associations in the alpine-nival ecotone will mix (Parolo & Rossi, 2008 and Vittoz *et al.*, 2009). However, it is not clear how this process will work in detail and which consequences will result. A problem might be that species or populations moving upward slowly could get overrun by fast moving, more dominant species and thereby be driven to extinction. Species occurring on the top of a mountain cannot escape further up. It is possible that these species also get replaced by more dominant species moving from lower altitudes. This could lead to a bottleneck effect with high extinction rates and a loss of genetic and species diversity in alpine regions. As migrating species originate from the same species pool of lower vegetation belts, homogenization of summit floras will increase (Jurasinski & Kreyling, 2007).

Many studies within the last 20 years resurveyed sites for which historical data of the altitudinal distribution of alpine vegetation is available and thereby observed upward shifts of alpine plants. Most of them are from the European Alps, because of the availability of historical records from the end of the 18th and the first half of the 19th century. The canton Grisons in Switzerland is the most intensively studied region in the Alps (Hofer, 1992; Walther et al., 2005b; Holzinger et al., 2008; Parolo & Rossi, 2008).

One of the biggest and most well-known projects is the GLORIA-Europe initiative established by Prof. Dr. Georg Grabherr from University of Vienna. The aim of this initiative is to establish a world-wide long-term monitoring network in alpine ecosystems to detect effects of climate change on the vegetation of mountain summits using standardised methods (Pauli *et al.*, 2004).

In the course of the GLORIA-Europe initiative four summits on calcareous and four on siliceous bedrock were resurveyed next to the Swiss National Park. The aim was to figure out how vegetation is spatially distributed and if there are changes with altitude and cardinal direction between the first and the second survey and if so which are the driving factors behind it. The following questions were to be clarified:

Are there changes between both surveys for:

(1) ...plant species number? Are there differences between species types (a) alpine and nival plant species, b) plant life forms) and plot characteristics (altitude, aspect, bedrock)?

(2) ...plot similarity due to species change? Are there differences in plot characteristics?

(3) ...species abundance and are there differences between species types?

And:

(4) ...What are the reasons behind it? Are there hints for short-term climate change or is it due to fluctuation?

4 Materials and Methods

4.1 Study area

In summer 2002 and 2003 eight mountain summits were selected and investigated in a first survey (Camenisch, 2002, Scheurer & Camenisch, 2002) following the multi-summit approach field manual of the Global Observation Research Initiative in Alpine Environments (GLORIA) proposed by Pauli *et al.* (2004). The study area is located in the Upper Engadine, canton Grisons, in the South-Eastern part of Switzerland (Fig. 1a). The investigated summits belong to three different mountain ranges (Ortler Alps, Livigno Range, Sesvenna Range) within the Central Eastern Alps (Tab. 1). Four summits are situated on calcareous (Upper Triassic sediments of the Engadine Dolomite) and four on siliceous (Sesvenna-Crystalline) bedrock (Fig. 1b), but the geological and tectonic structure is very complex (Schmid, 1973).

Tab. 1: Investigated summits.

Summit	Altitude [m a.s.l.]	Mountain Range	Bedrock
Munt Buffalora (MBU)	2438	Ortler Alps	calcareous
Munt Chavagl (MCH)	2542	Ortler Alps	calcareous
Piz Murter (PMU)	2836	Livigno Range	calcareous
Piz Foraz (PFO)	3092	Sesvenna Range	calcareous
Mot sper la Chamana Sesvenna (MCS)	2424	Sesvenna Range	siliceous
Minschuns (MIN)	2519	Sesvenna Range	siliceous
Mot dal Gajer (MDG)	2797	Sesvenna Range	siliceous
Piz Plazer (PPL)	3104	Sesvenna Range	siliceous

In summer 2009 and 2010 the summits were reinvestigated using the same methods. As the summits are located in or close to the border of the Swiss National Park (Fig. 1a) all summits are with low or almost no anthropogenic disturbance. The summits follow an altitudinal gradient from the sub-alpine to the sub-nival ecotone.

The vegetation at the lower summits is mostly alpine grassland with botanical elements from the montane and treeline ecotone. At the higher summits vegetation is more scarce with elements from the alpine vegetation as surface is mostly rocky with a high proportion of scree material (Fig. 2). Grazing impacts affect the summits MCS and MIN (Fig. 3) and marginally MBU and MDG. There are big differences in vegetation between the main cardinal directions especially at the lower summits. The northern and western slopes are rocky with scarce vegetation (weather side) while vegetation on southern and eastern slopes of lower altitudes is dense with well-developed soils.

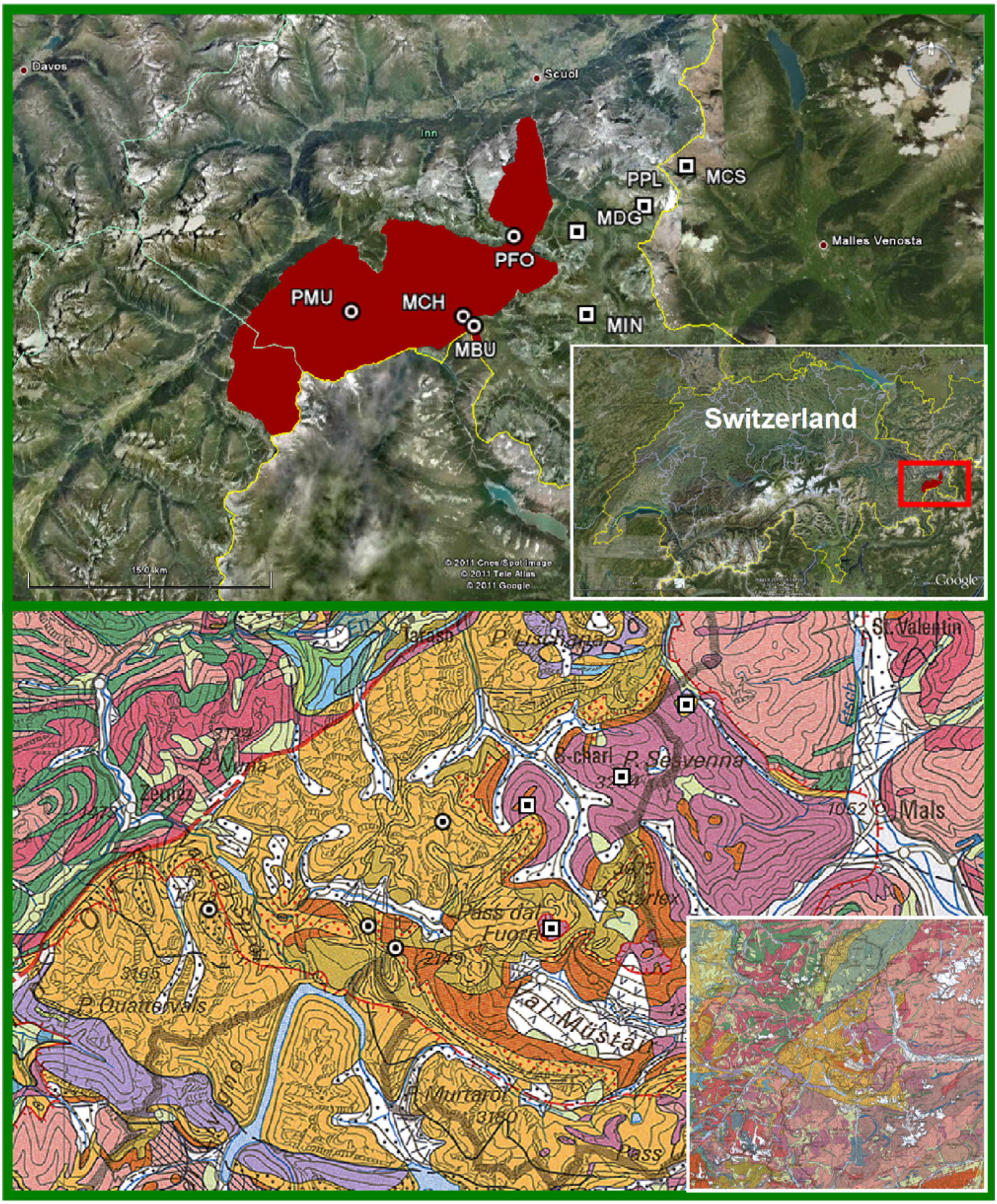


Fig. 1: GLORIA target region SN. (a) Swiss National Park (red area) and investigated summits (circles: calcareous and squares: siliceous summits). © Google (b) Geological map and investigated summits (dark purple: Sesvenna-Crystalline; orange and brownish colours: Engadine Dolomite). Small map: Large scaled geological map showing the isolated, triangle shaped Engadine Dolomite surrounded by crystalline bedrocks (red, purple and green colours). geodata © swisstopo (2005)

Fig. 2: Pictures of the summits: MBU (2438m), MCH (2542m), PMU (2836m), PFO (3092m), MCS (2424m), MIN (2519m), MDG (2797m) and PPL (3104 m) (top left to bottom right).

Fig. 3: Grazing impact at MCS. Left: Cow "tasting" measuring tape (Photo: B. Ganser). Right: Cows at MCS.

4.2 Field work

At each summit the sampling design of the GLORIA-Europe project proposed by Pauli *et al.* (2004) was applied. Therefore, the summits were divided into eight large-scale summit areas (SA) with an upper (highest summit point (HSP) to 5m below HSP) and a lower summit area (5 to 10m below HSP) for each main compass direction (Fig. 4). In the SA's all vascular plant species were recorded and abundance estimated using the 5 abundance classes “very rare”, “rare”, “scattered”, “common” and “dominant”.

For more meticulous records a 3x3m grid with four small-scale 1x1m² plots at each corner of the grid was installed for each main compass direction. All vascular species and estimate percent cover abundance of each species was recorded at the 1x1m² plots. Furthermore, a 1x1m² grid frame divided into 100 10x10cm² cells was used for presence-absence frequency counts for each species. To minimize sampling errors a second control recording was made after the first 'blind' record by comparing the 'blind' records with the data from the first survey at all SA's and plots.

Species were identified according to Flora Helvetica (Lauber & Wagner, 2007) and Flora Vegetativa (Eggenberg & Möhl, 2007), but nomenclature follows Flora Europaea (Tutin, 2010). Field work lasted from 07/20/2009 to 08/14/09 for the calcareous summits and from 07/26/2010 to 08/22/10 for the siliceous summits with interruptions. Thereby, 64 summit areas, 124 1x1 m² plots and 12.400 10x10 cm² grid cells were investigated for this study.

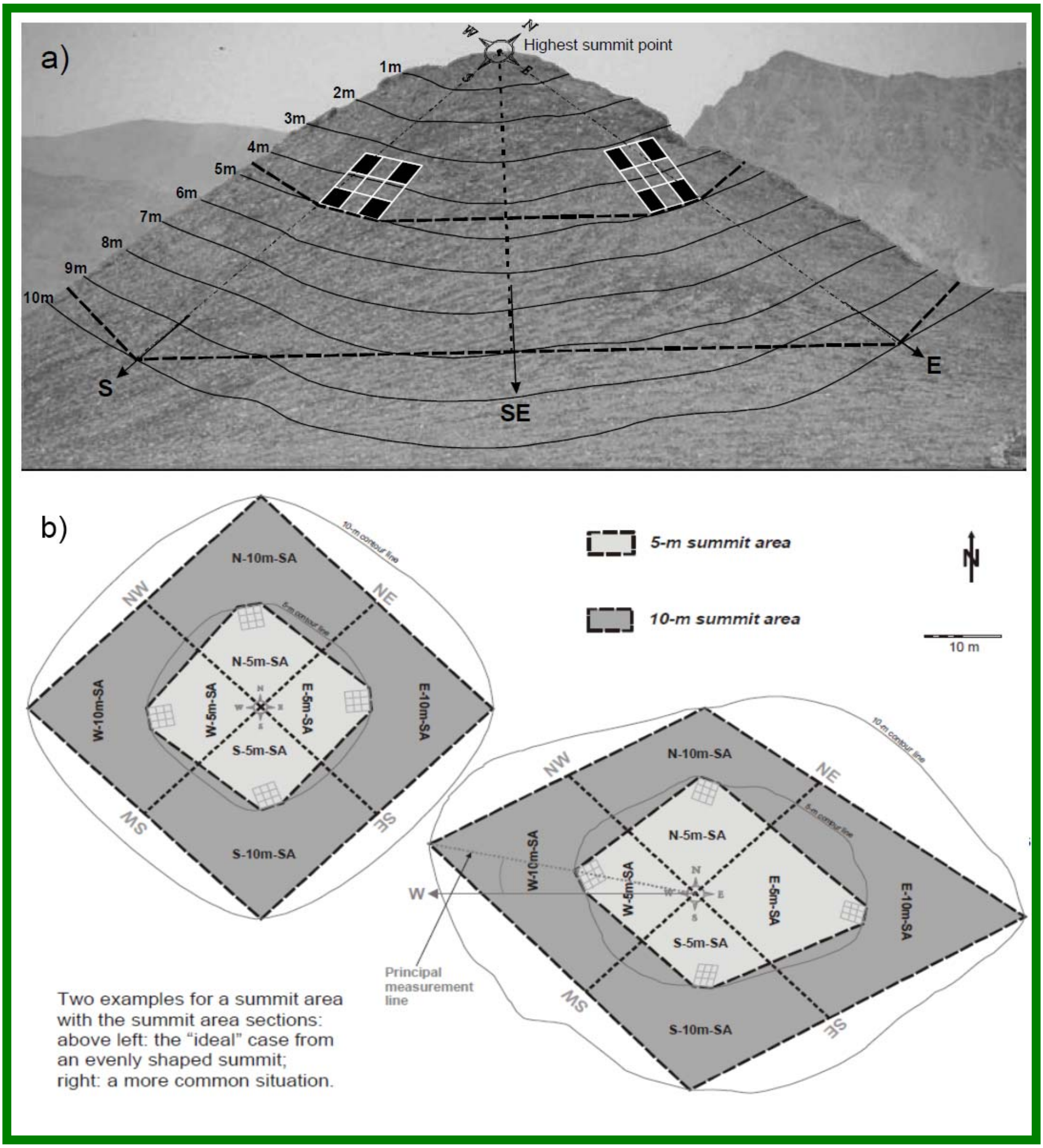


Fig. 4: "The Multi-Summit sampling design shown on a hypothetical example summit: (a) oblique view with schematic contour lines; (b) top view. The 3x3 m² quadrat clusters and the corner points of the summit areas are arranged in the main geographical directions. Eight summit area sections (= 4 subdivisions of the 5-m summit area and 4 subdivisions of the 10-m summit area). The area of the sections depends of the shape of the summit. Thus, it is usually different among the main directions (see the right sketch). The sections of the 10-m summit area are usually larger. The intersection lines always point from the HSP to the geographic NE, SE, SW, NW directions, respectively. In contrast, the principal measurement lines (from the HSP to N, E, S, W, respectively) may deviate from their geographic direction, dependent on the habitat situation." The 4 investigated 1x1 m² plots are arranged at the corners of the 3x3 m² cluster(Pauli et al., 2004).

