MASTERARBEIT / MASTER'S THESIS

Titel der Masterarbeit / Title of the Master's Thesis

„High mountain snowbed species population dynamics"

verfasst von / submitted by

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angestrebter akademischer Grad / in partial fulfilment of the requirements for the degree of

Master of Science (MSc)

Wien, 2024 / Vienna, 2024

Studienkennzahl lt. Studienblatt /degree programme code as it appears on the student record sheet:	UA 066 0833
Studienrichtung lt. Studienblatt /degree programme as it appears on the student record sheet:	Masterstudium Ecology and Ecosystems
Betreut von /Supervisor:	Univ.-Prof. Mag. Dr. Stefan Dullinger

Acknowledgment

I would like to express my deepest respect and thanks to my advisor, Stefan Dullinger. I feel honored to work with such a professional expert on biodiversity in alpine regions. Thank you for all the help and trust in my work.

In addition I will express my deepest honor to Karl Hülber who helped me with a lot of questions and essential inputs for my master thesis. Thank you also for supporting me with tips and materials.

My deepest gratitude I owe my Family on both sides. On the one hand Teischinger Florian, Valentina, Marie and my parents Wolfgang and Barbara Teischinger to support me in every challenge of my life. My aunt Barbara Teischinger who supported me and my family mentally. On the other hand the Family Favry with my life partner Franziska her parents Eva and Serge Favry and Peter Marksteiner for their supportive help and consciousness.

In the end I will express my deepest respect for help in my most challenging part of my life to the medical doctors Dr. In. Kamaleyan Schmid, Dr. Nikzad, Dr. In Brunner as well as Dr. In Pelzl and Lisa Schmid for my psychical fitness during sports in my latest life period.

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Introduction

Due to climate change, snow cover duration declined in nearly all mountain region on earth (excluding the Canadian and Russian Arctic, Svalbard, Greenland and Antarctica). The snow cover duration has decreased on average by 5 days per decade since 1950 (IPCC, 2019). The mountain surface air temperature has increased in western North America, European Alps and high mountains of Asia up to an average warming of 0,3° C per decade since 1950 (IPCC, 2019). This magnitude of warming is higher than the overall global warming rate of 0,2 +- 0,1 °C per decade since 1950 (IPCC, 2019).

Snow is an essential component in the mountain ecosystem and has several functions in the mountain ecosystem. Especially the snow cover is a protection against mass movement of the mountains, a reflective cover of the surface and works as an insulation layer for plants during cold winters. Additionally the snow cover influences the micro climate, the nutrition flux as well as plant and microbial habitat under the snow surface (Lafaysse et al., 2014; Mankin and Diffenbaugh, 2014). Most of the alpine plants start growing at a temperature of 0°C (Billings and Bliss, 1959). The snow cover provides the whole snow season a temperature between 0 and -5 °C(Björk and Molau, 2007) and protects plants against deeper frost as well as against wind erosion. These advantages trade off against a shorter growing season at sites with a long snow cover.

With the shortened snow season and therefore less snow cover, many plant species, mammals and invertebrates are challenged to find habitable niches. The earlier snow melt and the shorter snow cover period in winter leads additionally to an uprising or range shift of lower alpine plant species. This shift of species can result in locally higher species richness and biomass (Wang et al., 2017; Xie et al., 2018). However, narrow-range species and habitat specialists, including those adapted to snow beds, often face local and regional decline as they are competitively inferior to those species coming up from below (Alexander et al. 2015, Steinbauer et al., 2016; Zhang and Zhang, 2017; Muellner-Riehl, 2019).

In Europe current massive vegetation changes in alpine communities, especially alpine snow bed species are predicted (Dullinger et al., 2012). Michele Carbognani, Marcello Tomaselli and Alessandro Petraglia. Carbognani, Tomasseland Petraglia analyzed the species composition and turnover of plants in the south eastern alps of Northern Italy from 2004 to 2010 (Carbognani et al., 2014).

In general the local species invasion from lower alpine altitudes in Northern Italy was much higher than in Norwegian region (Sandvik et al., 2004). In the Norwegian study the vascular plant mass significantly rises by 25 percent. The change indicates an assimilation, a stronger competition and an increase of species abundance in snowbed habitats (Sandvik et al., 2004). To nearly the same conclusion comes Gritsch 2016 et al. by sampling graminoids and snowbed species in the northeastern calcareous Alps of Austria. For two plant communities, the α – and ɣ – diversity remained constant, but β – diversity increased. Indicator values other than temperature either did not change or changed idiosyncratically in the different communities (Gritsch et al., 2016) All in all these results shows that snowbed habitats are much more complex in relation to climate change and more studies are needed to discover general trends (Carbognari et al., 2014).

In this study, I want to contribute to filling this gap by analyzing the abundance, alpha, beta and gamma diversity change of snowbed habitat specialists in a study region of the northeastern Alps between 2005 and 2018. In particular, I want to test if there is a change between 2005 and 2018. Furthermore i also want to describe and answer open questions of preceded study's in vegetation dynamics about and in between every unique snowbed habitat plant species in alpine regions.

Material and methods

Study Sites

My study is focused on 178 snowbed sites situated in the northeastern calcareous Alps of Austria. The snowbeds in the study area are located in the subalpine zone or in the subalpine to alpine ecotone (1850 to 1950 m.a.s.l.) of the four Mountains Mt. Schneeberg, Mt. Rax, Mt. Schneealpe, and Mt. Aflenzer Staritzen (15° to 16° E, and 47° 309 to 47° 509 N). The mean annual temperature in the area is between 0 – 2°C, the annual precipitation between 1500 – 2000mm. (Pavuza, 1993). Mt. Schneeberg is more exposed to the warm Pannonic Climate than Mt. Rax and as a result of this Mt. Schneeberg is a bit warmer and lesser humid with less precipitation through the year (Trimmel, 1952). The subalpine and alpine vegetation of these mountains consists of a mosaic of postrate pine *(Pinus mugo)* shrublands, calcareous alpine grasslands, scree and rock vegetation. Snowbed vegetation is typically concentrated in in calcareous dolines and tranches. The flora of these snowbeds mainly consists of low-growing rosette-forming herbs (Englisch et al., 1993).

The studied region is part of the Mesozoic limestone Greywacken zone with “Wettersteinkalk” layers. The “Wettersteinkalk” layer in the northeastern calcareous Alps consists primarilyt of dolomite and limestone.

Aflenzer Staritzen

Mt. Aflenzer Staritzen is a karstic mountain located in Styria and consists primarily of triad limestone so called Wettersteinlimestone. It is part of the Mt. Hochschwab mountain range. In the eastern part of the Mt.Hochschwab the Aflenzer limestone is present. Some parts of marl, breccie and greenshist are also present. (Englisch 1999, Spengler, 1920,1922,1925, Flügel und Neubauer, 1984)

Schneealpe

Mt. Schneealpe at the Lower Austrian and Styrian boarder, is a typical plateau mountain with the highest peaks of Windberg (1903 m), Schönhaltereck (1860 m) and the Amaißbichl (1828 m). Mt. Schneealpe is also part of the “Mürzalpendecke” nappe and consists primarily of limestone and dolomite. (Bauer et al., 2012)

Schneeberg

Mt. Schneeberg with 2075m is the highest peak of Lower Austria. Its also a part of the “Mürzalpendecke” nappe and primarily consists of Wettersteinlimestone.

Rax

Mt. Rax is part of the Rax- Schneeberg reef which lies on the “Mürzalpenlayer” nappe in Lower Austria. The formation is like Mt. Schneeberg, a mix of Wettersteinlimestone and Wettersteindolomite. The Rax mountain build a unique plateau the by Lichtenecker 1926 called “Raxlandschaft”. The highest peak on the plateau is the “Heukuppe” (2007m) (Wendelberger, 1970).

Study species

My study focuses on six species that are mainly to exclusively growing on calcareous sites characterized by late snow melt (syntaxonomical alliance Arabidion caeruleae): *Achillea clusiana, Achillea atrata, Arabis caerulea, Gnaphalium hoppeanum, Sedum atratum, Saxifraga stellaris*. The alliance has a number of other characteristic species such as *Saxifraga androsacea, Carex parviflora, Salix reticulata, S. retusa, Sagina saginoides,* but the species selected are those most common and indicative of snowbeds regionally. (Jenny, 1926)

Arabis caerulea

A. caerulea belongs to the plant family of *Brassicaceae* and is a character species of the subnival and alpine region. *A. caerulea* reaches a size of around 2 and 12 cm (Fischer et al., 2008).

Achillea atrata

A. atrata belongs to the plant tribe Anthemidia within the daisy family and is widely distributed in snowbed habitats, on moraines and in wet grasslands on limestone form subalpine to subnival elevations. The species is more frequent in the western than in the eastern calcareous alps. It reaches a sizes of around 11 and 20 cm (Fischer et al., 2008).

Achillea clusiana

A. clusiana belongs to the plant tribe Anthemidia and is a close relative to *A. atrata. A. clusiana* occurs in similar habitats like *A. atrata*, but is endemic to the most northeastern Calcareous Alps. It also reaches a size of around 11 and 20cm (Fischer et al., 2008).

Gnaphalium hoppeanum

G. hoppeanum is a small rosette plant form the Asteraceae family which mainly occurs in limestone snowbeds. It reaches a size of around 4 to 10 cm (Fischer et al., 2008)

Saxifraga stellaris

The so called Stone break plant *S. stellaris* belongs to the plant family of Saxifragaceae. *S. stellaris* is a common plant in humid alpine spring meadows, stonefields and also under water. *S. stellaris* occurs over the whole Alps. It reaches a size of around 5 to 30 cm (Fischer et al., 2008)

Sedum atratum

S. atratum belongs to the large genus *Sedum* of the family Crassulacea which is commonly known as stonecrops. *S. atratum* is a pioneer plant on stony calcareous sub alpine – alpine meadows and rocks. *Sedum atratum* is wide spread over Europe from Pyrenees, Carpathians, Apennines, Balkan region and in the Alps. It reaches a size of around 3 to 10 cm (Fischer, 2008).

Study design

The 178 snowbed sites studied are clustered in 4 1 km² areas, one on each of the four mountain ranges. All sites in the four areas have been first surveyed between May and September of 2005 (cf. Dullinger et al. 2011). During this survey, the abundance of the study species in each snowbed has been quantified according to an approximate square-root scale:

- A=0,
- B=1-3;
- C=4-10;
- D=11-30;
- E=31-100;
- F=101-300;
- G=301-1000;
- H=1001-3000;
- J=3001-10000.

In addition, the contour of the snowbed had been mapped and the size of each snowbed subsequently calculated from these contour maps (min: 4 m2 and max: 11000 m2 and mean: 580 m2). The center of each snowbed was labeled with GPS coordinates.

In 2018, I spotted these coordinates again. I classified a snowbed by different characteristics like snowbed vegetation borders, scree cover, changeover to rocky and craggy terrain and late snow melting event area. I re-mapped the contour lines of the snowbed polygons with the classified characteristics and compared them to the original ones to assess whether the snowbed habitats of 2005 and 2018 are comparable in size. Similarly, I re-did the counting of all six species in all snowbeds in the classified snowbed.

Analyses

Abundance

I defined the abundance as sum of the number of individuals in all snowbeds at each of the four mountains. The median of the classes A – J 2005 and 2018 was calculated and compared.

Percentage

Percentage is defined as the proportion of snowbed habitats occupied by a species. I calculated the percentage with the value of all per plant occupied snow bed divided by all 178 snow beds multiplied to 100. I used the binomial test for statistical significance.

Shannon diversity

For each snowbed, I calculated the Shannon Wiener index as a diversity index to integrate information on the number of the 6 snowbed species and their relative abundances. Shannon diversity was calculated with Shannon Index in R package "vegan" and presented with ggplot2. Normal distribution was tested with the RStudio "ggpubr" and "rstatix" packages. Statistical significance between 2005 and 2018 was tested with the Welch two sided t- test of the R "vegan" package. The Shannon Index of each snowbed from 2005 and 2018 were integrated and compared in a nested Shannon Test. The Shannon diversity index was calculated as follows (Weaver and Shannon, 1949):

$$H = -\sum_{j=1}^{S} p_i \ln p_i$$

p_i = proportion of total sample presented by species I

S= number of species, H = species richness

As I focused on a total of six species, *S* varies between 0 and 6; *p* was calculated from the total number of individuals of all species which was estimated by calculating the median of the classes A – J 2005 and 2018.