4.3 Data analyses

All graphs and statistical analyses were created with the software R (v. 2.12.1) using the libraries lattice (Sarkar, 2008), latticeExtra (v. 0.6-14), RcolorBrewer (v. 1.0-2), vegan (v. 1.17-6) and lme4 (v. 0.999375-37). For more information on the differentiation of migrating species in the summit areas indicator values and life forms were used following Ellenberg (1991) and Landolt (1977) as well as information about lower and upper altitudinal limits using an separate list provided by the GLORIA Europe project completed with Flora Alpina (Aeschimann, 2004). Median indicator values of each 1x1 m² plot was used to get more information about environmental factors. For analysis summits are grouped in low (MCS, MBU, MIN and MCH < 2700 m.s.l.) and high summits (MDG, PMU, PFO and PPL > 2700 m.s.l.) as well as in calcareous (MBU, MCH, PMU and PFO) and siliceous summits (MCS, MIN, MDG and PPL). Additionally each summit was divided up into corresponding cardinal direction.

The correlation between species richness and altitude in interaction with bedrock and aspect was analysed with linear repeated mixed ANCOVA models. Heterogeneity between the plots was analysed by using Sørensen similarity index and visualised with dendrograms (average linkage clustering) and presence-absence DCA ordination plots. Changes of the ordination scores between first and second survey were tested with paired t-Test and paired Wilcoxon Test to detect changes in species composition within the plots.

5 Results

5.1 Species turnover on Summit Areas

In total 226 species were found in 2009 and 2010, although there were almost 80% more species found on the siliceous summits (Tab. 2). For all summits 16 new species were found (6.6%) in comparison to 15 missing species (6.2%). Species turnover occurred at all summits from 15.9 to 30.8 % except for Piz Plazer where no changes were observed. For the lower summits species number was marginally higher for missing than for new found species, whereas it is the opposite for two of the higher summits and balanced for the others. Nevertheless, merging all lower summits together species change was positive (1.5 %), but still lower as for higher summits (6.7 %). On calcareous and siliceous summits relative species number change was negative (-3 and -2.8 % respectively) and for all summits species number nearly did not change (0.4 %) even if turnover rate was still relatively high (12.9 %). Hence, change of species number is a matter of scale shown by the fact that there are different results for the single summits as for summit groups of the same summits (Tab. 2).

Tab. 2: Changes of species for the single summits and grouped for calcareous, siliceous, lower and higher summits and for all summits between survey 1 and 2.

	Survey 1	Survey 2	New species	Missing species	Relative change [%]	Turnover [%]
MBU	64	64	5	5	0.0	14.5
MCH	61	59	8	9	-3.3	25.0
PMU	39	39	4	4	0.0	18.6
PFO	10	12	3	1	20.0	30.8
MCS	120	118	16	18	-1.7	25.0
MIN	111	109	17	18	-1.8	27.6
MDG	55	59	11	7	7.3	27.3
PPL	9	9	0	0	0.0	0.0
calcareous	101	98	7	9	-3.0	15.0
siliceous	177	171	15	20	-3.4	18.3
low	201	202	19	16	0.5	16.1
high	89	95	12	7	6.7	18.6
total	226	224	16	15	-0.9	13.0

5.1.1 Classification in cardinal direction

Mean species occurrence rate for the four aspects is 3:3:2:2 (E:S:W:N) for unchanged species, 4:2:2:2 for new found species, except for PFO where E is missing, and diverging for the missing species (Fig. 5). Hence, importance of the eastern side for new found species is marginally higher and much higher for missing species on MBU and MCH, but for the latter sample size is relatively low. At northern plots proportion of missing species is low compared to new found and unchanged species. For new found and unchanged species there are no interactions with altitude or bedrock as the proportion of the different aspect is almost the same for each summit.

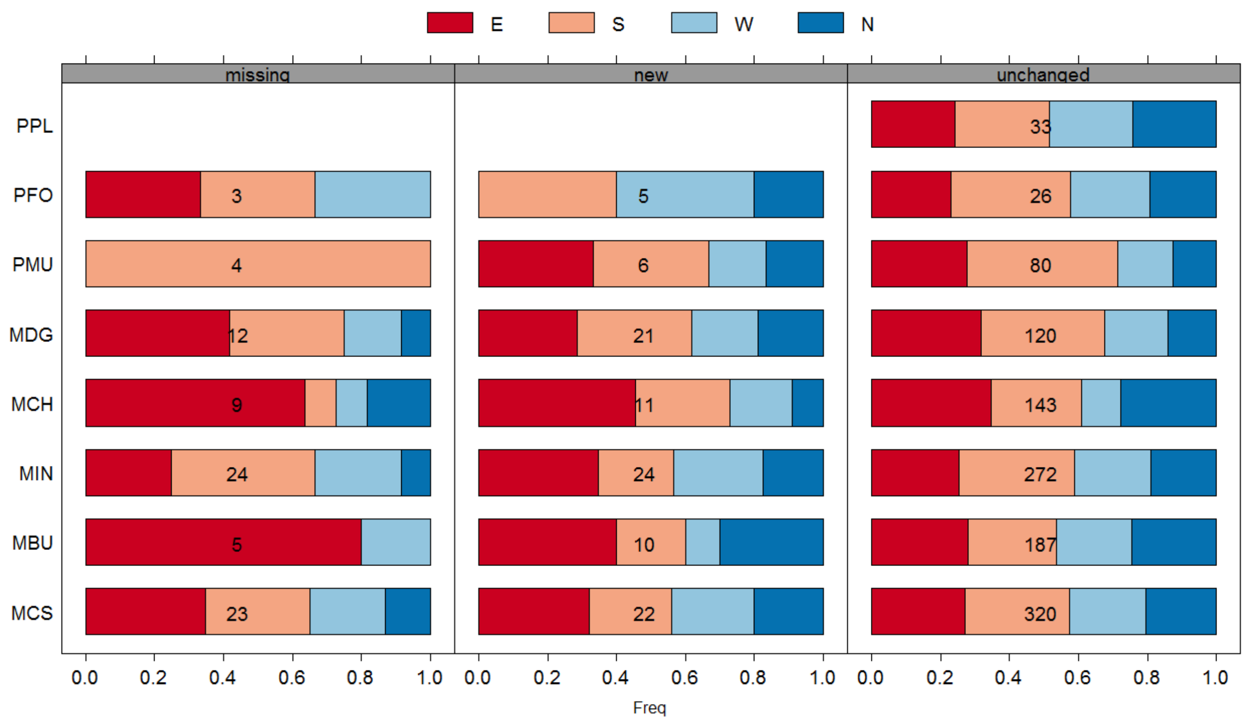


Fig. 5: Missing, new found and unchanged species of the resurvey for different aspects. Numbers in the figure are the sample size.

5.1.2 Classification in plant life forms

Most plant life forms following Ellenberg (1991) are herbaceous hemicryptophytes with a higher content of herbaceous chamaephytes at higher altitudes (Fig. 6). Geophytes, therophytes, (nano-) phanerophytes and woody chamaephytes occur at the lower summits only. Percentage of plant life forms is generally the same for missing, new found and for unchanged species except the new found phanerophyte (*Larix decidua*) at MCH, MIN and MCS. In contrast to the first survey (nano-) phanerophytes (*Pinus mugo* and *L. decidua*) occurred at all lower summits in 2009/10.

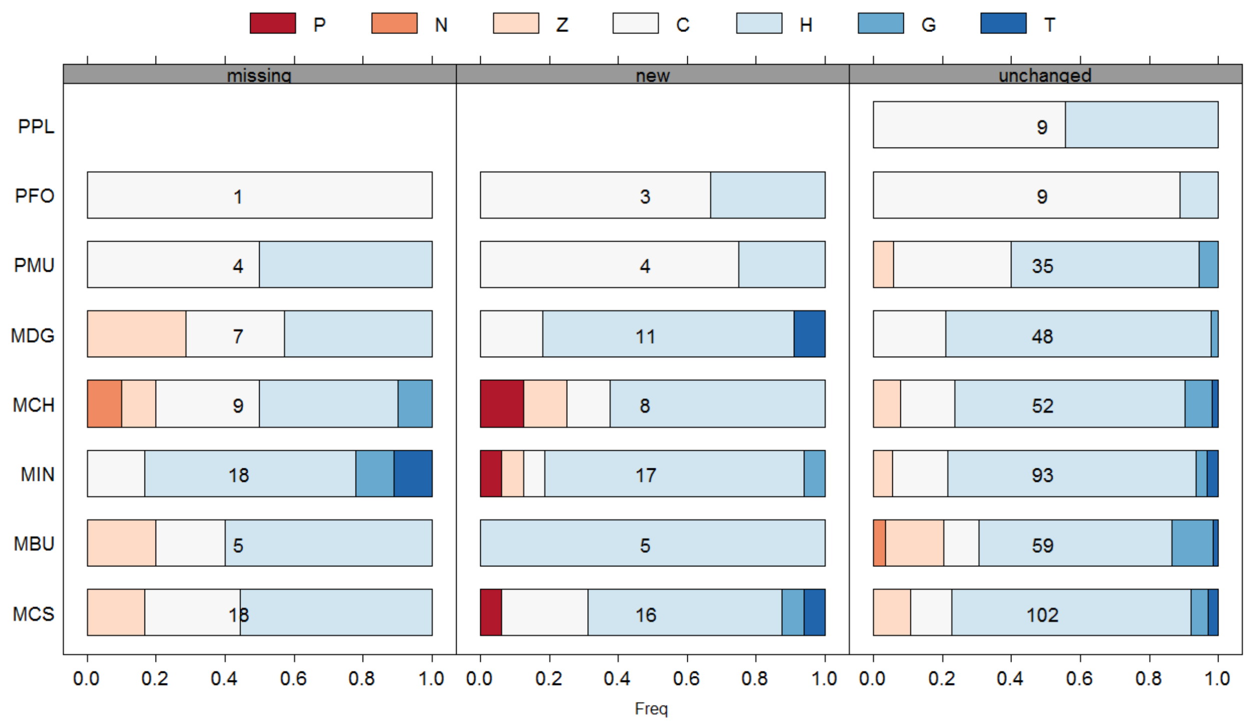


Fig. 6: Missing, new found and unchanged species of the resurvey for different plant life forms. Numbers in the figure are the sample size (P: phanerophytes; N: nanophanerophytes; Z: woody chamaephyt; C: herbaceous chamaephytes; H: hemicryptophytes; G: geophytes; T: therophytes).

5.1.3 Classification in altitudinal distribution limits

Species of the lower summits had their lower altitudinal limit mostly at the montane zone and treeline ecotone while it was the treeline ecotone and alpine zone for species of the higher summits (Fig. 7). Whereas for missing species the proportion of species with montane and alpine limits was still the same compared to unchanged species, it is different for the new found species. For example there are many species with a lower montane distribution limit at PMU.

For upper altitudinal limits it is obvious that content of species with a maximal distribution at the treeline ecotone is higher for new and not found species as to unchanged species. Species with a maximal distribution in the montane elevation zone occurred for the first time at MCS and MIN.

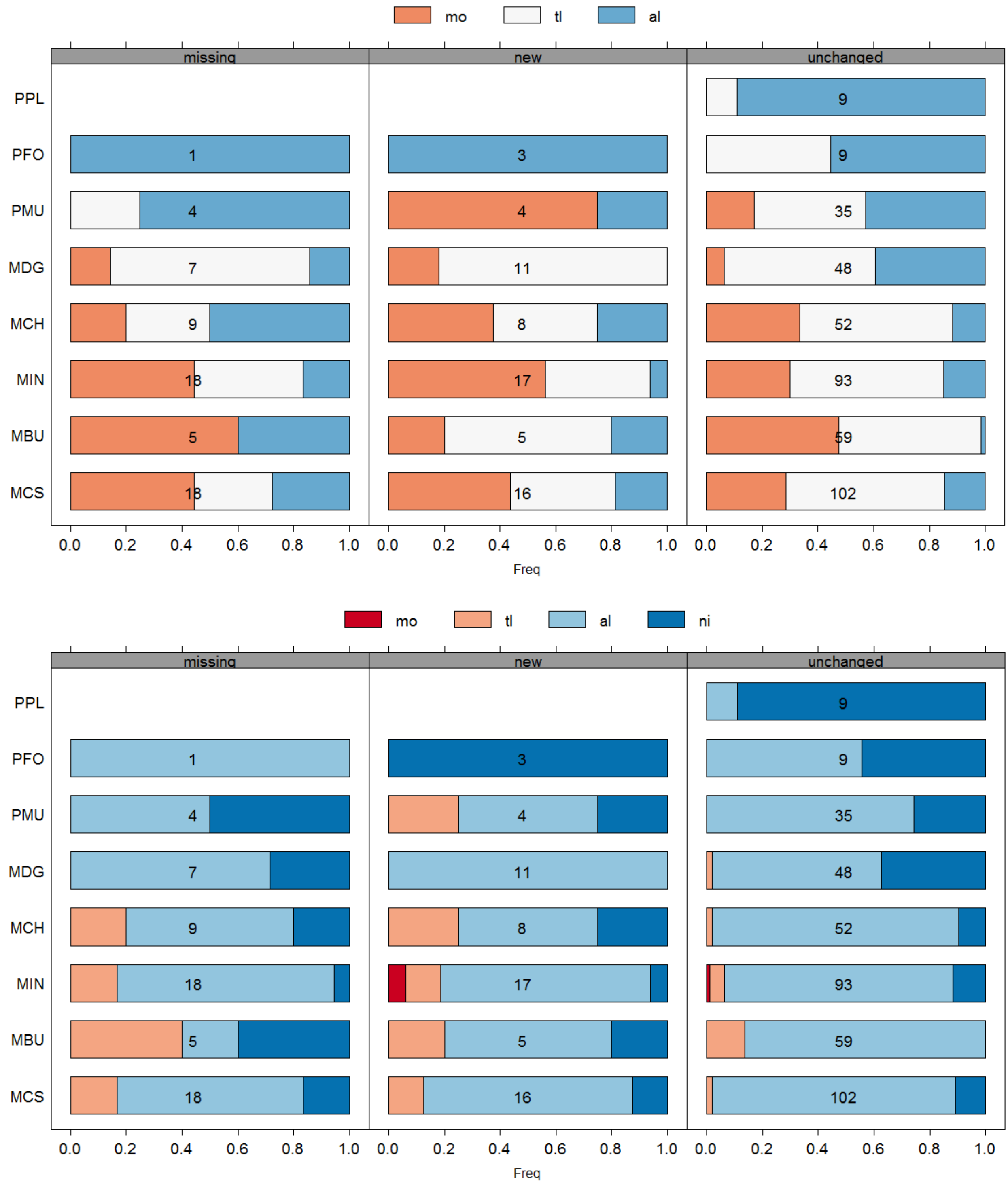


Fig. 7: Missing, new found and unchanged species of the resurvey for the lower (top) and upper altitudinal limits (bottom) with mo: montane, tl: treeline ecotone, al: alpine and ni: nival. Numbers in the figure are the sample size.