Jaccard Index

The Jaccard index was calculated to show similarity in species composition. The Jaccard index was calculated as follows (Jaccard, 1908):

$$JACC\ [\%] = \frac{a}{a+b+c} \times 100$$

a= Sum of common Species

b= Species which only occur 2005

c= Species which only occur 2018

Gleason Index

The Gleason richness index was calculated to show similiarity in species abundances. The Gleason richness index was calculated as follows (Gleason, 1922):

$$GLEA\ [\%] = \frac{Ma}{Ma+Mb+Mc} \times 100$$

Ma = Shares/Mass of all common species

Mb = Shares/Mass of all species which occur 2005

Mc = Shares/Mass of all species which occur 2018

The snowbed habitats between 2005 and 218 were analyzed in a comparative context by calculating the Abundance, Frequency, occupied plots and Shannon diversity. The areas in between the year 2005 and 2018 were compared using 2018 GPS data. The surface area retrieved from QGis was used to calculate the Abundance. Abundance and Frequency were calculated with Libre Office Calc and presented as Boxplot, Scatterplots and Histograms in Rstudio. The Welch two sided t – test from the R package "vegan" was used to perform the H_0 hypotheses testing.

Results

Change of snowbed area size

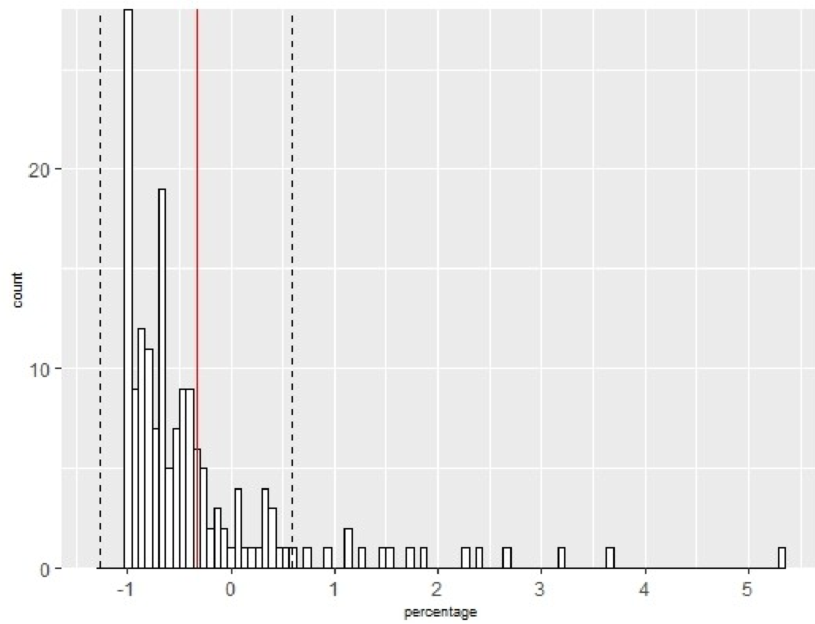

Figure 1: *Changes in snowbed area size between 2005 and 2018 of all four Mountains in the eastern calcoures Alps (AS = Mt. Aflenzer Saritzen, RA =Mt. Rax, SA= Mt. Schneealpe, SB= Mt. Schneeberg) in percentage. The red line represent the Mean. The dashed line represent the Standard Deviation*

The snowbed area over all of the four mountains decreased on average by -33,54% (see Fig.1 red line). 33 of 178 snowbed areas increased. For the individual mountains the following can be observed:

- For Mt. Schneealpe the largest decrease of the four mountains is observed, i.e. -76,75%. 33 of 34 Snowbed areas decreased.
- Mt. Rax has a mean decrease in snowbed area of -61,91%. 43 of 47 snowbed areas decreased.
- Mt. Schneeberg shows a decrease of -33,54% on average. 23 of 29 snowbed areas decreased. (Appendix 3 Tab. 1)

Additionally 32 out of 178 snowbed habitats disappeared or were overgrown by graminoides between 2005 and 2018 (Appendix 5)

Ratio of snowbed habitats

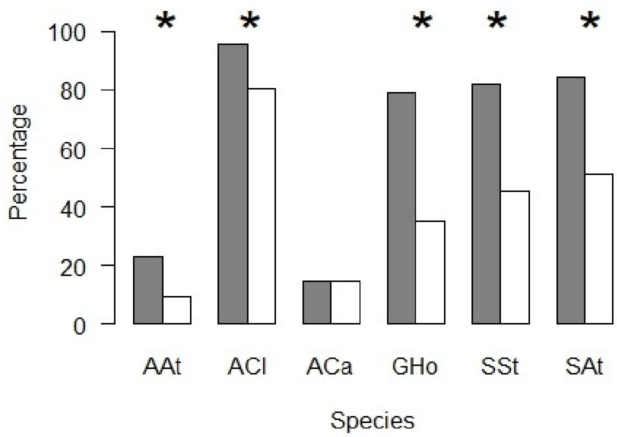

Figure 2: *Percentage of snowbeds occupied by the study species in 2005(grey) and 2018(white). AAt = Achillea atrata, ACl=Achillea clusiana, ACa= Arabis caerulea, GHo =Gnaphalium hoppeanum, SSt=Saxifraga stellaris, SAt= Sedum atratum. * highlighted the significant.*

The number of snowbeds occupied by the study species decreased significantly from 2005 to 2017, by approximately 50% in all species except *A. caerulea* (ACa) and *Achillea clusiana* (ACl) (Fig. 2). A*rabis caerulea* was the only species that kept the number of occupied snowbeds constant between the two surveys.(Appendix 3, Tab. 2). Additionally 32 out of 178 snowbed habitats disappeared or were overgrown by graminoides between 2005 and 2018 (Appendix 5, Tab. 2).

Abundance

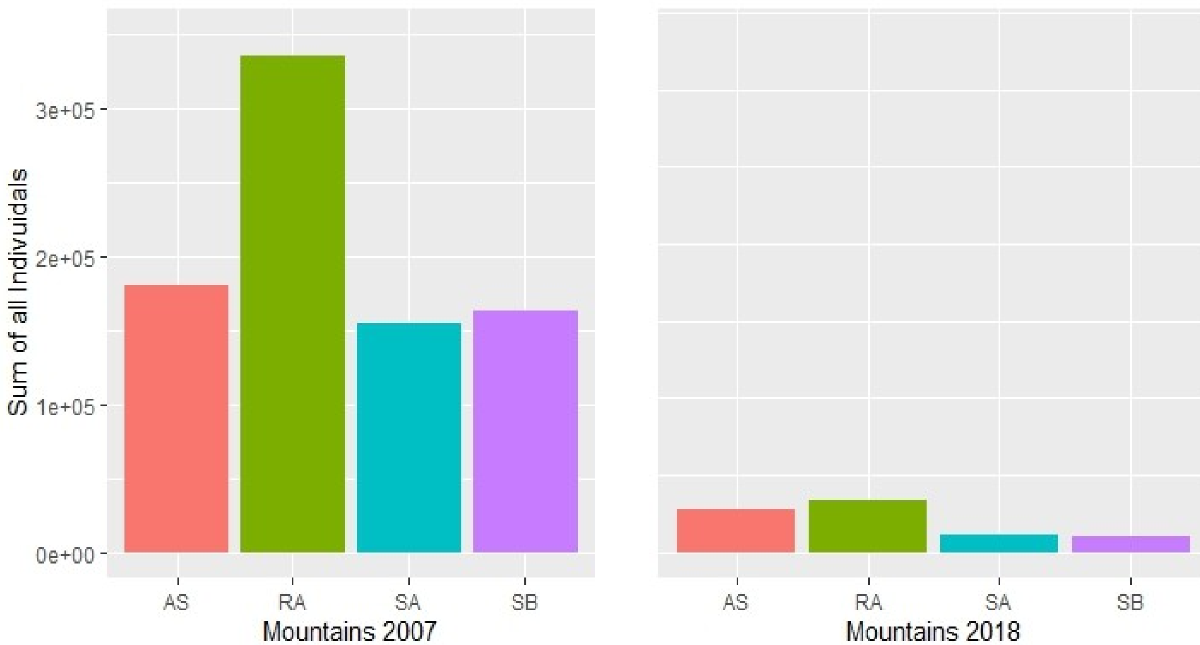

Figure 3: *Changes in abundance of all species between 2005 and 2018 on the four Mountains in the eastern calcoures Alps (AS =Mt. Aflenzer Saritzen, RA = Mt. Rax, SA= Mt. Schneealpe, SB= Mt. Schneeberg). All plants Achillea clusiana, Achillea atrata, Arabis caerulea, Gnaphalium hoppeanum, Sedum atratum, Saxifraga stellaris. of the different Mountains add together.*

The Abundance of all species between 2005 and 2018 radically decreased from 800.0000 plants to 90.000 plants. The Data shows that Mt. Rax has the highest individual rate of all Mountains in both years. Mt. Aflenzer Staritzen (AS) are 2nd in individual species rate. Mt. Schneeberg (SB) has increased and overruled Mt. Schneealpe to 3rd individual Species Richness Mountain (Fig. 3) (Appendix 3, Tab. 2).

Abundance per Species

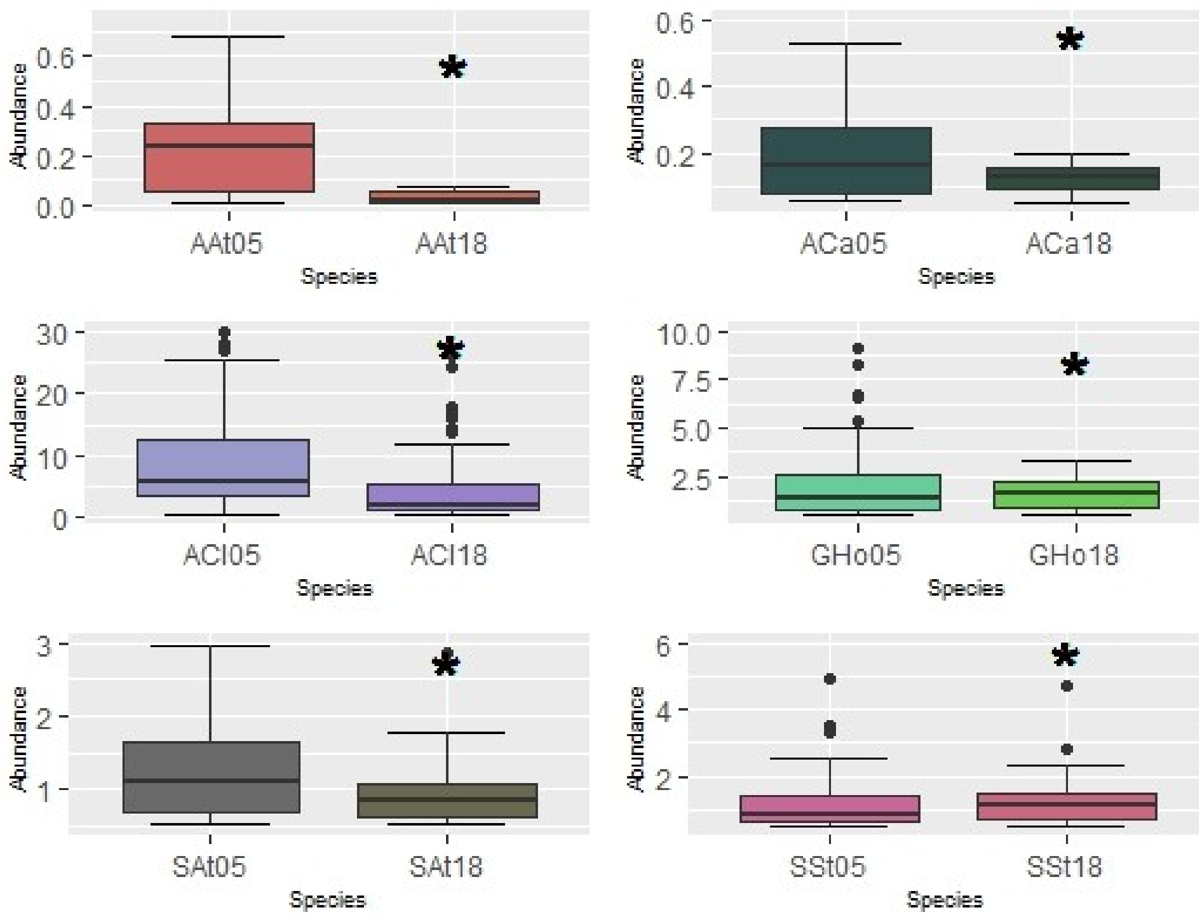

Figure 4: *Abundance of species in snowbed habitats between the 2005 (plant abbr. 05) and 2018 (plant abbr. 18) investigated snowbed from the six target plants of eastern calcareous Alps (AAt =Achillea clusiana, ACl=Achillea atrata, ACa= Arabis caerulea, GHo =Gnaphalium hoppeanum, SAt= Sedum atratum, SSt=Saxifraga stellaris). * highlighted the significant.*