5.2 1x1 m² Plots

5.2.1 Species richness

In all of the 1x1 m² plots 126 plant species were found. In general species number declined with altitude, but there were differences between siliceous and calcareous bedrock as well as between different cardinal directions. A three-way interaction ($p = 1.14\ 10^{-5}$) for diversity is seen dependent on altitude related to bedrock and aspect (Fig. 8). Diversity was higher for the siliceous than for the calcareous bedrock with highest diversity at eastern and lowest at western sides. Species richness of eastern calcareous sides was more similar to siliceous than to the other aspects of calcareous bedrock.

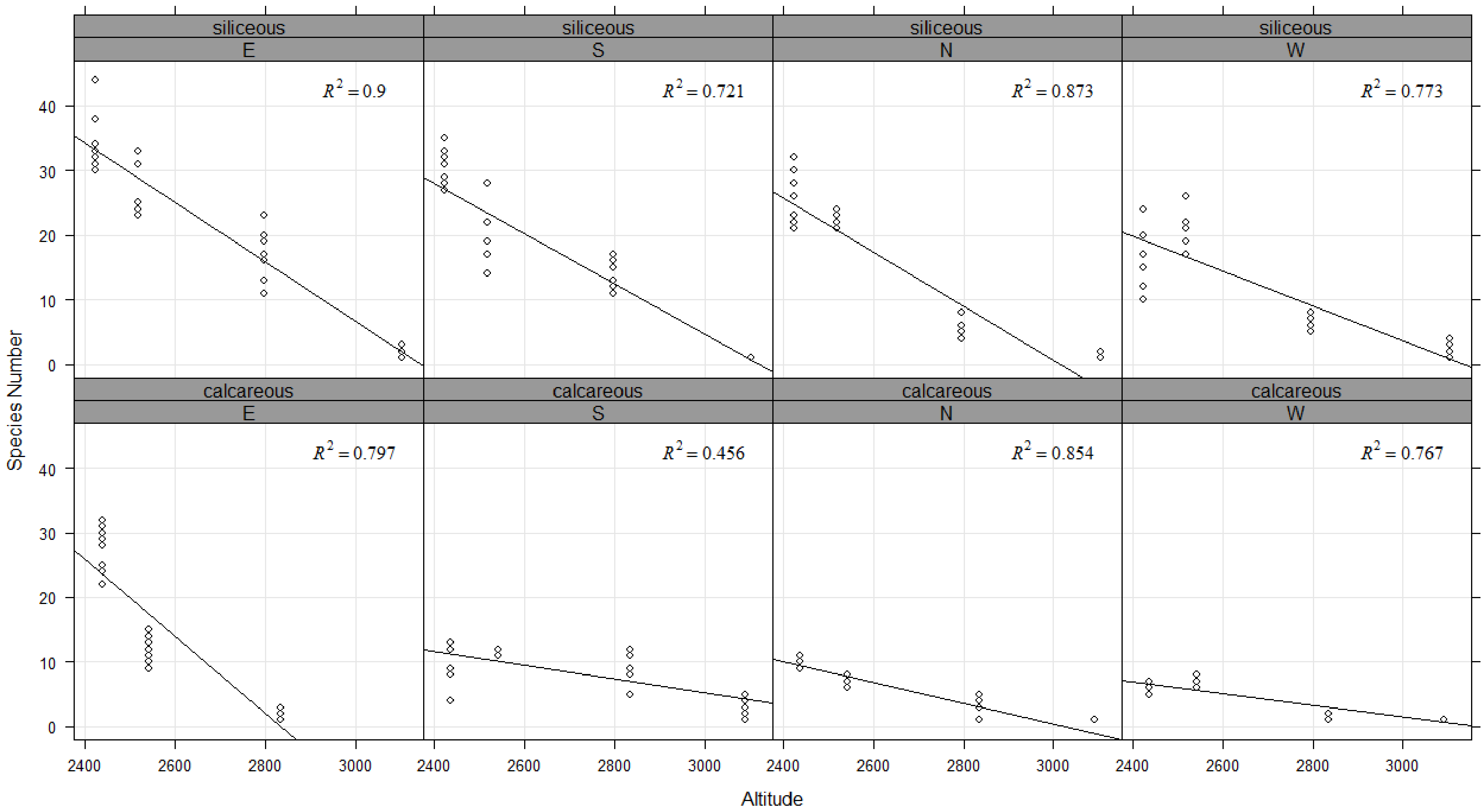


Fig. 8: Diversity interacts with bedrock and aspect when correlated with altitude and is highest for siliceous eastern and southern sides.

5.2.2 Species frequency

The results for species frequency sampled within the grid frame is showing an increase for most plant species. From 126 plant species 85 increased, 34 were unchanged and only 7 species decreased, but only few changes were significant (Tab. 8, see Appendix). In general, there are no differences of frequency changes for species groups (Tab. 3) or plot types, but species cover change is higher for the western plots of PMU (Fig. 9). The decreasing species were *Veronica aphylla*, *Geum montanum*, *Gentiana nivalis*, *Gentianella campestris*, *Ranunculus kuepferi*, *Campanula cochlearifolia* and *Polygonum aviculare*.

Tab. 3: Changes in species frequency for plant life forms (LF) and lower (AL) and upper altitudinal (AU) limit of the species (LF: woody chamaephytes (Z), herbaceous chamaephytes (C), hemicryptophytes (H), geophytes (G) and therophytes (T); AL/AU: mo: montane, tl: treeline ecotone, al: alpine and ni: nival).

		Increase [%]	Unchanged [%]	Decline [%]	n
LF	Z	60.0	40.0	0	10
	C	72.0	28.0	0	25
	H	67.5	26.3	6.3	80
	G	71.4	28.6	0	7
	T	0	0	100	2
AL	mo	75.9	13.8	10.3	29
	tl	66.2	28.2	5.6	71
	al	61.5	38.5	0	26
AU	mo	0	0	100	1
	tl	100	0	0	2
	al	67.3	26.9	5.8	104
	ni	68.4	31.6	0	19

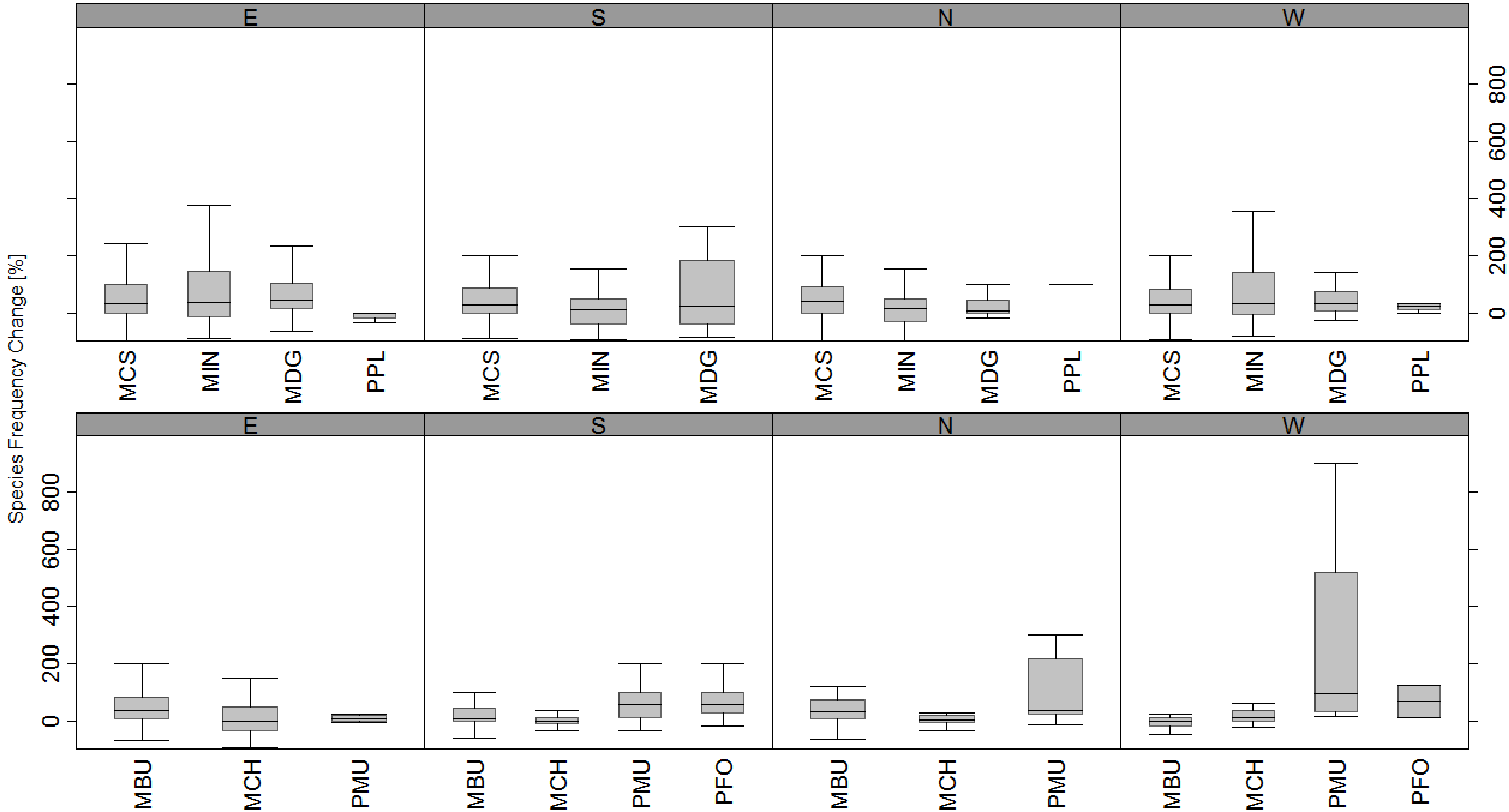


Fig. 9: Species Frequency Change (top: siliceous summits; button: calcareous). Species Frequency is rising in general. There are no differences in cardinal direction or bedrock. Only PMU W is higher than the other plots.

5.2.3 Plot heterogeneity

Plot heterogeneity is illustrated by dendrograms and ordination. In the dendrograms the most important factor for heterogeneity between the plots is altitude followed by bedrock (Fig. 10 and 11). Plots of summits with low altitude in cluster 1 and 2 are very heterogeneous compared to plots of summits with high altitude in cluster 3 and 4. Species composition within the plots of the lower as well as the higher summits is divided by bedrock. Heterogeneity between calcareous (cluster 1) and siliceous plots (cluster 2) of the lower summits and between calcareous (cluster 3) and siliceous plots (cluster 4) of the higher summits is very high.

But there are exceptions from this result as the eastern and southern sides of the relatively high summit MDG are more similar to the lower siliceous summits (cluster 1) than to the plots of the higher summits and even the plots of other aspects of MDG. Another exception are the western plots of PPL which are more similar to the plots of the higher calcareous summits than to the plots of the siliceous summits. Furthermore, one plot of PFO (S33) is more similar to MDG and PPL than to high calcareous summits. These results are shown in the dendrograms (Fig. 10 and 11) as well as in the ordination (Fig. 12).

Due to the characteristics of the data a presence-absence DCA ordination was used. As similarity is controlled mainly by the first axis there is a big arch effect on CA ordination occurring. Using percentage cover did not separate data along the second axis, because species cover for higher summits is just a fraction of species cover of lower summits leading to a suppression of the second axis.

In the ordination there are 7 similarity centres (1: MBU and MCH, 2: MCS, 3: S plots of MIN, 4: MIN and SE plots of MDG, 5: NW plots of MDG and PPL, 6: W plots of PPL, PFO and PMU, 7: S plots of PMU). High and low summits are divided in the ordination along the DCA 1 axis except for the southern plots of PMU, which are in between low and high summits, and except MDG where the southern and eastern plots are more similar to MIN. At almost all summits southern and sometimes eastern plots are divided from the other aspects along DCA 1 and 2 axes. All the calcareous summits and MCS, which is intermediate with calcareous inclusions, occur more or less at the negative part of axis 2 whereas all the siliceous summits occur at the positive part except for MCS.

Hence, the main axis DCA 1 is mainly explained by altitude, but also aspect, whereas DCA axis 2 is mainly explained by bedrock. This result can be verified by plotting the significant environmental factors to the ordination ($p < 0.001$ for altitude and the indicator values temperature, continentality, soil moisture and pH; $p = 0.01$ for indicator value nutrients) (Fig. 13). Moisture, altitude and temperature are correlated with DCA axis 1, the latter negatively. Nutrients are correlated positively with DCA axis 2, continentality and pH negatively. The indicator values of pH for the different summits (Tab. 4) are another hint that MCS is intermediate. Its median pH is in between those of siliceous and calcareous summits.

Tab. 4: Median pH indicator values for different summits

	MDG	PPL	MIN	MCS	MBU	MCH	PFO	PMU
Indicator value pH	3	3	4	6	8	8	8	8

Comparing the dendrograms of 2002/03 and 2009/10 the results are almost the same. Therefore heterogeneity has not changed considerably between the two surveys except for the southern plots of PMU. In the first survey these plots are more similar to the lower calcareous summits than to the higher summits, but in the second survey these plots are more similar to the latter. Plotting the changes of plot similarity of both surveys as arrows in the ordination (Fig. 14) the similarity change of PMU S can be explained, because of the change of two plots with DCA 1 direction. Both plots move marginally from lower to higher altitude direction expressing a big effect on the dendrograms. For the whole ordination there is no apparent unique direction for the change. Similarity changes seem to be more or less controlled by chance, but considering subsets, changes are more evident (Fig. 15). Testing the coherence of the DCA scores from survey 1 with the scores from survey 2 of the ordination there is no coherence for the whole data ($n = 103$, DCA 1: $p = 0.224$, DCA 2 $= 0.706$), but it is significant for DCA 2 axis of MDG ($n = 16$, $p = 0.022$) and very significant for MBU ($n = 16$, $p = 9.72\ 10^{-3}$) and MCS ($n = 16$, $p = 9.19\ 10^{-3}$). There is also a trend for changes of DCA 1 axes of MBU ($p = 5.04\ 10^{-2}$).

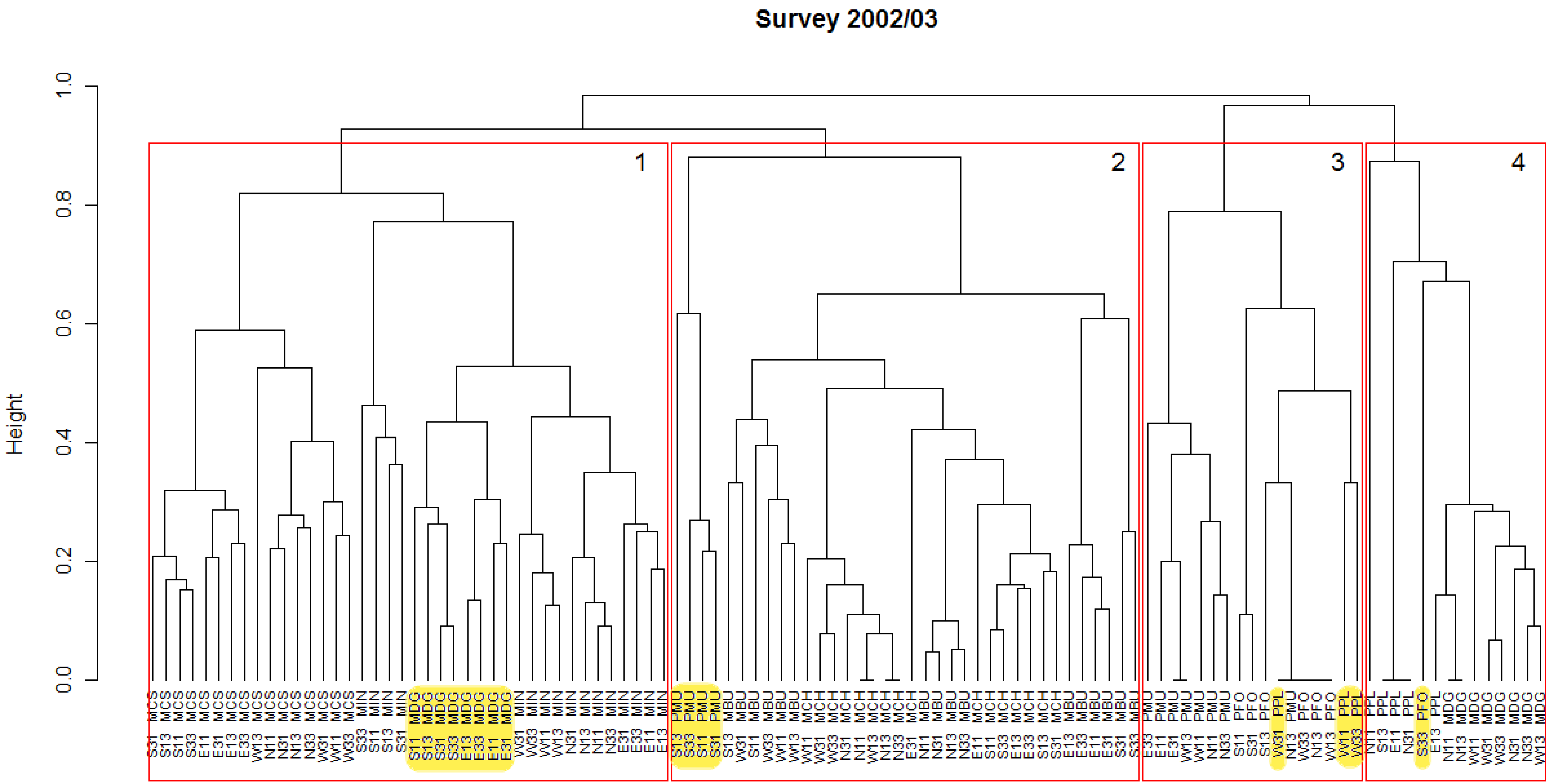


Fig. 10: Dendrogram of the plots from the first survey. Cluster 1 and 2 are the lower summits, cluster 3 and 4 the higher one. Cluster 1 and 4 are siliceous, 2 and 3 calcareous summits. Outliers from these groupings are marked yellow.

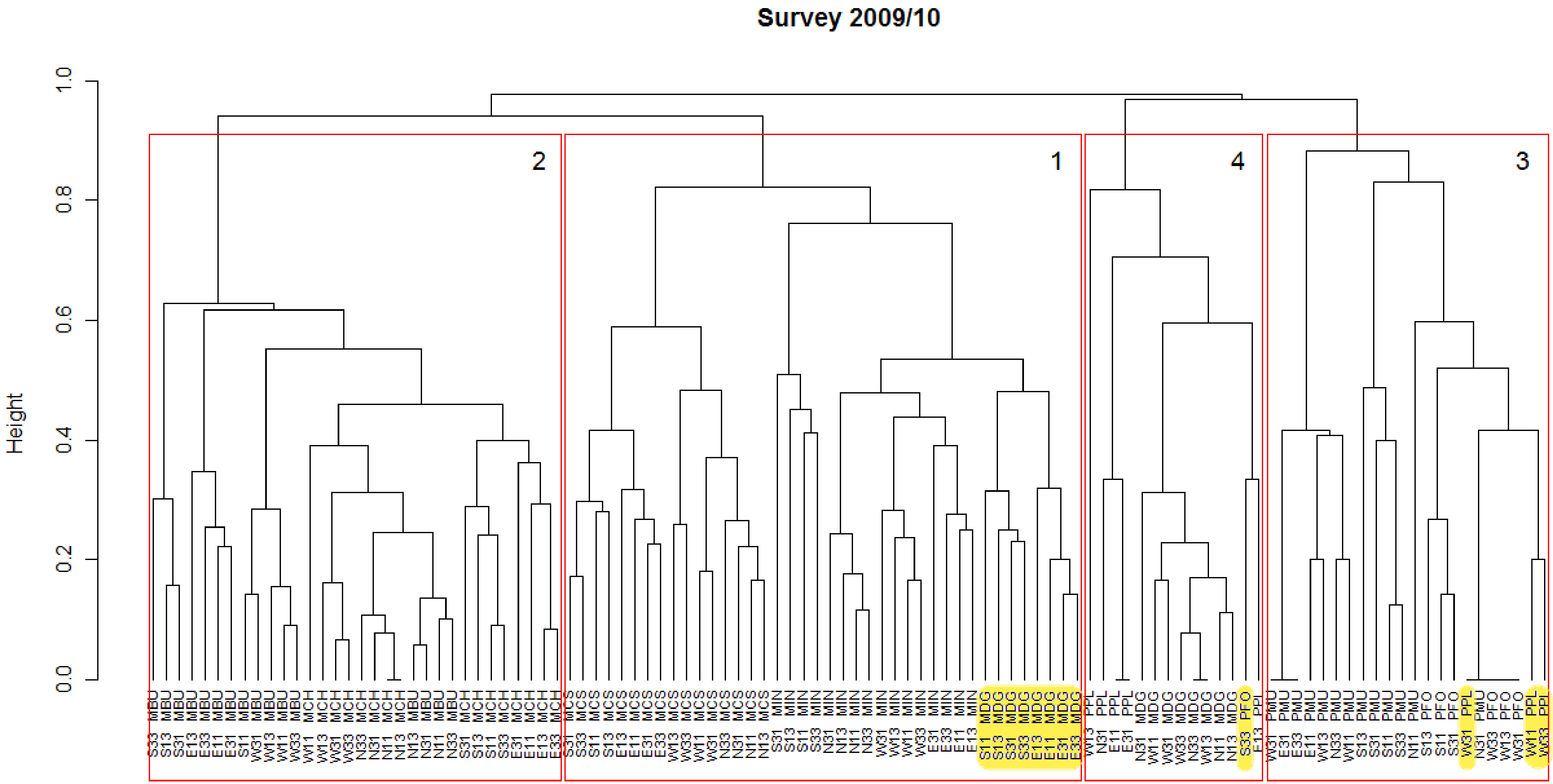


Fig. 11: Same as Fig. 10 for the second survey.

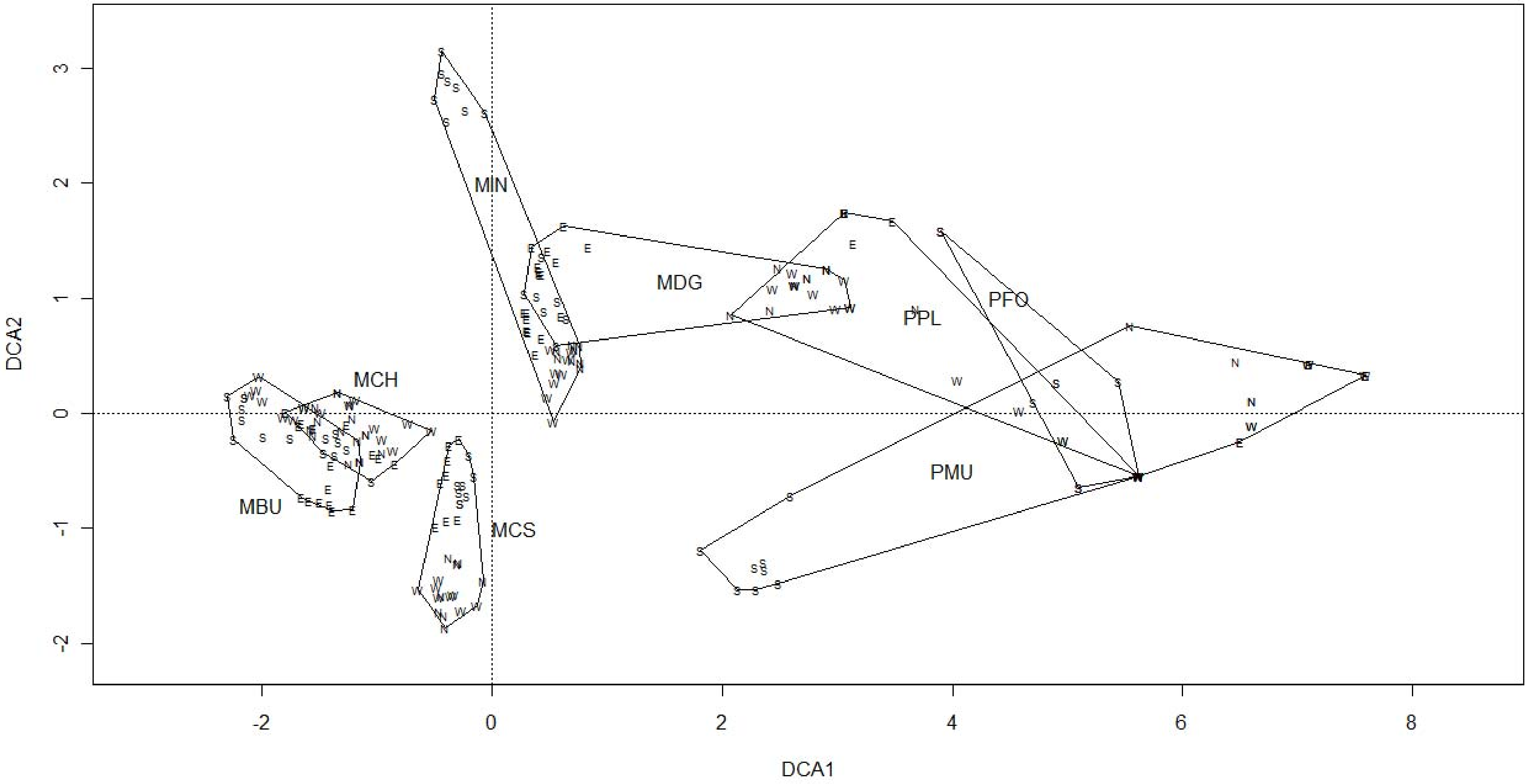


Fig. 12: Ordination of the plots from the different summits. Each plot is marked with its aspect information. High and low summits are divided by DCA 1 axis, whereas calcareous summits are located at the negative part and the siliceous summits are located at the positive part of DCA 2 axis. One exception is MCS which is a siliceous summit, but with calcareous inclusions.

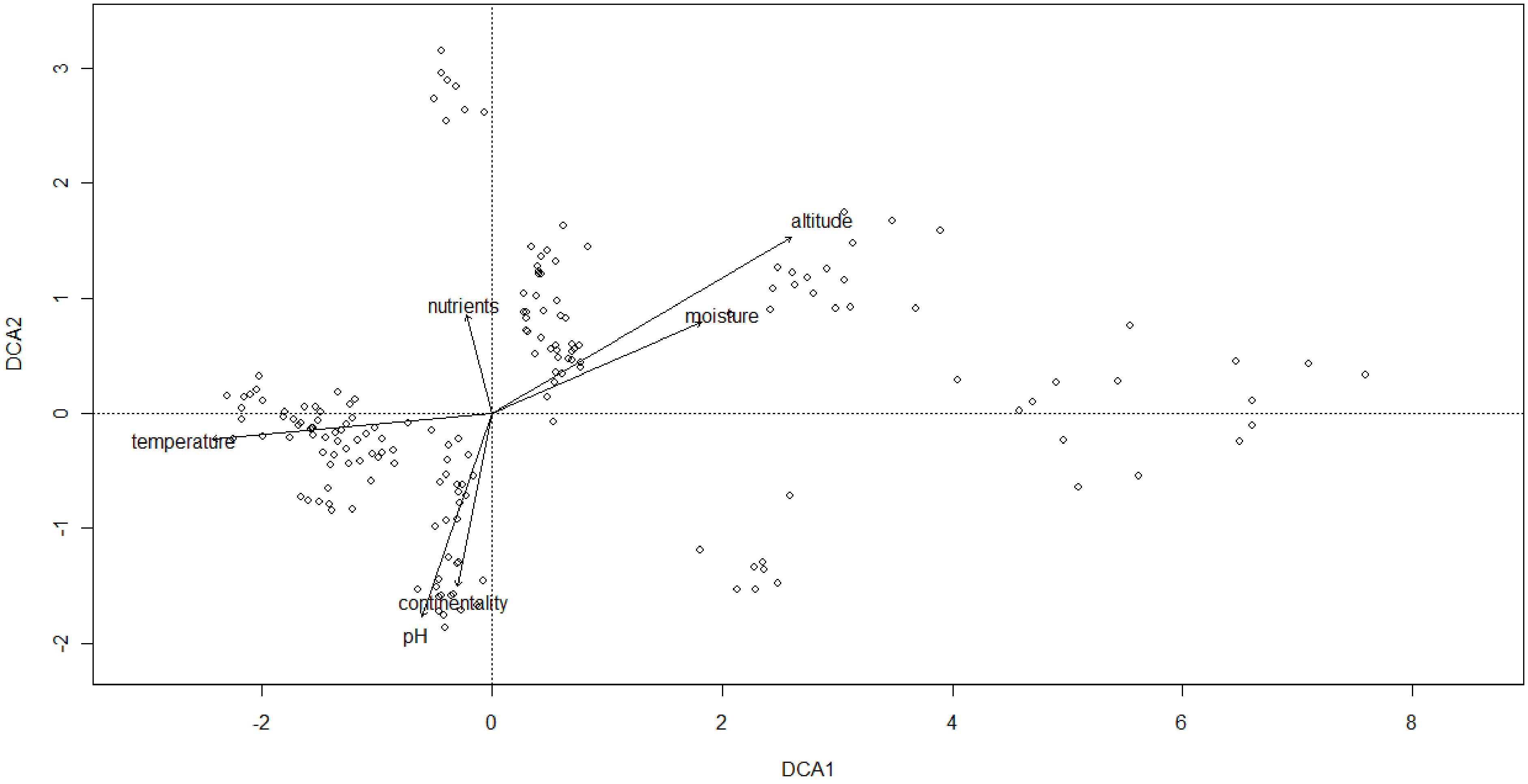


Fig. 13: Environment fits of the ordination. DCA 1 axis is controlled by temperature, altitude and moisture, DCA 2 axis by nutrients, continentality and pH.