Analyzing the data across the Abundance between 2005 and 2018 shows a significant decrease of the species in abundance across the 178 snowbed habitats (Fig. 4). All plant species lost significant on the level of abundance except *A. atrata, A. caerulea* and *S. stellaris*. These three plant species have a significant decrease in abundance but in contrast to the other plant species the abundance level decrease is not that much. (Appendix 3, Tab.3)

Abundance per Mountain

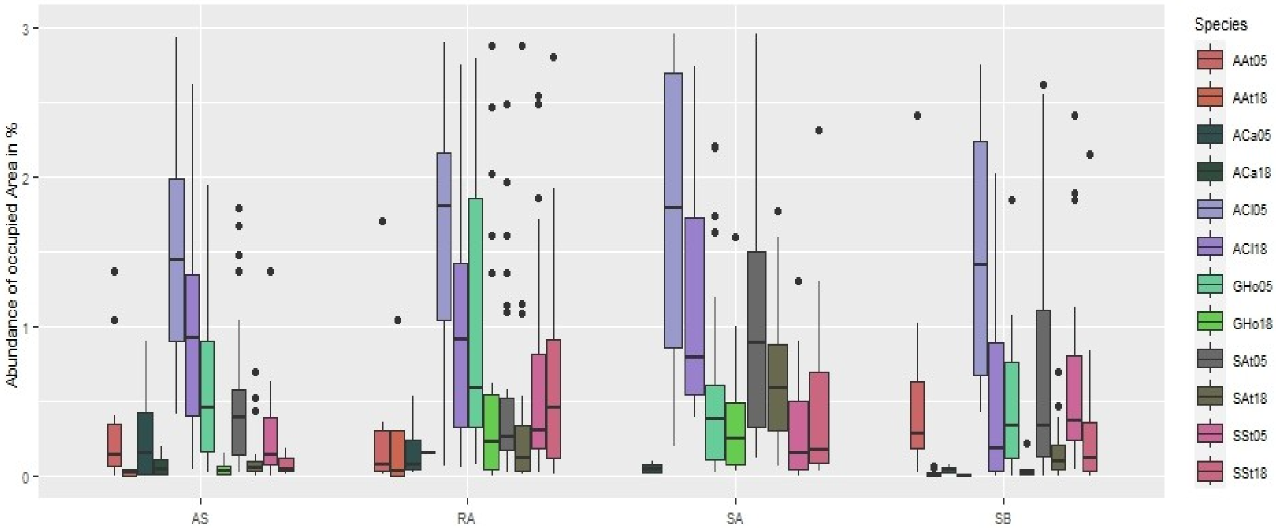

Figure 5: *Change of species abundance between 2005 and 2018 (Species : AAt =Achillea atrata, ACa= Arabis caerulea, ACl=Achillea clusiana, GHo =Gnaphalium hoppeanum, SSt=Saxifraga stellaris, SAt= Sedum atratum) and in between the four researched Mountains (AS = Mt. Aflenzer Staritzen, RA = Mt. Rax, SA= Mt. Schneealpe, SB= Mt. Schneeberg). The black points represents outliers. Because of the much higher abundance of Achillea clusiana(ACl) the chart is reduced to a limit of 3 % to get a clearer view on the data.*

The comparison of species abundance per each mountain shows a significant decrease of abundance from 2005 to 2018 by *A. clusiana* and *S. atratum* at all four mountains. *G. hoppeanum* had a decrease of abundance at three of four mountains. *A. atrata*, *A. caerulea* and *S. stellaris* are stable in abundance on nearly every mountain. *A. atrata* is stable at Mt. Aflenzer Staritzen with a p-value = 0,2196 and Mt. Rax with a p-value= 0,353. *A. atrata* has a significant decrease of abundance at Mt. Schneeberg with a p-value= 0,01365. At Mt. Schneealpe *A. atrata* is not abundant in 2005 and 2018. *A. caerulea* is stable at Mt. Aflenzer Staritzen with a p-value= 0,1637, Mt. Rax with a p-value = 0,224 and Mt. Schneealpe with p-value= 0,2393. *A. caerulea* increases from 2005 to 2018 in abundancy at Mt. Schneeberg but not significant with a p-value= 0,2393. *S. stellaris* is stable at Mt. Rax with a p-value = 0,7845, at Mt. Schneealpe with a p-value= 0,7425 and Mt. Schneeberg with a p-value= 0,42210. *S. stellaris* has a significant decrease of abundance at Mt. Aflenzer Staritzen with a p-value= 0,00003604. *G. hoppeanum* is stable only at Mt. Aflenzer Staritzen with a p-value= 0,06751 and decrease on the other mountains (Appendix 3, Tab. 4)

Shannon Diversity Index

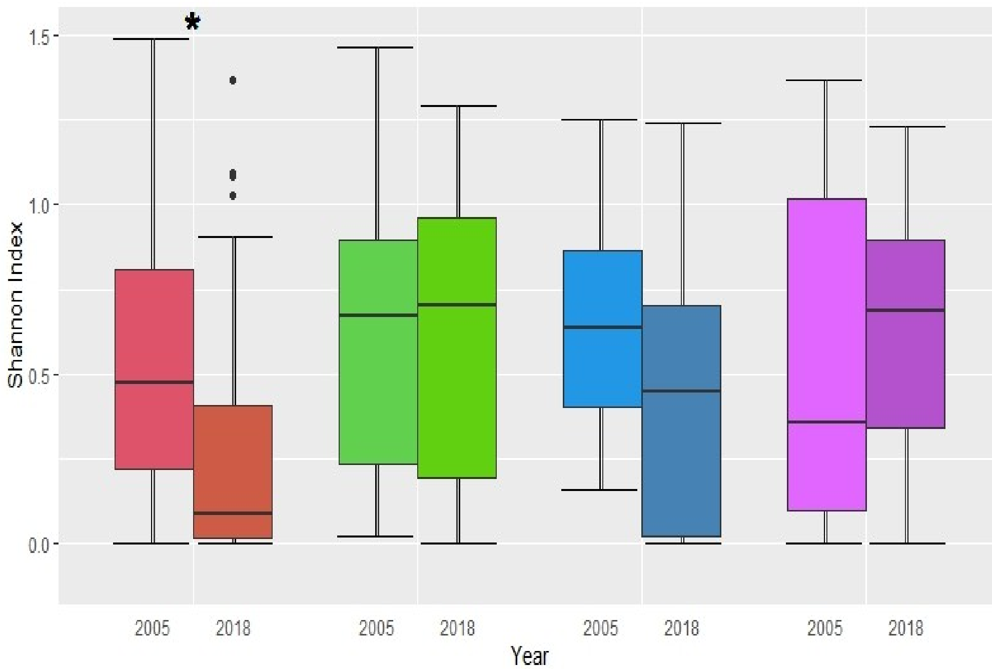

Figure 6:. *Comparison of the Shannon diversity index between 2005 and 2018 from the four target mountains: Mt. Aflenzer Staritzen = red, Mt. Rax = green, Mt. Schneealpe = blue and Mt. Schneeberg = magenta*

The average Shannon-diversity of snowbed species did not change between 2005 and 2018 on Mts. Rax, Schneealpe und Schneeberg. On Mt. Aflenzer Staritzen it decreased significant (Appendix 3, Tab. 5).

Comparison of Jaccard and Gleason Index

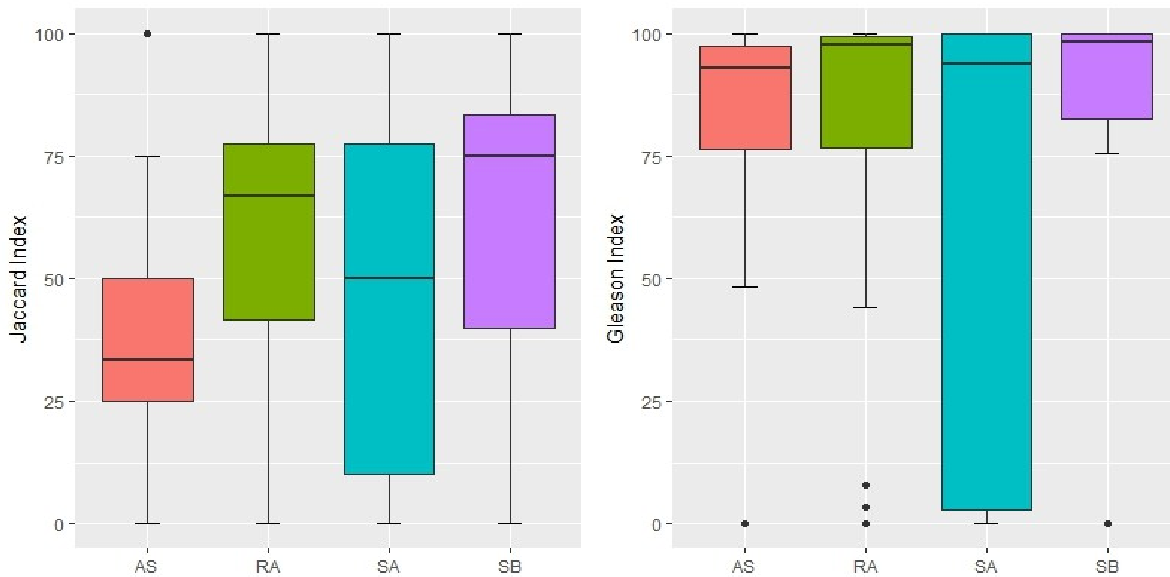

***Figure 7:**. Comparison of the Jaccard species and the Gleason mass index in percent of the four target mountains: AS= Mt. Aflenzer Staritzen, RA =Mt. Rax, SA= Mt. Schneealpe and SA=Mt. Schneeberg*

<u>The comparison of Jaccard species index and Gleason mass index shows results as followed:</u>

The snowbeds on Mt. Aflenzer Staritzen and Mt. Schneealpe have obviously undergone a larger turn-over of their snowbed species composition than those on Mt. Rax and Schneeberg. Differences are particularly clear in case of the Jaccard-Index, but rather minor in case of the Gleason-Index.