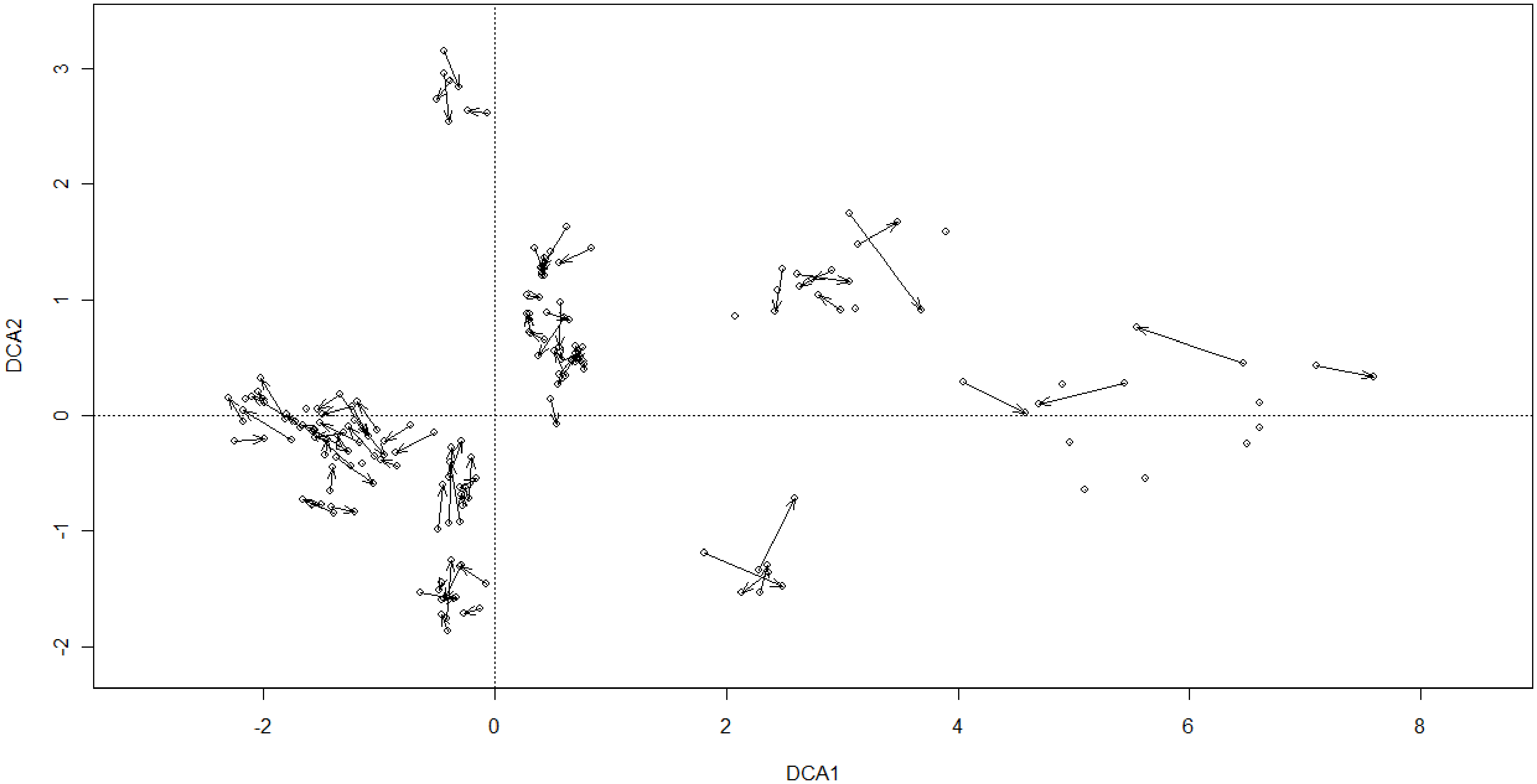
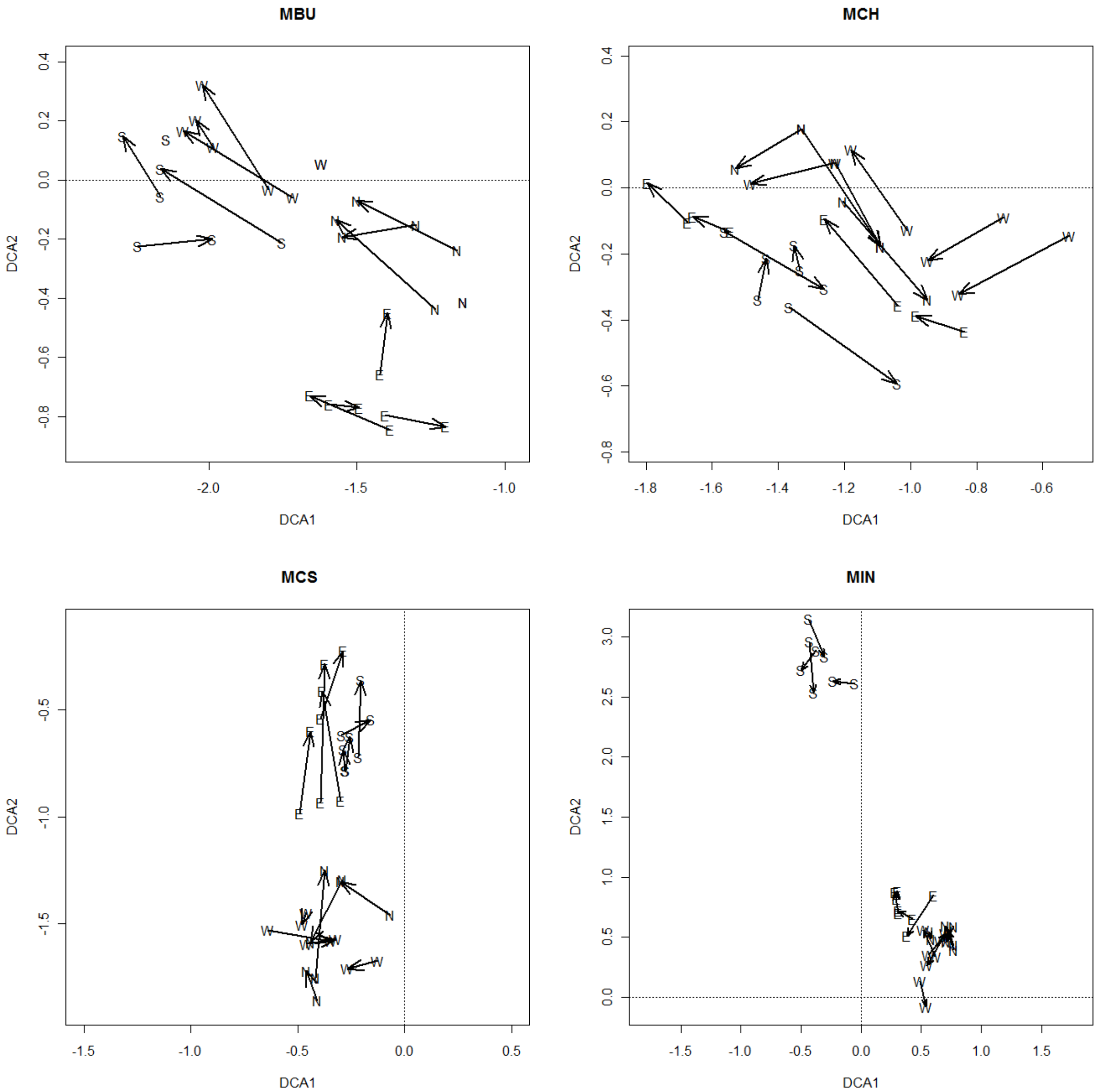


Fig. 14: Changes of the plots between first and second survey.



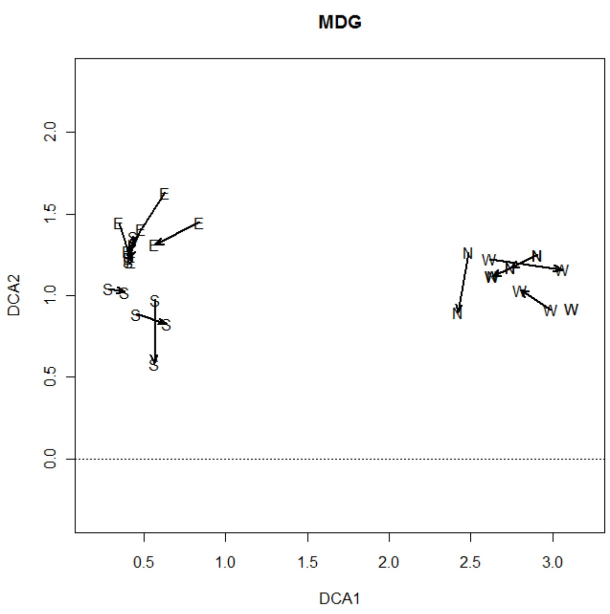


Fig. 15: Details from Fig. 14 for lower summits and MDG. The arrows show the changes from survey 1 to survey 2. Changes of DCA2 axes are very significant for MBU ($p = 0.0097$) and MCS ($p = 0.0092$) and significant for MDG ($p = 0.022$).

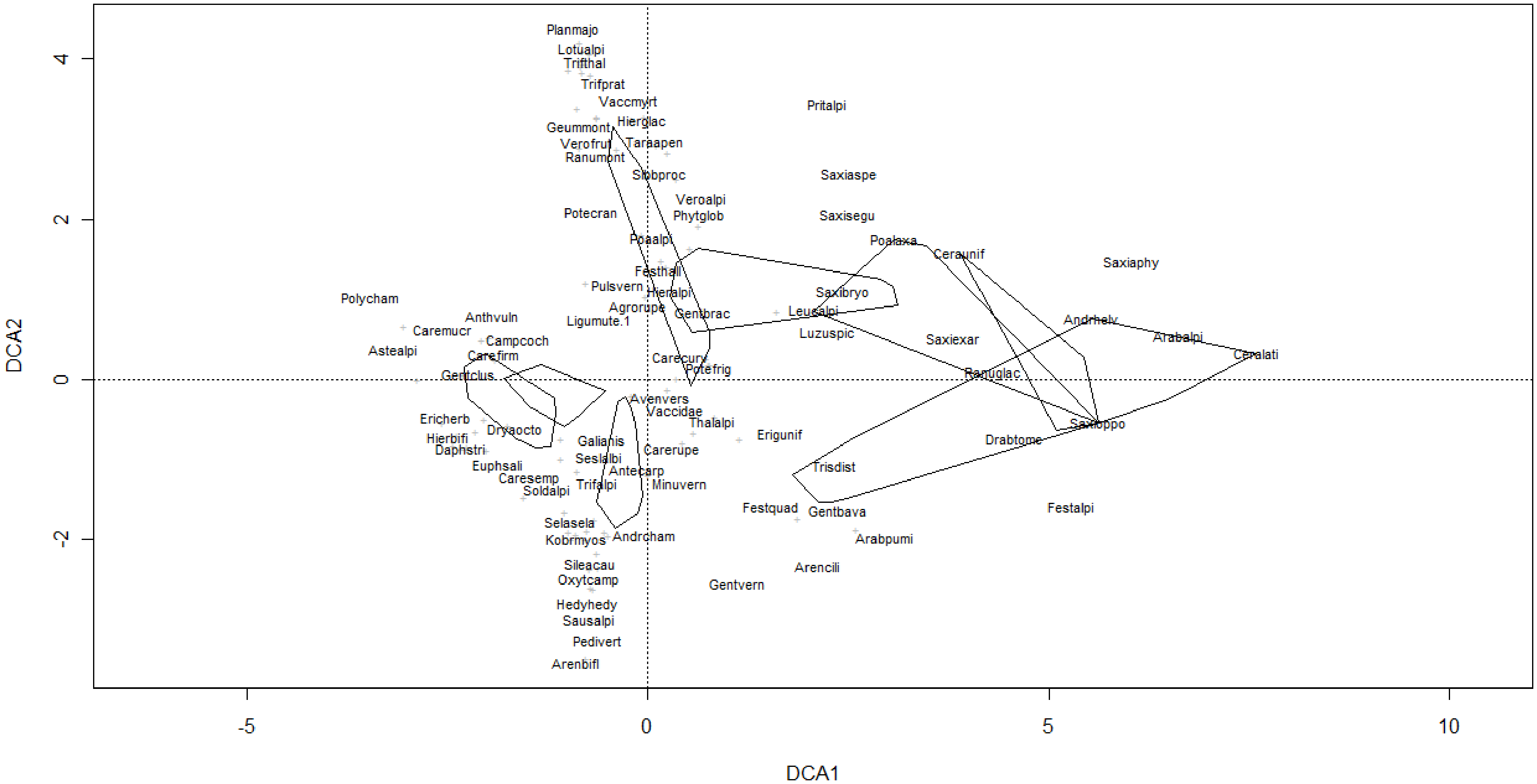


Fig. 16: Ordination for the species. Polygons are the same as from Fig. 12.

6 Discussion

6.1 Phenology

Differences in annual weather conditions and seasonality are leading to variations in development of vegetation. Hence, phenology fluctuates within each year. Due to climate change vegetation development starts earlier in average since the 1990's. Concerning the years of investigation development of the vegetation started very soon in the years 2002 and 2003, but was on average for the years 2009 and 2010 (Fig. 17).

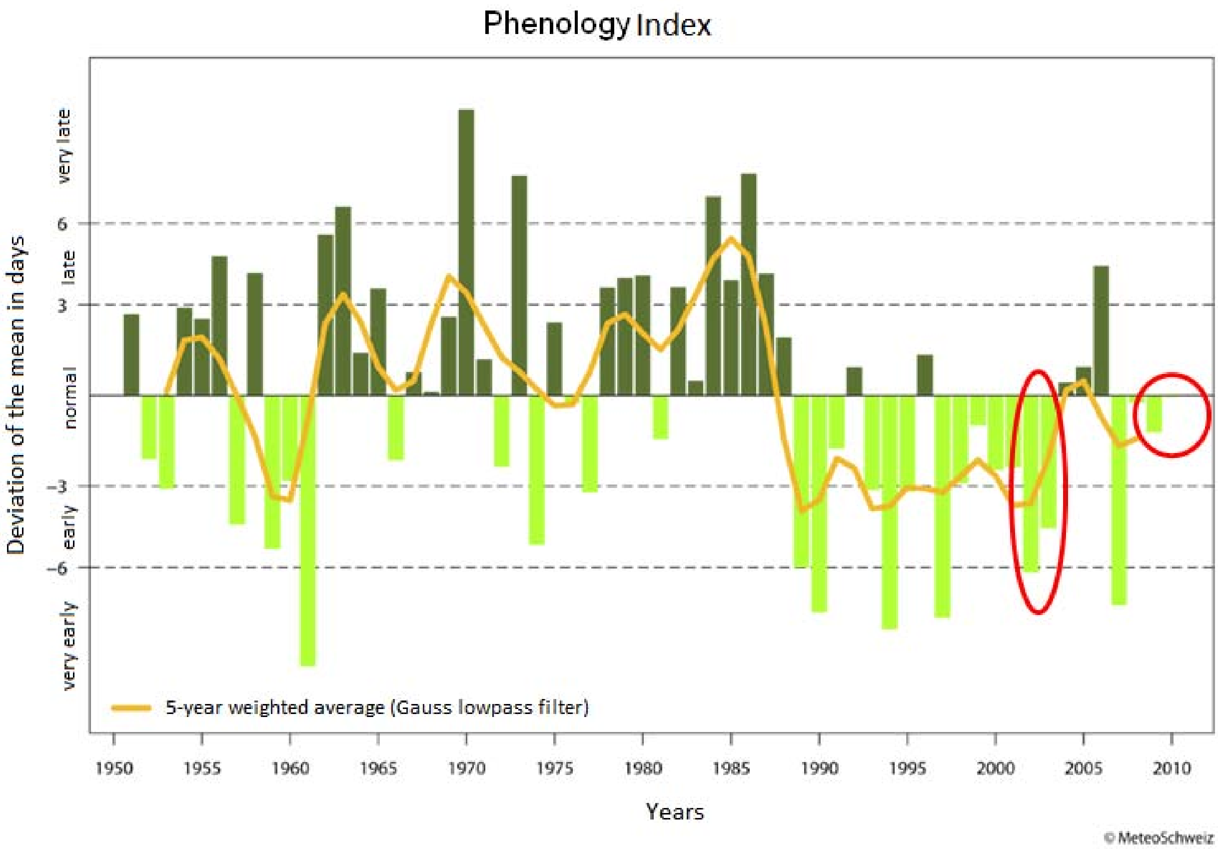


Fig. 17: Phenology Index: The deviation of vegetation development of each year from the mean in days shows that phenology developed faster in the years of the first compared to the ordinary second survey (red circles). The phenology index consists of 10 development stages of 9 plant species from about 80 observation stations within Switzerland. © (MeteoSwiss)

6.2 Species number

The resurvey of four calcareous and four siliceous summits in the Swiss National Park showed changes in species number and even more pronounced in plot heterogeneity. In general there were 80% more species at siliceous summits compared to calcareous summits, what has already been shown for high alpine summits (Grabherr *et al.*, 2001), although calcareous summits are expected to have a higher species number compared to siliceous summits as species pool is higher (Wohlgemuth, 1998, Wohlgemuth, 2002, Virtanen *et al.*, 2003). One reason for the observed situation might be higher erosion rates for calcareous bedrock and therefore better developed soils with more ecological niches at siliceous bedrock contrary to lowlands. Another factor might be area size and isolation. The small sized calcareous bedrock area in the region of Swiss National Park is relatively isolated from the large sized northern and southern Limestone Alps and surrounded by large-scale crystalline bedrock like the Silvretta Nappe in the North-West, the Ötztal Nappe in the East and the Campo-Ortler Nappe in the South-West (Fig. 1b and Schmid, 1973). Mean size of the Lower Engadine calcareous Alps is about 40 km² (n = 16 mapping areas), whereas it is almost twice for the Silicate Alps at the Central massif (n = 37 mapping areas) (Wohlgemuth, 2002). Therefore, the absolute species pool for siliceous substrate may be bigger compared to the calcareous, but not in relation to the area size of the substrate. However, species richness only correlates with area size below of 20 km² and saturates for bigger areas (Wohlgemuth, 2002, Virtanen *et al.*, 2003). The most important factor leading to a lower species richness on calcareous summits seems to be drought stress during growing seasons on mountains of the Southern and Central Alps due to high sun radiation combined with few precipitation rates and disability to water storage on calcareous summits (Virtanen *et al.*, 2003). Especially on the sun exposed southern aspects of the calcareous summits drought stress is causing extremely low species number (Fig. 8).

6.3 Species turnover

Neither species number nor bedrock is influencing species percentage change or turnover rate of the summits in contrast to altitude (Tab. 2). Contrary to higher summits there are more missing species than new found species at lower summits. Similar results were observed for the South-Alps, where relative change was higher at the upper than at the lower summits (Erschbamer *et al.*, 2009).

Absolute species turnover is highest for southern and eastern aspects, but it is the same relation to western and northern aspect as for unchanged species (Fig. 5). Hence, aspect has no influence on species turnover rate contrary to recent findings of (Erschbamer *et al.*, 2009) where new found species were mainly found for eastern and southern aspects at the higher summits.

Recent studies forecast expansions of tree species like *Larix decidua, P. cembra* and *P. mugo* (Dirnböck *et al.*, 2003) in the sub-alpine belt and shrubs and dwarf shrubs respectively in the sub-alpine-alpine ecotone as well as chamaephytes in the alpine belt (Cannone *et al.*, 2007). These expansions will cause displacements of alpine swards hemicryptophytes like *Carex curvula*, but also snowbeds with *Salix herbacea* (Theurillat & Guisan, 2001) what has been shown mainly by a GIS-based study comparing a historical phytosociological map with a recent one (Cannone *et al.*, 2007) and by another GLORIA re-investigation study (Erschbamer *et al.*, 2009). The latter showed an increase in abundance of *L. decidua*, *P. cembra* and *Juniperus communis.*

These findings corroborate the present study were plant life form (Fig. 6) seems to influence species turnover. In contrast to the first survey *L. decidua* (phanerophyte) is occurring at three lower summits for the first time, whereas there were many missing woody (*Erica herbacea*, *Helianthemum oelandicum*, *Polygala chamaebuxus* and *S. herbacea*) and herbaceous chamaephytes (*Androsace chamaejasme*, *Gentiana bavarica*, *Hippocrepis comosa*, *Saxifraga muscoides*, *Sempervivum tectorum*, *Silene acaulis*, *Thymus praecox* and *T. serpyllum*). In addition there were some herbaceous chamaephytes missing where a different identification by the first investigators can not be excluded (*Arenaria biflora*, *Cersatium cerastoides*, *C. latifolium*, *Minuartia biflora*, *M. recurva*). Content of new found, missing and unchanged species for hemicryptophytes, geophytes and therophytes is more or less the same and therefore indifferent. Therefore, a displacement of hemicryptophytes can not be shown in this study.

These results do not apply to the highest summits PMU, PFO and PPL where only herbaceous chamaephytes and hemicryptophytes occur and which are estimated to be more conservative (Grabherr *et al.*, 2001, Camenisch, 2002, Walther *et al.*, op. 2005). It is obvious that *L. decidua* is growing at MCS, MIN and MCH, where it has not occurred yet in the first survey, and therefore consistent to recent studies. One reason for it might be climate change, but an alternative explanation is reduced grazing influence by cattle due to land abandonment. The eminent effect of abandoned grazing on the tree line has already been shown for the Swiss Alps by Gehrig-Fasel *et al.* (2007), which came to the result that it has been even more important than climate change. Grazing is highly relevant for the summits MCS and MIN (Fig. 3) and marginal for MBU and MDG. Contrary to this hypothesis is that phanerophytes were not occurring at MCH either, where grazing by cattle is excluded as this summit is located in the National Park, and the fact that several chamaephytes were missing at lower summits which should also benefit from reduced grazing. Therefore, occurrence of *L. decidua* is a hint for ongoing climate change.

Besides plant life form, altitudinal limits of species were also relevant for turnover rate. Thence, species were classified in their lower and upper altitudinal limit range for each summit (Fig. 7) as not only upper species range limits are shifting further up, but also lower limits are supposed to change (Frei *et al.*, 2010). However, there is no effect on species turnover for present study concerning the lower altitudinal limits of species, except PMU where almost 80% of the new found species have a lower distribution limit at the montane belt compared to less than 20% for the unchanged species. Concerning the upper range limit of species there are effects on turnover rate for the lower summits as content of missing and new found species with an upper range limit of the treeline ecotone is higher than of unchanged species. Species with an upper range limit of the montane belt occur for the first time at MIN (*Avenula pubescens*), whereas *Polygonum aviculare* occurred at MIN for the first and second survey.

6.4 Species frequency

In general there is an increase in species frequency. As phenology was earlier in the first survey the increase can not be explained by seasonality, but it could be a hint for climate change. Cover increase is not linked to special species groups, like plant life forms or from different vegetation belts (Tab. 3), or plot types (Fig. 9) except western plots of PMU where increase is much higher. However, changes are significant for few species only (Tab. 8, see Appendix). Results for frequency are very adequate as the method is objective and relative independent of investigators, whether there are species where identification is difficult, especially as development of phenology differed between the two surveys.

Probably, cover changes which are weighted for frequency would be even more adequate as changes of species with low frequency are over-weighted.

6.5 Plot heterogeneity

Changes of similarity in the ordination are significantly forced by DCA 2 axis (Fig. 14) which is correlated with nutrients, continentality and pH (Fig. 13). As chemical site conditions (nutrients and pH) are not supposed to change, it is continentality having an effect for plot similarity changes. Latter consists of information about daily and annual temperature changes and humidity which is influencing phenology. Vegetation development was very early for the years 2002/03 compared to the ordinary years in 2009/10 (Fig. 17). Therefore, many species, especially *Gentiana* and *Gentianella*, were missing or in an initial germination stadium in the second survey. Hence, this study is showing that the driving factor for short term similarity changes include also seasonal weather differentiations leading to fluctuation in phenology in addition to climate change as presumed by Erschbamer *et al.* (2009).

7 Conclusion

This study shows that fluctuation is very important for short-term studies as there is species turnover between the two surveys which can not be explained by climate change, but phenology. Also results of plot heterogeneity from the ordinations show the importance of fuctuation. However, there are hints for initiating effects of climate change. The occurrence of *L. decidua* on three lower summits and the high content of new found species with a lower distribution limit at the montane belt on PMU as well as general increase in plant frequency could be caused by climate change. Due to the results of this study a long- term effect of climate change is expected for the investigated summits which can be detected in future studies.

8 Acknowledgement

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9 Appendix

Tab. 5: Total species list with indicator values, plant life form (LF), lower (AL) and upper (AU) altitudinal limit of continuous distribution.

Species Name	Light	Temp.	Cont.	Moist.	pH	Nutr.	LF	AL	AU
Achillea erba-rotta All. subsp. moschata (Wulfen) I.Richardson	9	1	4	6	3	2	H	al	al
Achillea millefolium L.	8			4		5	H	mo	tl
Agrostis alpina Scop.	8	2	3	5	6	4	H	tl	al
Agrostis rupestris All.	8	2	2	4	2	1	H	tl	al
Alchemilla vulgaris agg.	6	4	2	7	7		H	mo	al
Androsace alpina (L.) Lam.	9	1		6	2	3	C	al	ni
Androsace chamaejasme Wulfen	9	2	6	5	9	2	C	tl	al
Androsace helvetica (L.) All.	9	2	4		8	2	C	al	ni
Antennaria carpatica (Wahlenb.) Bluff & Fingerh.	8	2		5	6	2	H	tl	al
Antennaria dioica (L.) Gaertn.	8			4	3	2	C	mo	al
Anthoxanthum odoratum L. subsp. alpinum (Á. & D.Löve) Jones & Melderis					5		H	tl	al
Anthyllis vulneraria L.	8	6	3	3	7	2	H	mo	al
Arabis alpina L. subsp. alpina	7	3	3	5	9	3	C	mo	al
Arabis caerulea (All.) Haenke	8	2	4	7	9	4	H	al	ni
Arabis pumila Jacq.	9	2	4		9	2	C	tl	al
Arctostaphylos alpinus (L.) Spreng.	7	2	5	5		2	Z	mo	al
Arctostaphylos uva-ursi (L.) Spreng.	6		5	3		2	Z	mo	al
Arenaria biflora L.	8	2	4	7	5	2	C	al	al
Arenaria ciliata L. subsp. ciliata	8	2	8	6	8	4	C	al	ni
Arnica montana L. subsp. montana	9	4	4	5	3	2	H	mo	al
Asplenium trichomanes-ramosum L.	5		3	5		3	H	mo	al
Aster alpinus L.	9	2	5	5	7	2	H	mo	al
Aster bellidiastrum (L.) Scop.	7	3	4	5	8	4	H	mo	al
Avenula pubescens (Huds.) Dumort.	5		3			4	H	mo	mo
Avenula versicolor (Vill.) M.Laínz subsp. versicolor	9	2	3	5	3	2	H	tl	al
Bartsia alpina L.	8	3	3	8	7	3	G	tl	al
Biscutella laevigata L. subsp. laevigata	8		4		7	2	H	mo	al
Botrychium lunaria (L.) Sw.	8		3	4		2	G	mo	al
Campanula barbata L.	7	2	4	5	1	2	H	tl	al
Campanula cochlearifolia Lam.	8	3	4	7		3	H	mo	al
Campanula scheuchzeri Vill.	8	2	4	5		3	H	mo	al
Capsella bursa-pastoris (L.) Medik.	7			5		6	T	mo	tl
Cardamine resedifolia L.	8	2	2	5	3	2	H	al	ni
Carduus defloratus L.	7		4	4	8	4	H	mo	al
Carex atrata agg.	9	2	3	5	6	2	H	tl	al
Carex capillaris L.	8	1		8	8	2	H	tl	al
Carex curvula All. subsp. curvula	9	1	5	4	2	1	H	al	al
Carex ericetorum Pollich	5	5	7	4		2	G	mo	al
Carex firma Host	9	2	4	4	9	2	H	tl	al
Carex montana L. subsp. montana	5		4	4	6	3	H	mo	tl
Carex mucronata All.	9	3	4	3	9	1	H	mo	tl
Carex nigra (L.) Reichard	8		3	8	3	2	G	mo	al
Carex ornithopoda Willd.	6		4	3	9	3	H	mo	al
Carex ornithopoda Willd. subsp. ornithopodioides (Hausm.) Nyman	8	1		6	9	3	H	tl	al
Carex panicea L.	8		3	8		4	H	mo	tl
Carex paniculata L.	7		3	9	6	4	H	mo	tl
Carex parviflora Host	9	2	3	7	8	4	H	tl	al
Carex rupestris All.	9	2	7	4	6	2	H	tl	al
Carex sempervirens Vill.	8		2	4	7	3	H	tl	al
Carlina acaulis L.	9	4	5	4	3	2	H	mo	tl
Cerastium arvense L. subsp. strictum Gaudin	8		5	4	6	4	C	tl	al
Cerastium cerastoides (L.) Britton	8	1		8	4	7	C	tl	al
Cerastium fontanum Baumg. subsp. fontanum	6	3	4	5	5	5	C	tl	al
Cerastium latifolium L.	9	1	4	5	9	3	C	al	al
Cerastium uniflorum Clairv.	9	1	4	5		3	C	al	ni
Chamorchis alpina (L.) Rich.	9	2	2	4	9	2	G	tl	al
Chenopodium bonus-henricus L.	8		2	5		9	H	mo	al
Cirsium spinosissimum (L.) Scop. subsp. spinosissimum	7	2	5	6	7	8	H	tl	al
Coeloglossum viride (L.) Hartm.	8			4	4	2	G	mo	al
Crepis jacquinii Tausch subsp. kerneri (Rech.f.) Merxm.	9	2	4	5	9	3	H	tl	al
Cystopteris montana (Lam.) Desv.	4		4	7	9	2	H	mo	tl
Dactylis glomerata L. subsp. glomerata	7		3	5		6	H	mo	tl