Discussion

My results demonstrate a significant decline of patch occupancy, per-patch abundance and overall population size in five of the six species analysed. In addition, 32 out of 178 snowbed habitats disappeared or were overgrown by graminoids between 2005 and 2018 (Appendix 6). The number of species, shows a dramatically statistic significant lost of snowbed species with the factor of 10 (Fig. 3). Snowbed habitats and their flora have thus experienced a dramatic decrease within only 13 years in this area of the northeastern-most calcareous Alps.
The dramatic decline documented in my work is likely attributable to climate change. The rising temperature advances snow melt times and thus expands the growing season for plants in the snowbeds. As a consequence, species from the surrounding sub alpine grasslands colonize with the rise of warmer and humid abiotic conditions in higher altitudes the snowbeds and have obviously started to replace the specialists of these sites (Matteo et al., 2010),(Hülber, Brady and Dullinger 2001). This competition with other plants for below ground nutrients and access to more radiation with better grow rate, influence the composition of snowbed habitat species negative (Matteo et al., 2010). Such replacement is facilitated by the fact that snowbed specialist a usually low-stature rosette plants likely to be inferior competitors, with probably limited phenotypic plasticity (Rixen et al. 2022)

In my study the alpine grassland graminoid *Deschampsia cespitosa* seems to occupy and displace the species on every mountain in several number of snowbeds. In general Mt. Aflenzer Staritzen and Mt. Schneealpe are affected by this *D. cespitosa* species turnover. There might be also a displace competition between *A. clusiana* and *A. caerulea* ongoing. *A. clusiana* is in ratio to *A. caerulea* less sensitive to abiotic conditions in snowbed habitats (Dullinger and Hülber, 2011). In my study *A. clusiana* is the dominant species in abundance and individual rate in most snowbed habitats between 2005 and 2018 (Fig. 5 and Fig. 9). Results of the Seed Limitation study show that *A. clusiana* is less sensitive to snowbed occupancy and abiotic variations than the other plant species. (Dullinger and Hülber, 2011) In my study *A. clusiana* displace the other plants primarily at Mt. Aflenzer Staritzen and Mt. Schneealpe. Due to the lower sensitivity of *A. clusiana* to abiotic conditions in ratio to *A. caerula*, the dominant species *A. clusiana* in abundance and individual rate in most snowbed habitats could lead to a displace of *A. caerulea*. All in all *A. caerulea* had on the one hand to survive the competition with graminoids and *A. clusiana* by choosing later snow melting sites. On the other hand *A. caerula* had to struggle with lower productivity rate over the warm season in colder snowbeds to grow and reproduce seeds. Furthermore *A. caerulea* increased the abundance- but not significant at several snowbed habitats on Mt. Schneeberg (Fig 5 and Fig 10). These results coincides with the Seed limitation Study of Dullinger and Hülber that both *A. caerulea* and *A. atrata* prefer colder later snow melting sites (Dullinger and Hülber, 2011).

The fact that *A. clusiana* and potentially *D. cespitosa* are responsible for the displacement of the other five snowbed species correlate with the results of the Jaccard/Gleason Index. These two plant species may be potentially responsible for high beta diversity and species turnover in the snowbed habitats at Mt. Aflenzer Staritzen and Mt. Schneealpe from 2005 to 2018.

At Mt. Aflenzer Staritzen the Shannon diversity decreased from 2005 to 2018 significant with a p-value < 0,001. The alpha diversity is lower than on other mountain (Fig. 6.) This loss of alpha diversity could maybe result on the *D. cespitosa* displacement could be caused by grazing of mammalian herbivores (Appendix 4). The grazing of plant communities by mammalian herbivores has ecological effects on the composition of plant communities, diversity and biomass in snowbed habitats. (Moen et al., 1993;Virtanen et al., 1997; Virtanen, 2000; Olofsson et al., 2002). In alpine regions the snow season is predicted to decrease. (Mankin, 2014) The shorter the snow season the longer mammals can graze on the snow free vegetation surface. Mammals also follow the attitudinal melt-off gradient by selecting habitats with the highest level of green phytomass at the most favorable growth stage (Björk & Molau, 2007). This will foster the encroachment of e.g. graminoides into snowbeds with earlier snowmelt, because the graminoids benefit from mammal grazing. In this study 20 of the 178 snowbed habitats have been largely overgrown by *Deschampsia cespisota* between 2005 and 2018. Several snowbed habitats in this study show signs of grazing by a huge amount of feces of mountain goats. This indicates that rising grazing pressure might indeed co-determine the loss of snowbed species from at least part of the snowbed sites studied.

Conclusion

This study shows a significant decrease in regional snowbed vegetation and snowbed-species population size over a 13 year period. The drastic change in frequency, and abundance of the species shows that snowbeds are not in a stable equilibrium with the current climate. With predicted future warming, these trends will likely continue or even intensify. As a consequence, at least part of these snowbed species might become locally extinct on the mountains surveyed, but also on others of similar, limited elevation in the marginal parts of the European Alps.

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Figures and Tables

Figure 1: Histogram of changes in snowbed area size between 2005 and 2018 of all four Mountains in the eastern calcareous Alps (AS = Mt. Aflenzer Saritzen, RA = Mt. Rax, SA= Mt. Schneealpe, SB= Mt. Schneeberg) in percentage. The red line represent the Mean. The dashed line represent the Standard Deviation

Figure 2: Barplot of the ratio between Percentage of snowbeds occupied by the study species in 2005(grey) and 2018(white). AAt = *Achillea atrata*, ACl=*Achillea clusiana*, ACa= *Arabis caerulea*, GHo =*Gnaphalium hoppeanum*, SSt=*Saxifraga stellaris*, SAt= *Sedum atratum*

Figure 3: Barplots of the changes in overall individuell species number of the mountains 4 Mountains in the eastern calcoures alps (AS = Mt. Aflenzer Saritzen, RA = Mt. Rax, SA= Mt. Schneealpe, SB= Mt. Schneeberg). All plant species *Achillea clusiana, Achillea atrata, Arabis caerulea, Gnaphalium hoppeanum, Sedum atratum, Saxifraga stellaris*. of the different Mountains add together.

Figure 4: Boxplots of Abundance of species in snowbed habitats between the 2005 (plant abbr. 05) and 2018 (plant abbr. 18) investigated snowbed from the six target plants of eastern calcareous Alps (AAt =*Achillea clusiana*, ACl=*Achillea atrata*, ACa= *Arabis caerulea*, GHo =*Gnaphalium hoppeanum*, SAt= *Sedum atratum*, SSt=*Saxifraga stellaris*)

Figure 5: Boxplot of the change of species abundance between 2005 and 2018 (Species: AAt =*Achillea atrata*, ACa= *Arabis caerulea*, ACl=*Achillea clusiana*, GHo =*Gnaphalium hoppeanum*, SSt=*Saxifraga stellaris*, SAt= *Sedum atratum*) and in between the four researched Mountains (AS = Mt. Aflenzer Saritzen, RA = Mt. Rax, SA= Mt. Schneealpe, SB= Mt. Schneeberg).

Figure 6: Boxplot of the Comparison of the Shannon diversity index between 2005 and 2018 from the four target mountains: Mt. Aflenzer Staritzen = red, Rax = green, Mt. Schneealpe = blue and Mt. Schneeberg = magenta. These index is used for Alpha diversity.

Figure 7:. Boxplot of the comparison of the Jaccard species and the Gleason mass index in percent of the four target mountains: AS= Mt. Aflenzer Staritzen, RA =Mt. Rax, SA= Mt. Schneealpe and SA= Mt. Schneeberg. The Jaccard and Glason inex is used for Beta diversity.

Figure 8: Geographical abundance map displayed as a scatterplott. Geographical abundance map of the plant Achillea atrata in the researched area on the 4 Mountains in the eastarn calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is *Achillea atrata*.

Figure 9: Geographical abundance map displayed as a scatterplott. Geographical abundance map of the plant Achillea clusiana in the researched area on the 4 Mountains in the eastern calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is *Achillea clusiana*.

Figure 10: Geographical abundance map displayed as a scatterplott. Geographical abundance map of the plant Arabis caerulea in the researched area on the 4 Mountains in the eastern calcareous alps (Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed on the mountain area. The bigger and more gray shaded the snowbed the more abundant is *Arabis caerulea*.

Figure 11: Geographical abundance map displayed as a scatterplott. Geographical abundance map of the plant Gnaphaleum hoppeanum in the researched area on the 4 Mountains in the eastarn calcareous alps (Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed on the mountain area. The bigger and more gray shaded the snowbed the more abundant is *Gnaphaleum hoppeanum*.

Figure 12: Geographical abundance map displayed as a scatterplott. Geographical abundance map of the plant *Saxifraga stellaris* in the researched area on the 4 Mountains in the eastarn calcareous alps (Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is *Saxifraga stellaris*.

Figure 13: Geographical abundance map displayed as a scatterplott. Geographical abundance map of the plant Sedum atratum in the researched area on the 4 Mountains in the eastarn calcareous alps (Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is *Sedum atratum*.

Appendix

Appendix 1: German Abstract

Pflanzen in Schneefeldern oder sogenannten Dolinen sind in ihrer Zusammensetzung sehr konservativ. Diese Pflanzen treten vor allem in alpinen Gegenden wie den östliche Kalkalpen von Österreich, den nördlichen Kalkalpen von Italien, in der Schweiz und Norwegen in Erscheinung. Das Vorkommen, die Verteilung, die durch den Klimawandel zeitliche Wanderung dieser einzigartigen Pflanzen und auch Verdrängung durch z.b. Graminiode in andere Habitat werden derzeit noch sehr kontrovers diskutiert. Es wird vermutet, das einerseits die abiotischen und andererseits die biotischen Faktoren das Vorkommen und die Verteilung der alpinen Pflanzen beeinflusst. Inwieweit die Gewichtung dieser Faktoren für die Verteilung und das Vorkommen dieser Arten ausschlaggebend ist, ist noch Gegenstand laufender Untersuchungen.

Um ein besseres Verständnis zwischen der zeitlichen Abfolge des Artenwechsel in alpinen Regionen und dem Klimawandel zu bekommen, wurde diese Studie an den Pflanzen *Achillea clusiana, Achillea atrata, Arabis caerulea, Gnaphalium hoppeanum, Sedum atratum, Saxifraga stellaris* in Folger einer vergleichenden Studie der Daten von Aufnahmen zwischen 2005 und 2018 gemacht.

Die Daten wurden mit mathematischen und statistischen Werkzeugen analysiert. Es wurde die Schneefeldgröße, Anzahl der Arten, mögliche Fluktuationen und Wanderung der Arten zwischen den Aufnahmen 2005 und 2018 gemacht. Ich beobachtete das möglicherweise biotische sowie abiotische Faktoren und die geographische Lage Einfluss auf den drastischen Rückgang fast aller untersuchten Pflanzen haben könnten. Der Rückgang und die Wanderung der Arten in andere Gebiet ist nachweislich durch Änderung der Frequenz und Abundanz statistisch nachgewiesen worden. Für mehr aussagekräftige Schlüsse sollte diese Studie alle 10 bis 20 Jahre wiederholt werden.

Appendix 2: Abstract

Plant snowbed species are conservative. They tend to occur on a small scale in the eastern European calcareous alps of Austria, North Italy, Suisse and Norway. The dispersal, occurrence and responding on climate change of this plant communities is very controversial, but it seems that abiotic and biotic factors have an influence on this points. To get a better understanding of the relationship between occurrence, the shift of species in time and space and climate change this study was made with *Achillea clusiana, Achillea atrata, Arabis caerulea, Gnaphalium hoppeanum, Sedum atratum, Saxifraga stellaris* in the eastern European calcareous Alps of Austria. I recorded the snowbed habitats 2018, which Dullinger and Hülber recorded in 2005. These data is compared and analyzed in a mechanistic way by calculating the patch size, connectivity, and fluctuation in population size of the communities in between 2018 and 2005.

I observed that the connectivity between patch size and occurrence of all plants in time and space is linked. The biotic stress by grazing, abiotic stress of climate change and the geographical location of the snowbed habitats can be a factor for the drastic shrinking of population size. Abundance, frequency and the lost habitat shows the breakdown of a significant number of habitable snowbed habitats between the sampling 2005 and 2018. For more value statement this study should be repeated frequently in the next years.

Appendix 3: Statistics

Table 1: Change of snowbed area size in percentage

Mountain	# of snowbeds	# snowbeds decreased	# snowbeds increased	Percentage area change 2005 to 2018
Aflenzer Staritzen (AS)	57	35	22	+ 1,70
Rax (RA)	47	43	4	- 61,91
Schneealpe (SA)	34	33	1	- 76,75
Schneeberg (SB)	29	23	6	- 33,54
	167 *			- 33,54

*In sum 178 snowbed areas. From 11 snowbed there were no recording in 2005 or 2018

Table 2: Ratio of snowbed habitats- binomial test

Species 2005/2018	p-value
Achillea atrata (AAt)	4.396e-06
Achillea clusiana (ACl)	1.868e-13
Arabis caerulea (ACa)	1
Gnaphalium hoppeanum (GHo)	< 2.2e-16
Saxifraga stellaris (SSt)	< 2.2e-16
Sedum atratum (SAt)	< 2.2e-16

Table 3: Abundance Overall. Results of the statistic Welch two sided t -test

Species	t	df	p-value
Achillea atrata (AAt)	2,4972	1177,3	0,01343
Achillea clusiana (ACl)	11,016	211,8	2,2e-16
Arabis caerulea (ACa)	3,2919	177,17	0,001201
Gnaphalium hoppea. (GHo)	4,7798	177,71	0,00003664
Saxifraga stellaris (SSt)	2,6765	251,56	0,007927
Sedum atratum (SAt)	4,453	178,93	0,0001488

Table 4: Abundance each mountain

Aflenzer Staritzen

Species	year	mean	sd	t	df	p-value
Achillea atrata (AAt)	2005	0,32	1,97			
Achillea atrata (AAt)	2018	0,00	0,01	1,241	58	**0,2196**
Arabis caerulea (ACa)	2005	0,13	0,13			
Arabis caerulea (ACa)	2018	0,04	0,04	1,4107	58	**0,1637**
Achillea clusiana (ACl)	2005	18,53	36,74			
Achillea clusiana (ACl)	2018	1,61	2,61	3,5598	57	0,00075767
Gnaphalium hoppea. (GHo)	2005	1,56	6,41			
Gnaphalium hoppea. (GHo)	2018	0,01	0,03	1,8631	58	**0,06751**
Sedum atratum (SAt)	2005	1,87	1,87			
Sedum atratum (SAt)	2018	0,05	0,13	3,6843	58	0,0005059
Saxifraga stellaris (SSt)	2005	0,17	0,25			
Saxifraga stellaris (SSt)	2018	0	0,02	5,1222	58	0,00003604

Rax

Species	year	mean	sd	t	df	p-value
Achillea atrata (AAt)	2005	0,06	0,25			
Achillea atrata (AAt)	2018	0,02	0,15	0,93754	50	**0,353**
Arabis caerulea (ACa)	2005	0,05	0,11			
Arabis caerulea (ACa)	2018	0	0,20	1,2311	50	**0,224**
Achillea clusiana (ACl)	2005	16,32	25,46			
Achillea clusiana (ACl)	2018	6,18	14,56	3,5598	57	0,01124
Gnaphalium hoppea. (GHo)	2005	1,45	1,45			
Gnaphalium hoppea. (GHo)	2018	0,29	0,64	3,7542	50	0,000454
Sedum atratum (SAt)	2005	0,85	1,83			
Sedum atratum (SAt)	2018	0,16	0,46	3,3166	50	0,0001703
Saxifraga stellaris (SSt)	2005	0,56	0,87			
Saxifraga stellaris (SSt)	2018	0,62	1,36	-0,6749	50	**0,7845**

Schneealpe

Species	year	mean	sd	t	df	p-value
Achillea atrata (AAt)	2005	0	0			
Achillea atrata (AAt)	2018	0	0	0,93754	50	**0,353**
Arabis caerulea (ACa)	2005	0	0			
Arabis caerulea (ACa)	2018	0,01	0,02	1,6746	38	**0,1022**
Achillea clusiana (ACl)	2005	15,61	25,24			
Achillea clusiana (ACl)	2018	3,59	5,84	3,0021	38	0,00472
Gnaphalium hoppea. (GHo)	2005	1,12	2,32			
Gnaphalium hoppea. (GHo)	2018	0,18	0,59	2,5008	38	0,01682
Sedum atratum (SAt)	2005	0,97	1,24			
Sedum atratum (SAt)	2018	0,37	0,67	3,189	38	0,002858
Saxifraga stellaris (SSt)	2005	0,23	0,32			
Saxifraga stellaris (SSt)	2018	0,2	0,47	0,33098	38	**0,7425**

Schneeberg

Species	**year**	**mean**	**sd**	**t**	**df**	**p-value**
Achillea atrata (AAt)	2005	0,4	0,8			
Achillea atrata (AAt)	2018	0,01	0,02	2,632	28	0,01365
Arabis caerulea (ACa)	2005	0	0,01			
Arabis caerulea (ACa)	2018	0	0	-0,71823	28	**0,2393**
Achillea clusiana (ACl)	2005	24,01	46,86			
Achillea clusiana (ACl)	2018	1,32	4,45	3,0021	38	0,00472
Gnaphalium hoppea. (GHo)	2005	0,25	0,43			
Gnaphalium hoppea. (GHo)	2018	0,01	0,04	2,9921	28	0,005728
Sedum atratum (SAt)	2005	0,66	0,87			
Sedum atratum (SAt)	2018	1,49	7,41	3,189	38	0,002858
Saxifraga stellaris (SSt)	2005	1,83	6,02			
Saxifraga stellaris (SSt)	2018	0,82	2,65	0,81473	28	**0,4221**

Table 5: Shannon-diversity

Mountain	**year**	**mean**	**sd**	**t**	**df**	**p-value**
Aflenzer Staritzen (AS)	2005	0,54	0,38			
Aflenzer Staritzen (AS)	2018	0,27	0,09	5,2988	462,07	**0,000001808**
Rax (RA)	2005	0,63	0,4			
Rax (RA)	2018	0,63	0,4	0,0088	99,9960	0,9929
Schneealpe (SA)	2005	0,62	0,29			
Schneealpe (SA)	2018	0,45	0,38	2,2461	71,284	0,0278
Schneeberg (SB	2005	0,36	0,48			
Schneeberg (SB)	2018	0,69	0,39	-0,8476	53,728	0,4004

Appendix 4: Geographical Abundance Map

The mapped distribution of the species demonstrates the general decrease in abundance and a widespread loss of occupancy for five of the six species (Fig. 8 to Fig. 13).

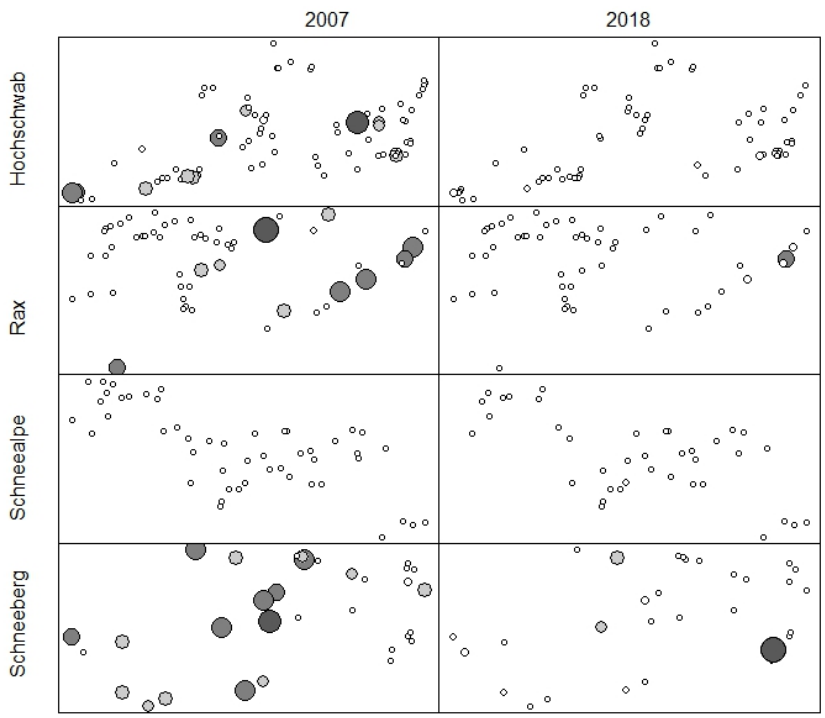

Figure 8: *Geographical abundance map of the plant Achillea atrata in the researched area on the 4 Mountains in the eastern calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed habitat the more abundant is Achillea atrata.*

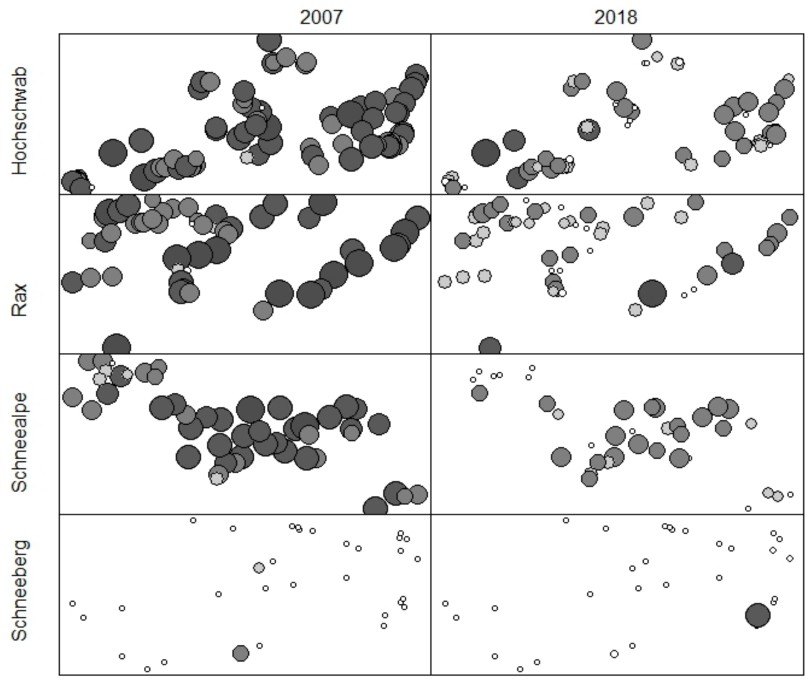

Figure 9: *Geographical abundance map of the plant Achillea clusiana in the researched area on the 4 Mountains in the eastarn calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is Achillea clusiana.*

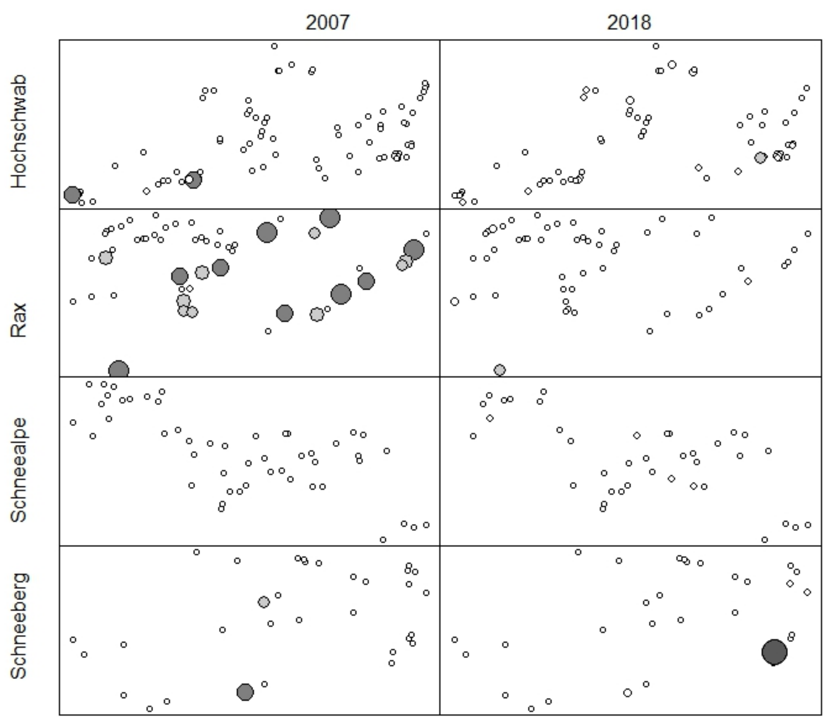

Figure 10: *Geographical abundance map of the plant Arabis caerulea in the researched area on the 4 Mountains in the eastarn calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is Arabis caerulea.*

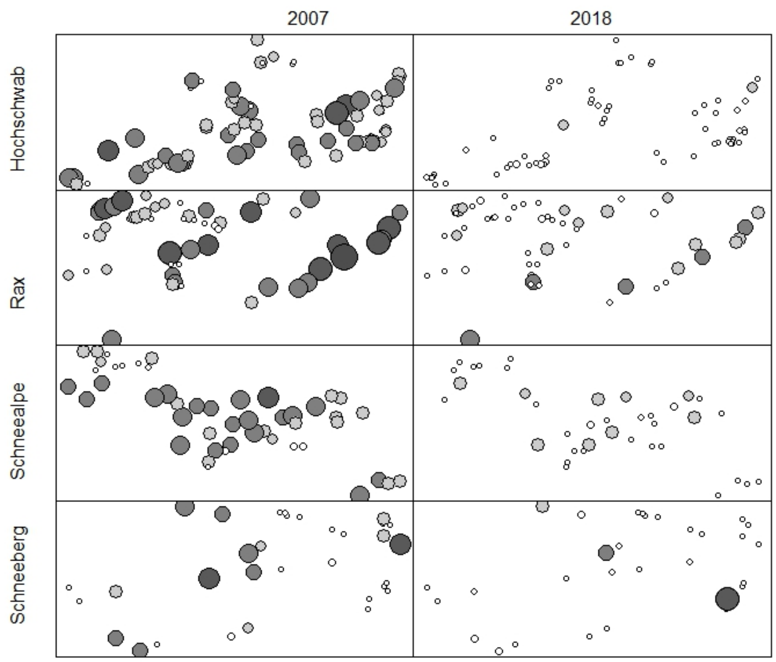

Figure 11: Geographical abundance map of the plant Gnaphaleum hoppeanum in the researched area on the 4 Mountains in the eastarn calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is Gnaphaleum hoppeanum.