Species Name	Light	Temp.	Cont.	Moist.	pH	Nutr.	LF	AL	AU
Daphne striata Tratt.	7	3	4	4	8	2	Z	tl	al
Deschampsia cespitosa (L.) P.Beauv. subsp. cespitosa	6			7		3	H	mo	al
Doronicum clusii (All.) Tausch subsp. clusii	9	2	6	6	4	6	H	tl	ni
Draba aizoides L.	8		4	3	9	1	C	tl	al
Draba dubia Suter	8	2	5	3		2	C	al	ni
Draba ladina Braun-Blanq.	8	2	7	4	9	2	C	al	al
Draba siliquosa M.Bieb.	8	2	4	5	6	2	C	al	al
Draba tomentosa Clairv.	9	1	4	2	9	2	C	al	ni
Dryas octopetala L.	9	2	7	4	8	4	Z	al	al
Erica herbacea L.	7		3	3		2	Z	mo	tl
Erigeron neglectus A.Kern.	9	2	4	5	9		H	tl	al
Erigeron uniflorus L.	9	1	6	5	5	2	H	al	ni
Euphrasia minima Jacq. ex DC. subsp. minima	7	2		5	2	3	T	tl	al
Euphrasia salisburgensis Funck	7	3	2	5	8	4	T	mo	al
Festuca alpina Suter	8	1	2	3	9	1	H	al	al
Festuca halleri All. subsp. halleri	9	1	7	4	1	1	H	tl	al
Festuca quadriflora Honck.	8	2	3	5	6	4	H	tl	al
Festuca rubra agg.				6	6		H	mo	al
Galium anisophyllon Vill.	9	2	4	5	8	3	H	tl	al
Gentiana acaulis L.	8	2	4	5	2	2	H	tl	al
Gentiana bavarica L.	8	2	4	6	8	2	C	al	ni
Gentiana brachyphylla Vill. subsp. brachyphylla	9	2	8	6	4	4	H	al	al
Gentiana brachyphylla Vill. subsp. favratii (Rittener) Tutin	9	2	8	6	4	4	H	al	al
Gentiana clusii E.P.Perrier & Songeon	9	3	4	5	9	3	H	mo	al
Gentiana lutea L. subsp. lutea	7	3	4	5		2	H	tl	tl
Gentiana nivalis L.	9	1	2	5	7	3	T	tl	al
Gentiana punctata L.	8	2	4	5	2	2	H	tl	al
Gentiana verna L. subsp. verna	8		4	4	7	2	H	mo	al
Gentianella campestris (L.) Börner subsp. campestris	8		2	5	4	2	H	mo	al
Gentianella germanica (Willd.) E.F.Warb.	7	5	4	4	8	3	H	mo	tl
Gentianella tenella (Rottb.) Börner	9	1	7	5	7	2	T	al	al
Geum montanum L.	7	2	2	5	2	2	H	tl	al
Geum reptans L.	9	1	4	5	2	2	H	al	ni
Globularia cordifolia L.	9	3	4	4	9	2	C	mo	al
Globularia nudicaulis L.	7	2	2	4	8	3	H	tl	tl
Gymnadenia odoratissima (L.) Rich.	6		4	4	9	2	G	mo	tl
Hedysarum hedysaroides (L.) Schinz & Thell.	8	2	7	5	8	2	G	tl	al
Helianthemum nummularium (L.) Mill.	7	6	4	3	7	1	Z	mo	al
Helianthemum oelandicum (L.) DC. subsp. alpestre (Jacq.) Breistr.	9	2	4	4	9	2	Z	tl	al
Hieracium alpinum L.	8	2	3	5	1	1	H	tl	al
Hieracium bifidum Kit.	8		3	4	8	3	H	tl	al
Hieracium glaciale A.Reyn.	8	1	4	5	1	1	H	tl	al
Hieracium glanduliferum Hoppe	9	2	8	4	4	4	H	tl	al
Hieracium glaucum All.	9	3	4	4	9	2	H	mo	tl
Hieracium intybaceum All.	8	3	2	4	4	2	H	tl	al
Hieracium murorum L.	4		3	5	5	4	H	mo	tl
Hieracium pilosella L.	7		3	4		2	H	mo	al
Hippocrepis comosa L.	7	5	2	3	7	2	C	mo	al
Homogyne alpina (L.) Cass.	6	4	2	6	4	2	H	mo	al
Juncus jacquinii L.	9	2	4	5	2	1	H	tl	al
Juncus trifidus L. subsp. trifidus	8	2	3	4	4	2	H	tl	al
Juniperus communis L. subsp. alpina (Suter) C$Kelak.	9	2	7	4	7	2	Z	tl	al
Kobresia myosuroides (Vill.) Fiori	9	2	7	4		2	H	al	ni
Larix decidua Mill.			6	4		3	P	mo	tl
Leontodon hispidus L.	8		3	5	7	6	H	mo	al
Leontodon montanus Lam. subsp. montanus	8	2	4	5	9	3	H	al	al
Leontodon pyrenaicus Gouan subsp. helveticus (Mérat) Finch & P.D.Sell	8	3	4	5	3	2	H	tl	al
Leontopodium alpinum Cass. subsp. alpinum	8	2	5	4	8	2	H	tl	al
Leucanthemopsis alpina (L.) Heywood subsp. alpina	8	2	4	7	2	2	H	al	ni
Leucanthemum vulgare Lam.	7		3	4		3	H	mo	tl
Ligusticum mutellina (L.) Crantz	7	2	4	6	5	4	H	tl	al
Ligusticum mutellinoides (Crantz) Vill.	9	1	6	5	3	1	H	al	al
Linaria alpina (L.) Mill. subsp. alpina	9	3	4	4	8	2	C	mo	tl
Lloydia serotina (L.) Rchb.	9	1	7	5	5	1	G	tl	al
Loiseleuria procumbens (L.) Desv.	9	2	3	5	3	1	Z	tl	al
Lotus alpinus (DC.) Schleich. ex Ramond	8	2	6	6	6	6	H	mo	al
Lotus corniculatus L.	7		3	4	7	3	H	mo	al
Luzula alpinopilosa (Chaix) Breistr. subsp. alpinopilosa	7	2		7	4	3	H	tl	al
Luzula lutea (All.) DC.	8	2	6	4	4	4	H	tl	al

Species Name	Light	Temp.	Cont.	Moist.	pH	Nutr.	LF	AL	AU
Luzula multiflora (Retz.) Lej.	7		4	5	5	3	H	mo	al
Luzula spicata (L.) DC.	8	2	3	4	4	1	H	al	ni
Luzula sudetica (Willd.) DC.	8	3	4	5	3	2	H	mo	al
Minuartia biflora (L.) Schinz & Thell.	8	2	6	6	8	8	C	al	ni
Minuartia recurva (All.) Schinz & Thell. subsp. recurva	8	1	7	4	3	1	C	al	al
Minuartia sedoides (L.) Hiern	9	1	2	4	4	1	C	tl	ni
Minuartia verna (L.) Hiern subsp. verna	9	4	5	3		1	C	tl	al
Myosotis alpestris F.W.Schmidt	8	2	4	5	9	4	H	tl	al
Nardus stricta L.	8		3		2	2	H	mo	al
Nigritella nigra subsp. rubra (Wettst.) Beauverd	8	2	4	4	6	2	G	tl	al
Omalotheca hoppeana (W.D.J.Koch) Sch.Bip. & F.W.Schultz	8	2	4	7	8	4	H	tl	al
Omalotheca supina (L.) DC.	7	2	3	7	3	4	H	tl	al
Oreochloa disticha (Wulfen) Link	9	1	4	5	1	1	H	al	ni
Oxytropis campestris (L.) DC. subsp. campestris	9	2	6	4	6	2	H	mo	al
Oxytropis jacquinii Bunge	8	2	4	4	9	2	H	al	al
Papaver alpinum subsp. rhaeticum (Ler. ex Gremli) Nyman	9	2	6	6	8	4	H	tl	al
Parnassia palustris L.	8			8	7	2	H	mo	al
Pedicularis tuberosa L.	6	4	6	4	4	4	H	tl	al
Pedicularis verticillata L.	8	3	7		8	2	H	tl	al
Phleum alpinum L. subsp. rhaeticum Humphries	8	3	3	5	6	7	H	tl	al
Phyteuma globulariifolium subsp. pedemontanum (Rich.Schulz) Bech.	9	2	8	4	4	4	H	al	al
Phyteuma hemisphaericum L. subsp. hemisphaericum	8	2	4	5	3	1	H	tl	al
Pinguicula leptoceras Rchb.	8	4	5	9	8	1	H	tl	al
Pinus mugo Turra	8	3	3			3	N	mo	tl
Plantago alpina L.	8	3	2	5	3	2	H	tl	al
Plantago atrata Hoppe subsp. atrata	8	3	4	7	8	5	H	tl	al
Plantago major L. subsp. major	8			5		6	H	mo	tl
Poa alpina L. subsp. alpina	7	3	5	5		7	H	tl	al
Poa annua L.	7		5	6		8	H	mo	tl
Poa laxa Haenke	8	1	2	5	3	2	H	al	ni
Poa minor Gaudin	8	2	2	5	8	3	H	tl	al
Poa pratensis L.	6			5		6	H	mo	tl
Poa supina Schrad.	8	3	4	5	7	7	H	tl	al
Polygala alpestris Rchb. subsp. alpestris	8	2	4	4	7	2	H	mo	al
Polygala chamaebuxus L.	6	4	4	3	8	2	Z	mo	tl
Polygonum aviculare L.	7	6		4		6	T	mo	mo
Polygonum viviparum L.	7	2		5	4	2	H	tl	al
Potentilla aurea L. subsp. aurea	8	3	4	4	3	2	H	tl	al
Potentilla brauniana Hoppe	7	2	2	7	9	5	H	tl	al
Potentilla crantzii (Crantz) G. Beck ex Fritsch subsp. Crantzii	9	2	3	5	8	2	H	tl	al
Potentilla frigida Vill.	9	1	6	4	2	1	H	al	ni
Potentilla nivea L.	8	2	8	4	6	8	H	mo	al
Primula farinosa L.	8		4	8	9	2	H	mo	al
Pritzelago alpina subsp. brevicaulis (Hoppe) Greuter & Burdet	8	2	6	8	6	4	H	tl	al
Pulsatilla alpina (L.) Delarbre subsp. apiifolia (Scop.) Nyman	9	2	2	5	3	2	H	tl	tl
Pulsatilla vernalis (L.) Mill.	7		5	4	5	2	H	tl	al
Ranunculus acris L.	7		3	6			H	mo	al
Ranunculus alpestris L. subsp. alpestris	9	2		7	8	4	H	tl	al
Ranunculus glacialis L.	8	1	4	6	3	2	H	al	ni
Ranunculus grenieranus Jord.	6	4	6	6	4	6	H	mo	al
Ranunculus kuepferi Greuter & Burdet	8	1	4	5	4	2	H	tl	al
Ranunculus montanus agg.	7	3	4	5	8	4.5	H	mo	al
Ranunculus montanus Willd.	6	3	4	5	8	6	H	tl	al
Ranunculus oreophilus M.Bieb.	8	3	4	5	8	3	H	tl	al
Rhododendron hirsutum L.	7	3	4	4	7	3	Z	tl	al
Sagina saginoides (L.) H.Karst. subsp. saginoides	7	3	3	6	5	4	C	tl	al
Salix breviserrata Flod.	8	4	6	6	6	4	N	tl	tl
Salix herbacea L.	7	2	3	7	3	4	Z	tl	ni
Salix reticulata L.	8	2		6	9	3	Z	tl	al
Salix serpillifolia Scop.	7	2	4	4	9	2	Z	al	ni
Saussurea alpina (L.) DC. subsp. alpina	9	1	7	5	5	3	H	tl	al
Saxifraga aizoides L.	8	3	3	9	8	3	C	mo	al
Saxifraga androsacea L.	7	2	5	7	8	4	C	al	ni
Saxifraga aphylla Sternb.	9	1	4	5	9	3	C	al	al
Saxifraga aspera L.	8	3	5	4	3	2	C	tl	tl
Saxifraga bryoides L.	9	1	4	5	3	2	C	al	ni

Species Name	Light	Temp.	Cont.	Moist.	pH	Nutr.	LF	AL	AU
Saxifraga caesia L.	8	2	4	3	9	2	C	tl	al
Saxifraga exarata Vill. subsp. exarata	8	1		4	2	2	C	al	ni
Saxifraga muscoides All.	9	2	8	6	4	4	C	al	ni
Saxifraga oppositifolia L. subsp. oppositifolia	8	2	3	5	8	2	C	al	ni
Saxifraga paniculata Mill. subsp. paniculata	7	3	3	3	8	2	C	tl	al
Saxifraga seguieri Spreng.	8	2	3	7	3	3	C	al	ni
Scabiosa lucida Vill.	9	3	4	4	8	3	H	mo	al
Sedum alpestre Vill.	8	2	2	5	4	2	C	tl	ni
Sedum atratum L.	9	2	2	5	8		H	tl	al
Sedum atratum L. subsp. atratum	9	2	2	5	8		H	tl	al
Selaginella selaginoides (L.) Link	8	3	3	7	7	3	C	tl	al
Sempervivum montanum L. subsp. montanum	8	2	2	3	2	1	C	tl	al
Sempervivum tectorum L. ssp. alpinum (Grieseb. et Schenk) Wettst.	8		2	2	4		C	mo	al
Senecio doronicum (L.) L. subsp. doronicum	8	2	4	5	8	3	H	tl	al
Senecio incanus L. subsp. carniolicus (Willd.) Braun-Blanq.	8	2	5	5	1	1	H	tl	al
Sesleria albicans Kit. ex Schult.	7	3	2	4	9	3	H	mo	al
Sibbaldia procumbens L.	7	2	3	7	2	4	H	tl	al
Silene acaulis (L.) Jacq. subsp. acaulis	9	1	3	4	8	1	C	al	ni
Silene acaulis (L.) Jacq. subsp. bryoides (Jord.) Nyman	9	1	3	4	8	1	C	al	ni
Silene nutans L. subsp. nutans	7		5	3	7	3	H	mo	al
Silene rupestris L.	9	3	2	3	3	1	H	mo	al
Silene vulgaris (Moench) Garcke subsp. vulgaris	8			4	7	4	H	mo	al
Soldanella alpina L.	7	2	4	7	8		H	tl	al
Soldanella pusilla Baumg.	7	1	4	7	2	3	H	al	al
Solidago virgaurea L. subsp. minuta (L.) Arcang.	5	3		5	2	3	H	mo	al
Taraxacum apenninum agg.	8	2	4	6	8	6	H	tl	al
Thalictrum alpinum L.	8	2	6	6	6	4	H	tl	al
Thesium alpinum L.	8	3	4	4	8	2	H	mo	al
Thesium pyrenaicum Pourr. subsp. pyrenaicum	8	4	4	4	4	2	H	mo	tl
Thymus praecox Opiz subsp. polytrichus (A.Kern. ex Borb s) Jalas	8	3	5	4	8	1	C	tl	al
Thymus serpyllum agg.	7	6	5	2	5	1	Z	mo	al
Trifolium alpinum L.	8	2	4	4	2	2	H	tl	al
Trifolium badium Schreb.	8	2	4	6	8		H	mo	al
Trifolium pratense L.	7		3	5			H	mo	al
Trifolium pratense L. subsp. nivale Arc.	8	2	3	5	6	6	H	tl	al
Trifolium repens L.	8			5	6	6	H	mo	al
Trifolium thalii Vill.	7	2	2	5	8		H	tl	al
Trisetum distichophyllum (Vill.) P.Beauv.	8	2	4	5	9	2	G	tl	al
Trisetum spicatum (L.) K.Richt. subsp. spicatum	9	2	8	6	6	4	H	al	ni
Trollius europaeus L.	9	3	5	7	6	5	H	mo	al
Vaccinium myrtillus L.	5		5		2	3	Z	mo	al
Vaccinium uliginosum L. subsp. microphyllum Lange	8	3	4	5	3	2	Z	tl	al
Vaccinium vitis-idaea L. subsp. vitis-idaea	5		5	4	2	1	Z	mo	al
Veronica alpina L.	8	2	4	8	4	6	G	al	ni
Veronica aphylla L.	8	2	4	5	8	2	H	tl	al
Veronica bellidioides L. subsp. bellidioides	8	2	4	4	1	1	H	tl	al
Veronica fruticans Jacq.	8	2	2	4		2	Z	tl	al
Veronica serpyllifolia subsp. humifusa (Dicks.) Syme	7	3	3	5	6	7	H	tl	tl
Viola calcarata L.	9	2	6	6	6	4	H	tl	al

Tab. 6: New found species of the second survey for each summit with information of location aspect. Species which were found for the first time for all summits are listed as total.