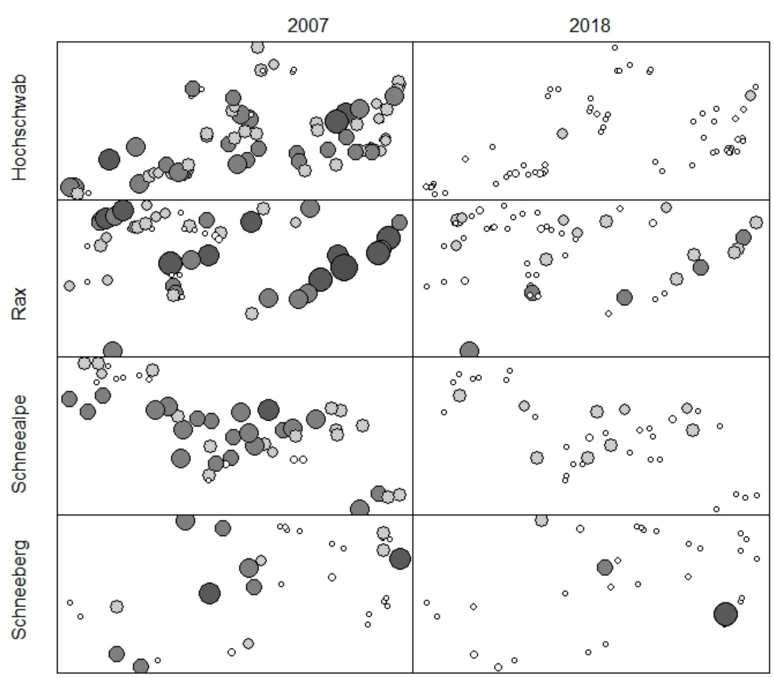

Figure 12: Geographical abundance map of the plant Saxifraga stellaris in the researched area on the 4 Mountains in the eastern calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is Saxifraga stellaris.

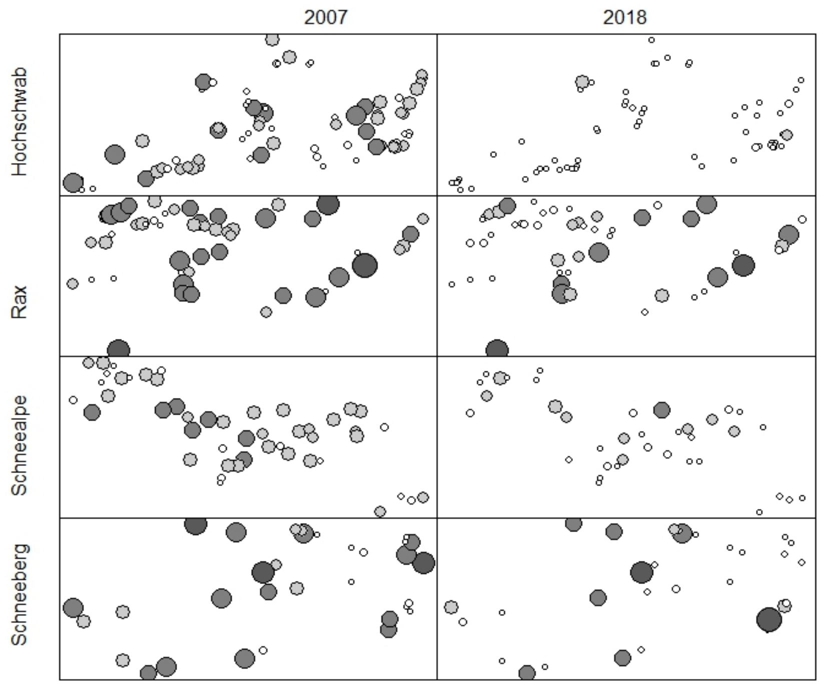

Figure 13: *Geographical abundance map of the plant Sedum atratum in the researched area on the 4 Mountains in the eastarn calcareous alps(Mt. Schneeberg, Mt. Schneelpe, Mt. Rax, Mt. Aflenzer Staritzen). Each shaded circle is a researched snowbed habitat on the mountain area. The bigger and more gray shaded the snowbed the more abundant is Sedum atratum.*

Appendix 5: List of all recorded snowbeds and species table

Table 1: Species recorded in 2005

AreaCode	Snowbed_GIS	Altitude	Rocks	ScreeCoarse	ScreeSoil	Plantcover	PopulationAAt	PopulationACl	PopulationACs	PopulationGH	PopulationSSt	PopulationSAt	Comment
AS	401	1876,618	10	20	10	60	A	F	A	A	A	C	
AS	402	1877,552	10	10	10	70	A	F	A	A	B	C	
AS	403	1877,903	0	10	20	70	F	H	A	G	A	E	
AS	404	1878,017	5	10	15	70	A	G	A	D	A	D	
AS	405	1883,59	2	20	20	40	G	H	F	G	G	E	
AS	406	1887,175	5	10	20	65	A	H	A	E	A	E	
AS	407	1883,494	30	20	20	30	A	A	A	A	A	A	
AS	408	1847,368	5	20	45	30	E	J	B	G	F	F	AAt
AS	409	1830,389	15	5	25	55	A	I	A	E	E	B	
AS	410	1821,857	10	5	10	75	A	G	A	D	D	D	
AS	411	1817,199	20	25	15	50	A	G	A	D	C	A	
AS	412	1844,863	3	40	40	20	A	J	A	H	G	H	
AS	413	1833,232	10	25	40	25	B	I	A	G	E	H	AAt
AS	414	1811,21	40	10	10	50	A	H	A	D	D	F	
AS	415	1807,982	15	5	20	60	A	G	A	F	C	E	
AS	416	1801,44	20	10	10	60	A	G	A	E	E	A	
AS	417	1802,01	30	15	15	40	A	F	C	E	A	C	
AS	418	1802,253	30	10	20	40	E	G	F	F	E	F	AAt
AS	419	1804,531	15	10	20	55	E	H	C	G	D	E	AAt
AS	420	1799,878	30	10	20	40	A	F	A	E	D	A	
AS	421	1824,996	35	35	20	10	F	H	A	E	F	F	AAt
AS	422	1829,058	25	25	10	40	A	H	A	E	D	F	
AS	429	1769,286	20	15	30	35	C	I	A	G	G	G	AAt
AS	430	1798,918	30	30	25	15	A	H	A	G	F	G	
AS	433	1786,201	15	20	25	40	A	H	A	E	D	E	
AS	434	1769,841	40	25	15	20	D	G	A	E	A	E	
AS	435	1764,122	15	0	35	40	A	F	A	D	A	D	
AS	436	1750,708	30	25	20	25	A	H	A	F	B	D	
AS	437	1701,95	20	30	15	35	A	H	A	E	C	E	
AS	438	1688,515	0	0	10	90	A	F	A	A	A	A	
AS	439	1664,141	10	35	15	40	A	G	A	A	B	A	
AS	440	1654,755	10	30	10	30	A	G	A	A	A	A	
AS	441	1664,189	5	45	15	35	A	G	A	D	E	D	
AS	442	1651,432	20	40	15	25	A	I	A	E	E	E	
AS	445	1697,732	5	75	5	15	A	E	A	B	A	A	
AS	447	1714,616	10	65	10	15	A	I	A	G	E	G	
AS	449	1711,92	10	45	15	30	A	H	A	E	E	D	
AS	451	1715,604	5	40	15	40	A	H	A	D	D	D	
AS	452	1729,014	5	40	15	40	D	F	A	A	D	A	AAt
AS	453	1758,361	10	75	5	10	A	H	A	H	F	G	
AS	454	1740,13	5	80	5	10	A	H	A	G	E	G	
AS	457	1765,516	10	50	25	15	H	J	A	I	G	H	
AS	459	1775,31	5	50	15	30	A	H	A	F	F	H	
AS	460	1732,823	15	45	10	30	A	H	A	D	C	D	
AS	461	1731,522	15	50	10	25	A	G	A	C	B	D	
AS	464	1740,156	5	20	15	60	E	I	A	E	E	E	AAt
AS	465	1744,315	30	20	10	40	A	G	A	C	C	D	
AS	466	1750,195	30	20	20	30	A	G	A	D	A	C	
AS	467	1748,754	40	10	20	30	A	G	A	E	C	D	
AS	468	1750,215	60	10	10	20	A	E	A	E	A	D	
AS	469	1751,114	30	30	10	30	A	H	A	F	D	G	
AS	470	1757,376	40	20	10	30	A	G	A	E	D	G	
AS	471	1758,544	40	25	25	10	A	I	A	F	F	F	
AS	476	1822,475	20	25	15	40	A	H	A	F	C	G	
AS	477	1809,423	5	20	15	60	A	G	A	E	A	E	
AS	478	1799,205	0	20	0	80	A	I	A	E	A	F	
AS	479	1741,204	5	30	5	60	A	H	A	A	A	D	
AS	480	1737,172	30	40	15	15	A	H	A	F	F	G	
AS	481	1731,031	15	10	20	55	A	G	A	A	C	E	

AreaCode	Snowbed_GIS	Altitude	Rocks	ScreeCoarse	ScreeSoil	Plantcover	PopulationAAt	PopulationACl	PopulationACa	PopulationGHo	PopulationSSt	PopulationSAt	Comment
RA	1201	1873,84	20	5	5	70	A	H	A	D	D	D	
RA	1202	1875,494	20	10	20	50	A	G	A	A	A	A	
RA	1203	1879,2	10	10	20	60	A	G	A	D	A	A	!
RA	1204	1854,265	40	45	10	5	A	F	A	A	D	A	
RA	1205	1858,802	35	35	15	15	A	H	E	E	E	E	
RA	1206	1855,988	40	25	20	15	A	H	A	G	E	C	
RA	1207	1854,217	60	20	5	15	A	G	A	F	B	D	
RA	1208	1856,589	20	35	35	10	A	J	A	H	G	F	
RA	1209	1860,349	5	30	35	30	A	I	A	G	G	F	
RA	1210	1868,397	0	25	50	25	A	I	A	H	F	F	
RA	1211	1881,131	10	50	15	25	A	G	A	D	D	D	
RA	1212	1867,25	20	20	30	30	A	G	A	D	A	C	
RA	1213	1875,615	65	17	15	3	A	G	A	A	F	B	
RA	1214	1878,97	20	50	10	20	A	F	A	D	E	B	
RA	1215	1885,58	35	35	15	10	A	H	A	F	F	F	
RA	1216	1874,728	40	45	10	3	A	F	A	E	F	E	
RA	1217	1882,143	40	42	15	3	A	D	A	A	E	E	
RA	1218	1873,241	30	30	15	25	A	G	A	A	D	A	
RA	1219	1871,621	60	15	10	25	A	A	A	A	E	A	
RA	1220	1860,264	10	15	5	70	A	G	A	A	A	A	
RA	1221	1853,547	30	10	25	35	A	G	A	A	D	A	
RA	1222	1851,743	0	30	10	60	A	G	A	D	B	A	
RA	1223	1857,399	45	10	20	25	A	G	A	E	E	E	
RA	1224	1856,974	25	10	30	35	A	G	A	E	A	A	
RA	1226	1884,689	15	30	35	20	I	I	G	H	G	H	
RA	1227	1878,553	5	15	40	40	A	I	A	E	E	F	
RA	1229	1885,487	30	5	20	45	A	G	A	C	D	B	
RA	1230	1895,312					B	H	D	D	F	E	
RA	1231	1884,884	30	35	30	5	E	J	G	G	H	G	AAt
RA	1232	1889,234	10	60	20	10	A	I	A	E	E	A	
RA	1233	1883,311	5	40	25	30	A	I	A	F	D	D	
RA	1234	1894,374	10	20	55	15	G	J	G	I	F	G	
RA	1235	1885,545	15	40	40	5	F	I	E	G	E	E	
RA	1236	1882,259	5	30	50	15	A	J	D	I	D	E	
RA	1237	1915,521	10	30	30	30	A	I	A	H	A	H	
RA	1238	1897,55	20	40	38	2	D	J	F	H	F	F	
RA	1239	1905,171	15	70	10	5	E	J	E	G	F	F	
RA	1240	1902,552	40	35	20	5	A	J	F	I	G	H	
RA	1241	1898,953	20	50	15	15	A	E	A	A	A	A	
RA	1242	1892,191	20	45	30	5	A	C	B	A	D	D	
RA	1243	1910,837	30	40	35	5	A	I	E	F	G	G	
RA	1244	1883,602	40	40	17	3	G	J	F	J	I	J	
RA	1245	1888,57	10	40	50	2	G	J	G	I	G	J	
RA	1246	1864,434	10	50	30	10	A	H	A	G	A	G	
RA	1247	1858,491	20	45	30	5	A	J	E	G	G	H	
RA	1248	1882,63	5	10	35	40	E	J	F	G	F	I	
RA	1249	1922,777	35	15	15	35	A	H	A	F	D	E	
RA	1250	1921,757	40	30	10	20	A	I	D	E	F	E	
RA	1251	1917,587	30	55	10	5	A	G	D	A	F	E	
RA	1252	1887,896	10	40	30	20	A	G	A	E	D	F	
RA	1253		30	40	25	5	F	J	G	G	H	H	-
SA	1601	1861,649	0	10	15	75	A	H	A	E	E	E	
SA	1602	1870,884	10	45	20	25	A	I	A	E	E	G	
SA	1603	1833	15	60	15	10	A	I	A	G	E	G	
SA	1604	1849,466	10	50	20	20	A	F	A	D	C	E	
SA	1605	1832,566	15	60	15	10	A	I	A	H	E	H	AAt
SA	1606	1829,024					A	J	A	G	E	G	-
SA	1607	1750,001	0	50	20	30	A	I	A	G	D	C	AAt
SA	1608	1768,257	30	25	15	30	A	I	A	F	B	D	
SA	1609	1762,422	50	10	20	20	A	G	A	E	D	A	

AreaCode	Snowbed_GIS	Altitude	Rocks	ScreeCoarse	ScreeSoil	Plantcover	PopulationAAt	PopulationACl	PopulationACa	PopulationGHo	PopulationSSt	PopulationSAt	Comment
SA	1610	1752,546	30	20	15	35	A	F	A	E	C	A	
SA	1611	1780,771	0	20	10	70	A	G	A	C	B	E	
SA	1612	1776,409	25	40	15	20	A	I	A	C	E	F	AAt
SA	1613	1786,961	15	35	20	30	A	I	A	D	E	F	
SA	1615	1797,494	10	50	20	20	A	I	A	G	E	G	-
SA	1616	1786,028	20	45	25	10	A	I	A	F	F	G	AAt
SA	1617	1789,092	5	75	10	10	A	G	A	C	E	F	
SA	1618	1780,392	20	50	15	15	A	H	A	F	E	G	
SA	1619	1753,718	10	45	20	25	A	G	A	E	C	E	
SA	1620	1741,468	10	75	10	5	A	E	A	A	A	A	
SA	1621	1776,198	10	30	30	30	A	I	A	G	E	F	
SA	1622	1804,639	20	35	15	30	A	I	A	E	C	F	
SA	1623	1818,481					A	I	A	F	F	F	
SA	1624	1833,868	10	20	20	50	A	H	A	G	D	F	
SA	1625	1815,681	10	45	15	30	A	I	A	F	E	E	
SA	1626	1845,2	10	30	20	40	A	H	A	E	C	G	
SA	1627	1826,65	5	20	25	50	A	H	A	E	D	G	
SA	1629	1807,004	10	40	40	10	A	J	A	G	D	E	
SA	1630	1808,937	10	40	25	25	A	G	A	E	D	E	
SA	1634	1820,261	10	40	25	25	A	G	A	E	D	G	
SA	1635	1829,778	25	40	15	20	A	H	A	G	F	H	
SA	1637	1786,243	15	30	30	25	A	H	A	F	D	H	
SA	1638	1787,93	20	30	25	15	A	G	A	F	F	G	
SA	1639	1781,984	35	30	20	15	A	H	A	F	E	G	
SA	1645	1782,335	20	50	15	15	A	F	A	E	C	B	
SA	1646	1782,496	15	20	20	35	A	F	A	B	E	E	
SA	1647	1789,638	40	35	15	10	A	H	A	A	E	F	
SA	1648	1783,415	70	10	10	10	A	D	A	A	A	D	
SA	1649	1814,497	30	30	20	20	A	E	A	D	B	F	
SA	1650	1800,632	30	30	15	25	A	E	A	A	A	E	
SB	1101	1976,639	15	45	25	15	A	J	A	A	F	G	
SB	1102	1963,623	35	20	20	25	A	H	A	A	F	D	
SB	1104	1957,821	35	20	35	10	A	A	A	A	A	A	
SB	1105	1955,948	0	15	10	75	A	I	A	A	C	E	
SB	1106	1926,419	15	15	35	35	E	J	A	H	H	I	
SB	1107	1905,397	20	15	15	50	C	I	A	E	G	F	
SB	1108	1908,228	60	20	10	10	A	A	A	A	F	A	
SB	1110	1909,222	30	20	10	50	A	H	A	E	A	D	
SB	1111	1881,534	10	10	10	70	A	H	A	A	C	C	
SB	1112	1889,034	20	10	10	60	D	H	A	A	A	A	AAt
SB	1113	1835,246	30	20	30	20	A	A	A	A	A	A	
SB	1114	1833,508	10	35	40	15	G	A	A	A	G	G	
SB	1115	1824,382	20	20	45	15	D	E	A	B	D	E	
SB	1116	1821,196	0	20	60	20	A	A	A	A	D	D	
SB	1117	1857,217	20	25	5	50	F	J	A	D	D	D	
SB	1118	1876,328	10	10	40	40	H	J	A	F	F	E	
SB	1119	1914,354	20	20	55	5	G	H	F	C	G	F	
SB	1120	1809,451	5	30	15	50	E	G	A	E	E	E	
SB	1121	1763,88	20	40	35	3	F	H	A	A	G	E	
SB	1122	1797,638	30	20	20	30	A	J	A	A	E	B	
SB	1123	1856,581	30	20	15	35	E	J	A	F	E	F	
SB	1124	1864,864	30	40	15	15	D	J	A	F	F	E	
SB	1125	1867,779	35	35	25	5	E	A	A	A	G	F	
SB	1126	1889,662	40	30	27	3	G	I	A	H	G	G	
SB	1127	1919,65	5	5	20	70	D	H	A	D	C	D	
SB	1128	1830,758	40	40	15	5	G	J	A	G	H	G	
SB	1129	1831,981	35	30	30	5	E	G	A	F	G	F	
SB	1130	1863,188	30	30	40	3	G	I	D	G	H	F	

Table 2: Species recorded in 2018

AreaCode	Snowbed_GIS	Altitude	Rocks	ScreeCoarse	ScreeSoil	Plantcover	PopulationAAt	PopulationACl	PopulationACa	PopulationGH	PopulationSSt	PopulationSAt	Comment
AS	401	1876,618	44	5	10	50	A	E	A	A	A	A	
AS	402	1877,552	0	0	0	0	A	A	A	A	A	A	x
AS	403	1877,903	20	2	5	73	A	E	A	A	A	A	
AS	404	1878,017	0	0	0	0	A	A	A	A	A	A	x
AS	405	1883,59	15	20	5	60	C	C	A	B	A	B	
AS	406	1887,175	2	6	0	95	A	F	B	A	A	A	x
AS	407	1883,494	30	20	10	50	A	A	A	A	A	A	x
AS	408	1847,368	20	10	5	65	B	H	B	A	A	B	
AS	409	1830,389	30	22	5	70	A	G	A	A	A	A	ACa
AS	410	1821,857	1	10	30	85	A	F	A	A	A	A	
AS	411	1817,199	10	80	40	80	A	D	A	C	A	D	
AS	412	1844,663	10	40	50	45	A	J	A	B	A	F	
AS	413	1833,232	10	30	20	40	A	H	A	A	A	E	
AS	414	1811,21	20	20	1	59	A	G	A	A	A	A	
AS	415	1807,982	20	17	3	60	A	F	A	A	A	D	
AS	416	1801,44	40	10	0	50	A	E	B	C	A	A	ACa
AS	417	1802,01	40	20	0	40	A	E	B	A	A	A	
AS	418	1802,253	15	20	20	45	A	E	A	C	A	D	
AS	419	1804,531	15	10	0	75	A	F	A	A	A	D	
AS	420	1799,878	35	10	5	50	A	C	A	B	A	A	
AS	421	1824,996	30	30	10	30	A	H	A	B	A	D	
AS	422	1829,058	7	78	10	5	A	E	A	D	A	E	
AS	429	1769,286	2	0	0	98	A	F	A	A	A	A	D
AS	430	1798,918	30	30	10	30	A	G	A	B	B	E	
AS	433	1786,201	0	0	0	0	A	A	A	A	A	A	x
AS	434	1769,841	0	0	0	0	A	A	A	A	A	A	D
AS	435	1764,122	0	0	0	0	A	A	A	A	A	A	D
AS	436	1750,708	3	72	0	25	A	G	C	A	A	B	
AS	437	1701,95	30	30	15	25	A	A	A	A	A	A	
AS	438	1688,515	0	0	0	0	A	A	A	A	A	A	
AS	439	1664,141	18	70	5	7	A	E	C	A	A	A	ACa
AS	440	1654,755	60	20	10	10	A	C	A	A	A	A	
AS	441	1664,189	30	20	10	40	A	D	C	A	A	B	ACa
AS	442	1651,432	50	20	0	30	A	G	A	A	A	A	
AS	445	1697,732	10	60	5	30	A	D	A	A	A	A	D
AS	447	1714,616	30	8	12	50	A	G	A	D	A	F	
AS	449	1711,92	15	30	10	45	A	F	A	B	C	D	
AS	451	1715,604	5	30	10	55	A	G	A	B	A	C	
AS	452	1729,014	0	0	0	0	A	A	A	A	A	A	x
AS	453	1758,361	0	0	0	0	A	G	A	A	A	A	x
AS	454	1740,13	0	0	0	0	A	G	A	A	A	A	x
AS	457	1765,516	0	0	0	0	A	G	A	A	A	A	x
AS	459	1775,31	10	30	20	40	A	G	A	A	A	B	
AS	460	1732,823	10	50	5	35	A	F	A	B	A	B	
AS	461	1731,522	10	40	15	35	A	F	A	B	A	B	
AS	464	1740,156	7	50	0	43	A	D	A	A	A	A	
AS	465	1744,315	2	50	0	48	A	D	A	A	A	B	
AS	466	1750,195	15	60	0	25	A	E	A	A	A	A	
AS	467	1746,754	20	15	5	60	A	E	B	A	A	A	t
AS	468	1750,215	20	30	0	50	A	D	A	A	A	A	t
AS	469	1751,114	30	30	10	30	A	E	B	A	A	C	
AS	470	1757,376	33	33	0	33	A	D	B	A	A	C	
AS	471	1758,544	30	30	10	30	C	F	D	A	C	D	
AS	476	1822,475	25	40	5	30	B	F	B	A	A	D	
AS	477	1809,423	6	24	0	70	A	E	A	A	A	A	
AS	478	1799,205	20	30	10	40	A	F	B	A	A	A	
AS	479	1741,204	5	40	5	50	A	F	B	A	A	A	ACa
AS	480	1737,172	50	20	10	30	A	E	B	A	E	D	
AS	481	1731,031	10	15	5	70	A	F	A	A	A	A	