Species name	MBU	MCH	PMU	PFO	MCS	MIN	MDG	Total / ?
Androsace chamaejasme							N/W	
Antennaria dioica							S	
Arabis alpina					N			
Arabis caerulea		E		S/W				
Asplenium trichomanes-ramosum			S		S			x
Aster alpinus						S/N/W		
Avenula pubescens						S		x / i
Campanula scheuchzeri						E		
Carex atrata	E						S	i
Carex parviflora						E		i
Carex rupestris						N	E	i
Cerastium uniflorum		W	N					i
Daphne striata		E						
Draba dubia					W			x
Erigeron neglectus						S/W/E	S/N/W/E	x / i
Erigeron uniflorus	E/S							
Euphrasia minima							S/N/W/E	p
Festuca quadriflora		S/N/W/E				E/N/W	E/N/W	i
Gentianella germanica					E			x / p
Gentianella tenella					E/S/W			p
Globularia cordifolia			E					
Hieracium alpinum L					S/N/W/E		E/S	i
Hieracium glaciale					N			i
Hieracium murorum	E/S/N	E						x / i
Hieracium pilosella							E	i
Juniperus communis						E		
Larix decidua		S			E	W		x
Leontodon hispidus						W		
Leucanthemum vulgare						E		x
Linaria alpina			E/S/W					x
Luzula sudetica					S			
Nigritella nigra					E	E		p
Parnassia palustris					E			x
Pedicularis tuberosa					N/S/W			i
Phleum alpinum							S	
Pinguicula leptoceras	N							x
Potentilla crantzii		E						
Pritzelago alpina					W			
Pulsatilla vernalis							S	
Ranunculus acris						E/W		x
Saxifraga aizoides					E/N			x
Saxifraga exarata					E/W	N		
Saxifraga seguieri				S				
Sedum atratum	E/N/W							
Silene acaulis				N/W				
Silene nutans						S		x
Silene vulgaris		S				S		
Taraxacum apenninum					S			
48	5	8	4	3	16	16	11	x = 14 ? = 16

Tab. 7: Same as Tab. 6 for missing species.

Species name	MBU	MCH	PMU	PFO	MCS	MIN	MDG	Total / ?
Agrostis alpina						S/W		i
Androsace chamaejasme		E						
Arenaria biflora					N	S/W		x / i
Aster bellidiastrum					E/S			
Avenula versicolor		E						i
Capsella bursa-pastoris						S		x
Cardamine resedifolia					W			
Carex firma					E			i
Carex montana	E							x / i
Carex panicea						S		x / i
Carex paniculata						W		x / i
Cerastium cerastoides							E/S	x / i
Cerastium latifolium		W		E/S/W				i
Coeloglossum viride						E		p
Dactylis glomerata					W			x
Erica herbacea		E						
Festuca rubra						S		x / i
Gentiana acaulis						S/N/W	S	p
Gentiana bavarica			S		W			p
Gentiana brachyphylla		N	S					p
Gentiana brachyphylla		E/S						x / p
Gentiana nivalis						E		p
Gentiana punctata						E/W		p
Gentiana verna					E/S/N/W			p
Gentianella campestris						W		p
Helianthemum oelandicum					E		E	
Hieracium glanduliferum					N			i
Hieracium glaucum	W							x / i
Hippocrepis comosa					S			
Minuartia biflora		N	S				E/S/N/W	x / i
Minuartia recurva					E/S			i
Omalotheca supina						E/N		
Pedicularis tuberosa						S		
Pinus mugo		E						
Polygala alpestris					S			
Polygala chamaebuxus					E			
Polygonum viviparum							S	
Potentilla crantzii			S					
Pulsatilla alpina					E			
Pulsatilla vernalis		E						
Salix herbacea							E/W	x
Salix serpillifolia	E							
Saxifraga muscoides					W			x
Sempervivum tectorum						S		x
Silene acaulis	E							
Silene vulgaris	E				E			
Soldanella pusilla						S		
Solidago virgaurea							E	
Thalictrum alpinum					S			
Thymus praecox						E		x
Thymus serpyllum					S			x
Trollius europaeus						E		
Veronica alpina		E				S		
53	5	10	4	1	18	18	7	x = 16 ? = 23

Tab. 8: Species Frequency and its change between survey 1 and 2.

Species	N	Frequency Survey 2	Frequency Survey 2	Average Change [%]	p	?	LF	AL	AU
Agrostis alpina	8	37	21	6.5	0.15	i	H	tl	al
Agrostis rupestris	15	35	38	297.0	0.62	i	H	tl	al
Alchemilla vulgaris	2	4	7	73.3	0.50		H	mo	al
Androsace chamaejasme	3	3	4	66.7	0.41		C	tl	al
Androsace helvetica	1	18	24	33.3	1		C	al	ni
Antennaria carpatica	17	20	25	34.6	0.70		H	tl	al
Antennaria dioica	4	2	8	375.0	0.38		C	mo	al
Anthoxanthum odoratum	11	22	41	274.3	0.15		H	tl	al
Anthyllis vulneraria	21	12	18	58.3	0.22		H	mo	al
Arabis alpina	4	2	4	120.8	0.27		C	mo	al
Arabis pumila	3	1	3	133.3	0.41		C	tl	al
Arctostaphylos alpinus	1	22	22	0.0	NaN		Z	mo	al
Arenaria ciliata	10	12	19	69.6	0.28		C	al	ni
Aster alpinus	2	3	4	10.0	1		H	mo	al
Aster bellidiastrum	2	14	16	22.5	1		H	mo	al
Avenula versicolor	26	35	68	264.2	0.0028**	i	H	tl	al
Bartsia alpina	5	17	22	25.1	0.86		G	tl	al
Botrychium lunaria	1	1	2	100.0	1		G	mo	al
Campanula cochlearifolia	4	25	7	-71.4	0.13		H	mo	al
Campanula scheuchzeri	19	17	24	73.0	0.31		H	mo	al
Cardamine resedifolia	5	6	7	48.1	1		H	al	ni
Carex atrata	7	16	20	-0.1	0.69	i	H	tl	al
Carex capillaris	10	29	47	119.4	0.43	i	H	tl	al
Carex curvula	18	41	50	26.9	0.14	i	H	al	al
Carex ericetorum	18	24	50	620.7	0.031 *	i	G	mo	al
Carex firma	23	55	56	6.7	0.88		H	tl	al
Carex mucronata	14	55	59	28.0	0.58	i	H	mo	tl
Carex rupestris	35	43	43	41.4	0.82	i	H	tl	al
Carex sempervirens	6	38	31	-3.4	0.44		H	tl	al
Cerastium fontanum	2	4	6	241.7	1		C	tl	al
Cerastium latifolium	7	21	24	70.4	0.35		C	al	al
Cerastium uniflorum	12	45	43	14.1	1		C	al	ni
Coeloglossum viride	3	1	9	666.7	0.37	p	G	mo	al
Crepis jacquinii	22	9	10	20.7	0.53		H	tl	al
Daphne striata	2	7	11	35.0	1		Z	tl	al
Draba aizoides	7	2	4	82.1	0.55		C	tl	al
Draba siliquosa	4	11	14	11.9	1		C	al	al
Draba tomentosa	5	3	5	230.0	0.27		C	al	ni
Dryas octopetala	41	41	42	3.4	0.90		Z	al	al
Erica herbacea	6	25	29	48.6	0.92		Z	mo	tl
Erigeron neglectus	1	8	9	12.5	1		H	tl	al
Erigeron uniflorus	25	20	25	55.4	0.37		H	al	ni
Euphrasia minima	17	9	7	44.9	0.86		T	tl	al
Euphrasia salisburgensis	6	16	36	104.8	0.14		T	mo	al
Festuca alpina	3	6	7	40.0	0.75	i	H	al	al
Festuca halleri	30	52	73	101.3	0.039 *	i	H	tl	al
Festuca quadriflora	19	17	27	63.7	0.027 *	i	H	tl	al
Galium anisophyllon	6	4	11	375.2	0.21		H	tl	al
Gentiana acaulis	7	17	16	-13.7	0.93	p	H	tl	al

Species	N	Frequency Survey 2	Frequency Survey 2	Average Change [%]	p	?	LF	AL	AU
Gentiana nivalis	2	2	1	-50.0	0.35	p	T	tl	al
Gentianella campestris	7	12	4	-54.8	0.15	p	H	mo	al
Geum montanum	2	15	9	-46.4	0.50		H	tl	al
Globularia cordifolia	4	9	11	26.9	0.42		C	mo	al
Hedysarum hedysaroides	4	11	10	8.1	0.63		G	tl	al
Helianthemum oelandicum	14	17	18	-3.1	0.83		Z	tl	al
Hieracium alpinum	4	4	10	463.2	0.13		H	tl	al
Hieracium bifidum	1	4	4	0.0	NaN		H	tl	al
Hieracium glaciale	1	19	29	52.6	1		H	tl	al
Hieracium glanduliferum	3	6	10	51.3	0.75		H	tl	al
Homogyne alpina	6	12	18	32.2	0.34		H	mo	al
Juncus jacquinii	1	3	7	133.3	1		H	tl	al
Kobresia myosuroides	17	40	51	25.5	0.19		H	al	ni
Leontodon hispidus	10	25	36	55.1	0.26		H	mo	al
Leontodon pyrenaicus	9	9	16	119.4	0.29		H	tl	al
Leontopodium alpinum	4	14	14	2.3	1		H	tl	al
Leucanthemopsis alpina	28	25	29	56.4	0.70		H	al	ni
Ligusticum mutellina	1	1	3	200.0	1		H	tl	al
Ligusticum mutellinoides	2	6	9	27.3	1		H	al	al
Lloydia serotina	15	33	50	57.0	0.05 *		G	tl	al
Loiseleuria procumbens	4	18	27	120.5	0.63		Z	tl	al
Luzula lutea	17	35	45	34.6	0.31		H	tl	al
Luzula spicata	19	11	17	79.2	0.12		H	al	ni
Minuartia sedoides	15	19	15	-13.0	0.26		C	tl	ni
Minuartia verna	17	5	9	78.5	0.27		C	tl	al
Omalotheca supina	3	8	12	83.9	0.75		H	tl	al
Oreochloa disticha	8	37	12	38.4	0.11		H	al	ni
Oxytropis campestris	10	13	16	32.9	0.57		H	mo	al
Pedicularis verticillata	2	11	15	638.1	1		H	tl	al
Phyteuma globulariifolium	3	13	15	-1.4	1		H	al	al
Phyteuma hemisphaericum	17	12	18	150.9	0.052 .		H	tl	al
Plantago atrata	1	2	2	0.0	NaN		H	tl	al
Poa alpina	28	66	54	-1.8	0.19	i	H	tl	al
Poa laxa	11	26	28	14.6	0.64	i	H	al	ni
Polygala alpestris	4	5	12	174.2	0.25		H	mo	al
Polygonum aviculare	2	30	2	-95.0	0.50		T	mo	mo
Polygonum viviparum	20	15	21	177.2	0.53		H	tl	al
Potentilla aurea	21	36	37	22.7	0.93		H	tl	al
Potentilla crantzii	9	14	17	76.4	0.73		H	tl	al
Potentilla frigida	11	21	25	22.5	0.42		H	al	ni
Pulsatilla vernalis	14	20	27	75.2	0.66		H	tl	al
Ranunculus glacialis	3	3	4	83.3	0.37		H	al	ni
Ranunculus kuepferi	1	14	6	-57.1	1		H	tl	al
Ranunculus montanus	4	4	8	190.3	0.63		H	tl	al
Salix reticulata	1	3	3	0.0	NaN		Z	tl	al
Saussurea alpina	4	3	5	29.2	0.36		H	tl	al
Saxifraga aphylla	1	15	13	-13.3	1		C	al	al
Saxifraga bryoides	15	29	36	30.1	0.47		C	al	ni
Saxifraga caesia	24	12	14	17.0	0.83		C	tl	al
Saxifraga exarata	3	4	6	20.8	1		C	al	ni
Saxifraga oppositifolia	13	7	11	128.2	0.03 *		C	al	ni
Saxifraga paniculata	5	3	4	128.3	0.34		C	tl	al

Species	N	Frequency Survey 2	Frequency Survey 2	Average Change [%]	p	?	LF	AL	AU
Sesleria albicans	26	20	26	36.3	0.26		H	mo	al
Sibbaldia procumbens	8	23	29	30.9	0.55		H	tl	al
Silene acaulis	13	24	26	19.8	0.78		C	al	ni
Soldanella alpina	6	11	23	140.2	0.031 *		H	tl	al
Taraxacum apenninum	14	28	40	73.3	0.079 .		H	tl	al
Thalictrum alpinum	4	8	21	548.2	0.38		H	tl	al
Thesium alpinum	2	2	2	75.0	1		H	mo	al
Trifolium alpinum	1	14	16	14.3	1		H	tl	al
Trifolium badium	3	1	5	250.0	0.35		H	mo	al
Trifolium thalii	3	7	9	200.0	1		H	tl	al
Trisetum distichophyllum	6	4	6	19.7	0.67		G	tl	al
Trollius europaeus	1	1	1	0.0	NaN		H	mo	al
Vaccinium myrtillus	1	3	4	33.3	1		Z	mo	al
Vaccinium vitis-idaea	7	48	44	91.8	0.81		Z	mo	al
Veronica aphylla	3	3	2	-30.0	0.37		H	tl	al
Veronica bellidioides	24	8	17	236.7	0.0018 **		H	tl	al
Veronica fruticans	1	1	2	100.0	1		Z	tl	al
Viola calcarata	1	6	10	66.7	1		H	tl	al

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