AreaCode	Snowbed_GIS	Altitude	Rocks	ScreeCoarse	ScreeSoil	Plantcover	PopulationAAt	PopulationACl	PopulationACa	PopulationGH	PopulationSSt	PopulationSAt	Comment
RA	1201	1873,84	0	5	0	95	A	E	C	A	A	A	
RA	1202	1875,494	5	5	0	90	A	E	A	A	A	A	
RA	1203	1879,2	15	7	0	78	A	E	A	C	A	A	
RA	1204	1854,265	10	25	0	65	A	F	A	A	C	A	
RA	1205	1858,802	25	15	5	55	A	E	A	D	C	A	
RA	1206	1855,988	25	50	10	15	A	F	A	E	C	A	
RA	1207	1854,217	30	30	10	30	A	E	A	A	A	A	
RA	1208	1856,589	15	30	20	35	A	G	C	D	D	A	ACa
RA	1209	1860,349	10	50	10	30	A	F	A	A	E	C	
RA	1210	1868,397	5	50	20	25	A	F	A	C	F	D	x
RA	1211	1881,131	40	30	20	10	A	D	A	A	C	A	
RA	1212	1867,25	10	45	5	40	A	F	A	A	B	D	
RA	1213	1875,615	0	0	0	0	A	A	A	A	A	A	x
RA	1214	1878,97	0	0	0	0	A	A	A	A	A	A	x
RA	1215	1885,58	10	20	10	60	A	F	A	D	D	A	
RA	1216	1874,728	40	30	10	20	A	D	A	A	D	A	
RA	1217	1882,143	2	70	8	20	A	A	A	A	B	A	x
RA	1218	1873,241	2	38	10	50	A	A	A	A	B	A	
RA	1219	1871,621	20	60	0	20	A	D	A	C	D	A	
RA	1220	1860,264	10	10	0	80	A	D	A	A	C	A	
RA	1221	1853,547	7	8	0	85	A	F	A	A	B	A	
RA	1222	1851,743	2	11	7	80	A	E	A	A	A	A	
RA	1223	1857,399	30	30	0	50	A	D	A	A	B	A	
RA	1224	1856,974	50	40	0	55	A	D	A	B	C	A	
RA	1226	1884,689	20	60	0	30	A	G	A	E	F	F	
RA	1227	1878,553	0	5	5	90	A	E	A	D	A	C	
RA	1229	1885,487	0	10	0	90	A	E	A	A	A	A	
RA	1230	1895,312	20	60	10	10	A	E	A	C	F	D	
RA	1231	1884,884	5	25	60	10	A	F	A	D	G	F	
RA	1232	1889,234	20	30	15	35	A	E	A	B	C	C	
RA	1233	1883,311	2	46	2	50	A	F	A	E	C	A	
RA	1234	1894,374	30	40	20	10	C	G	A	F	G	E	
RA	1235	1885,545	30	30	25	15	F	F	A	E	E	B	ACaAAt
RA	1236	1882,259	50	30	25	40	C	F	A	E	C	A	
RA	1237	1915,521	0,3	10	38	50	A	F	A	E	A	E	
RA	1238	1897,55	20	40	20	20	A	A	A	A	G	C	
RA	1239	1905,171	10	40	30	20	A	F	A	E	D	D	
RA	1240	1902,552	10	70	12	3	A	F	A	A	E	E	x
RA	1241	1898,953	0	90	0	10	A	A	A	A	A	A	0
RA	1242	1892,191	0	0	0	0	A	A	A	A	A	A	x
RA	1243	1910,837	30	60	0	10	A	F	A	C	F	E	
RA	1244	1883,602	35	30	20	15	C	H	B	F	H	F	
RA	1245	1888,57	5	35	30	3	A	G	A	E	G	G	
RA	1246	1864,434	0	0	0	0	A	A	A	A	A	A	x
RA	1247	1858,491	0	0	0	0	A	A	A	A	A	A	na
RA	1248	1882,63	5	20	15	60	A	J	A	F	E	G	
RA	1249	1922,777	20	20	10	50	A	F	A	F	A	D	
RA	1250	1921,757	20	60	10	10	A	D	A	B	G	B	
RA	1251	1917,587	40	30	20	10	A	C	A	B	E	D	
RA	1252	1887,896	10	50	2	38	A	E	A	B	B	D	
RA	1253		35	45	10	10	A	H	D	G	H	F	
SA	1601	1861,649	0	10	0	90	A	G	A	A	A	D	
SA	1602	1870,884	0	35	5	60	A	G	A	D	C	E	
SA	1603	1833	3	64	3	30	A	G	A	C	D	F	
SA	1604	1849,466	30	45	5	20	A	G	A	A	D	E	
SA	1605	1832,566	10	10	70	10	A	F	A	D	F	E	
SA	1606	1829,024	25	50	15	10	A	G	B	E	C	D	ACa x
SA	1607	1750,001	0	0	0	0	A	A	A	A	A	A	x
SA	1608	1768,257	70	20	0	10	A	D	A	A	B	A	

AreaCode	Snowbed_GIS	Altitude	Rocks	ScreeCoarse	ScreeSoil	Plantcover	PopulationAAt	PopulationACl	PopulationACa	PopulationGH	PopulationSSt	PopulationSAt	Comment
SA	1610	1752,546	60	20	0	20	A	D	A	A	B	A	
SA	1611	1780,771	0	0	0	0	A	A	A	A	A	A	x
SA	1612	1778,409	10	40	0	50	A	G	B	A	A	A	ACa
SA	1613	1786,961	?	?	?	?	A	F	B	A	C	B	ACa
SA	1615	1797,494	7	28	5	60	A	G	A	E	C	E	
SA	1616	1786,028	20	38	2	40	B	G	A	E	D	F	ACa
SA	1617	1789,092	10	50	0	40	A	E	A	A	A	B	
SA	1618	1780,392	10	50	0	40	A	F	A	A	C	E	
SA	1619	1753,718	5	50	0	45	A	E	A	A	A	D	
SA	1620	1741,468	0	70	0	30	A	F	A	A	A	C	
SA	1621	1778,198	0	10	0	90	A	G	A	E	B	D	
SA	1622	1804,639	0	0	0	0	A	A	A	A	A	A	x
SA	1623	1818,481	15	32	3	50	A	G	A	C	D	F	
SA	1624	1833,866	0	1	0	99	A	A	A	A	A	A	x
SA	1625	1815,681	1	20	0	79	A	E	A	B	A	D	
SA	1626	1845,2	2	17	1	80	A	D	A	A	A	A	
SA	1627	1826,65	30	1	0	69	A	F	A	E	D	D	
SA	1629	1807,004	2	80	3	15	A	F	A	A	D	A	
SA	1630	1808,937	0	58	2	50	A	F	A	A	B	D	
SA	1634	1820,261	50	80	0	15	A	D	A	A	D	D	
SA	1635	1829,778	10	70	10	10	A	F	A	D	E	F	
SA	1637	1786,243	0	50	30	20	A	G	A	A	A	F	
SA	1638	1787,93	5	45	0	50	A	?	A	A	C	D	
SA	1639	1781,984	2	7	0	91	A	F	B	E	D	A	ACa
SA	1645	1762,335	0	0	0	0	A	A	A	A	A	A	x
SA	1646	1782,496	0	0	0	10000	A	A	A	A	A	A	x
SA	1647	1789,638	30	50	0	20	A	A	A	A	E	A	
SA	1648	1783,415	0	0	0	10000	A	A	A	A	A	A	x
SA	1649	1814,497	0	0	0	10000	A	A	A	A	A	A	x
SA	1650	1800,632	0	0	0	0	A	A	A	A	A	A	x
SB	1101	1976,639	10	20	10	60	B	D	A	A	B	C	z
SB	1102	1963,623	I	I	I	I	I	I	I	I	I	I	z
SB	1104	1957,821	0	10	80	10	A	F	A	A	E	D	
SB	1105	1955,948	0	10	70	20	A	F	A	A	C	B	
SB	1106	1926,419	17	38	15	30	A	F	B	A	B	C	
SB	1107	1905,397	0	0	0	0	A	D	B	A	B	D	
SB	1108	1908,228	30	30	10	50	A	E	A	A	A	D	
SB	1110	1909,222	10	60	5	20	A	B	A	A	A	D	
SB	1111	1881,534	0	10	0	90	A	C	A	A	A	A	
SB	1112	1869,034	1	5	0	94	A	A	A	A	A	A	x
SB	1113	1835,246	70	20	0	91	A	A	A	A	A	A	x
SB	1114	1833,508	5	15	65	15	A	A	A	A	G	E	
SB	1115	1824,382	10	20	60	10	A	D	A	A	B	B	
SB	1116	1821,196	10	29	30	40		A	A	A	D	E	
SB	1117	1857,217	5	10	2	83	A	F	A	B	B	D	x
SB	1118	1876,328	2	5	15	78	A	D	A	B	B	D	t
SB	1119	1914,354	10	40	40	10	B	D	C	A	F	D	
SB	1120	1809,451	2	20	0	78	A	F	A	B	A	A	x
SB	1121	1763,86	30	30	25	15	B	E	A	A	E	D	
SB	1122	1797,636	2	7	2	89	C	F	A	A	C	A	x
SB	1123	1856,581	5	14	1	80	B	E	A	C	A	C	
SB	1124	1864,864	30	30	20	20	A	B	A	C	F	F	z
SB	1125	1867,779	0	0	0	0	A	A	A	A	A	A	x z
SB	1126	1869,662	10	50	20	30	D	F	A	A	F	E	
SB	1127	1919,65	2	3	5	90	A	D	A	A	B	A	D
SB	1128	1830,758	2	73	10	15	A	H	A	E	F	F	
SB	1129	1831,981	65	20	5	10	E	D	A	C	F	F	
SB	1130	1863,188	20	30	40	40	C	F	A	F	H	G	ACa

Legend

AreaCode = Mountains	
AS	Aflenzer Staritzen
SB	Schneeberg
RA	Rax
SA	Schneealpe

Population species code	
PopulationAAt	Individuals of *Achillea atrat*a in the snowbed
PopulationACl	Individuals of *Achillea clusiana* in the snowbed
PopulationACa	Individuals of *Arabis caerulea* in the snowbed
PopulationGho	Individuals of *Gnaphalium hoppeanum* in the snowbed
PopulationSSt	Individuals of *Saxifraga stellaris* in the snowbed
PopulationSAt	Individuals of *Sedum atratum* in the snowbed

Snowbed conditions	
Rocks	Percentage of rocks in the snowbed
ScreeCoarse	Percentage of coarse scree in the snowbed
ScreeSoil	Percentage of soil scree in the snowbed
Plantcover	Percentage of plant cover in the snowbed

Comments	
x	snowbed extinguished or overgrown
z	two nearby snowbeds grown together
t	grazed by mammalians
D	overgrown by *Deschampsia cespisota*
AAt	unsteady if the species is *Achillea atrat*a
ACl	unsteady the species is *Achillea clusiana*