University of South-Eastern Norway
Faculty of Technology, Natural Sciences and Maritime Sciences
–
Master's Thesis
Natural Sciences and Environmental Health
Autumn 2019

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Analysis of shrub- and lichen-dominated vegetation types at Imingfjell

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This thesis is worth 60 study points
Front page: Picture from the study site at Imingfjell, taken during the field season the summer of 2018.

Abstract

Climate change can have a large impact on the vegetation composition in alpine areas. Lichen heaths are particularly vulnerable, among others because these are threatened by expanding shrub species like *B. nana.* Imingfjell in southern Norway is an area with a high density of lichen dominated vegetation.

This thesis examines the variation in composition and albedo in lichen- and shrub-dominated vegetation at Imingfjell. The study is a support to the PhD-project of Peter Aartsma, who investigates if lichen vegetation can have an impact on its direct environments. This master thesis has studied the vegetation plots from the PhD-project and compared the vegetation composition and albedo of these to plots in the surrounding area, in order to see if the plots in the PhD-project are representative for lichen- and shrub-dominated vegetation at Imingfjell.

In total, this study includes 74 plots, whereof 40 in zone 1 (0-200 meters from a local road) and 34 in zone 2 (200-1500 meters from the road). All the 20 plots in the PhD-project are located within zone 1, together with 20 plots from this MSc study. The plots are always coupled; one lichen plot always has a corresponding shrub plot. The cover percentage for the vegetation layers and each species is registered. In addition, albedo is measured at all plots within zone 1, always one shrub- and one lichen-dominated plot at the same time.

As expected, the results show a difference in composition between the vegetation dominated by lichen and shrub. The lichen-dominated vegetation shows no significant difference within zone 1. Further comparison of the plots in zone 1 to the plots in zone 2 shows significant difference in both composition and within specific species. Some of the difference can be explained by a higher density of exposed ridges near the road. For shrub-dominated vegetation, the same trends are found.

From the albedo data, a significant difference is found between the lichen- and shrub-dominated vegetation. Within the lichen vegetation, no difference was detected, whereas the shrub-dominated vegetation showed a difference between the PhD study plots and the MSc study plots.

With ongoing climate change, it is important to monitor the development of vulnerable alpine vegetation. This thesis, with its relation to the PhD-project, can be seen as a contribution to this research.

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Preface

Five years of studies in Bø in Telemark has now come to an end. This master thesis is the final assignment on the master study program.
I would like to thank my supervisors Stefanie Reinhardt and Hans Renssen for sharing of your knowledge and providing a lot of good feedback. Thank you for being patient with me.
A big thank you also goes to Peter Aartsma, for letting me in on this project, and for good cooperation, especially during the field season at Imingfjell.
Last, but not least, thank you Sunniva and Nansen for being there and supporting me every day through the work on this thesis.

15. November 2019, Oksfjordhamn
Kristine Hetlesæter

1 Introduction

1.1 Climate change and alpine ecosystems

Human-induced global warming is affecting ecosystems all over the world. Alpine and arctic ecosystems are particularly vulnerable (e.g. Callaghan & Jonasson 1995; Guisan *et al*. 1995; Körner 1995). Rising temperatures and the resulting local changes in environmental conditions are expected to alter vegetation productivity, composition and structure (Junchang & Masek, 2016). One of the vegetation types that are especially threatened is alpine lichen heath, which in general is decreasing in range (Joly et al., 2009). Due to these ongoing and accelerating processes, it is urgently required to do more research on the impact of climate change on alpine vegetation ecology, and lichens more particularly. As a contribution to this, my master project investigates the shrub and lichen dominated vegetation in the Imingfjell area in Southern Norway.

1.2 Climate change

Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels (Intergovernmental Panel on Climate Change [IPCC], 2018), and an additional increase of 1.5°C between 2030 and 2052 is expected (ibid.). This warming is predicted to be particularly pronounced at high latitudes (Serreze & Barry, 2011, Heggberget et al., 2002).
In Norway, 57°-71°N, the annual mean temperature is expected to increase by 2.3 – 4.6°C until 2100, with largest temperature increases during the winter months, and an increase in precipitation by 5-30% all over the country through all seasons. Also, the frequency of extreme precipitation events will increase, and more periods of drought are expected during summer in southern and eastern Norway (Hanssen-Bauer et al., 2015, Aarrestad et al., 2015).

Climate can be defined at different scales. Climate at large scale, the macroclimate, is the most common understanding of the term. But climate exists also in smaller scales, as the local climate at particular places. This is strongly determined by local conditions, such as the angle of slope, facing direction, and location considering wind conditions. In this way, the terrain has an impact on the amount of solar radiation, light, temperature and moisture vegetation receives. The local climate therefore differs substantially from the macroclimate (Moen, 1999). This is of great significance for vegetation in alpine areas, where the microenvironments can overrule the macroclimate during sunshine hours (Körner, 2003).

1.3 Alpine vegetation ecology – characteristics

Alpine areas are located above the tree line, and alpine vegetation is well adapted to the limiting environmental conditions in mountainous areas. The climatic conditions for alpine vegetation are mainly dependent on the following three components: solar radiation, slope and exposure, and plant stature (Körner, 2003). Other important factors are wind velocity, ambient air temperature over the vegetation and soil properties. Snow conditions also play a significant role for determination of the plant cover in the mountains. Wind contributes to distribution of snow in the terrain, which gives large variation in the snow depth over small distances.

Considering a typical alpine terrain, exposed ridges are among the most challenging environments for vegetation growth. Lichen heaths in the low alpine zone are mainly growing on exposed ridges which due to wind exposure either lack or have a thin and unstable snow cover during most of the winter (Fremstad, 1997, Forsgren et al., 2015). The species composing these vegetation types are more or less chionophobous, and can handle large variation in temperature through the year; very low winter temperatures and strong warming during summer. The limiting effect of frost on vascular vegetation often results in establishment of lichen species, like *Flavocetraria nivalis and Alectoria ochroleuca* (Stoutjedijk & Barkman, 2014). However, frost tolerant vascular plant species like *Loiseleuria procumbens* and *Arctous alpinus* can also be found at the most exposed ridges.

Shrub species, like *Betula nana* and *Juniperus communis*, can also grow on alpine ridges, but they are sensitive to frost, and demand a more stabile snow cover during winter (Fremstad, 1997). They are therefore more often found at smaller ridges, hills and slight slopes in the terrain. Together with vegetation dominated by *B. nana* or *J. communis*, other shrub species and a few graminoid and herbaceous species are present. The ground layer is dominated by mosses or lichens (ibid.).

1.4 Climate changes' impact on alpine vegetation

The change in climatic conditions has significant effects on alpine plant ecology. With an average rise in temperature over the year, snow melt will occur earlier in the spring, which results in prolonged growing seasons. Growing seasons in Norway are predicted to increase with 1-3 months until 2100 (Hanssen-Bauer et al., 2009). A consequence of elevated temperatures and a longer growing season are altitudinal upwards shift of the low-, mid- and high alpine zones. More species advance in altitude, resulting in harder competition for the well-established and adapted plants at higher altitudes. For some species already growing at mountain summits there might be no possibility to move further up, and they might be outcompeted by the new species (Grabherr et al. 1994, Steinbauer et al. 2018). In Norway, Odland et al. (2010) found an increase in taxa richness of 90.2% when they resampled 13 mountain summits after 40 years. They also found that the plant cover had become more homogenous, as more common species colonized the summits, outcompeting the specialized species (ibid.).

Lichen dominated heath is one of the most vulnerable vegetation types in circumpolar regions (Bjerke 2011). Increasing summer temperatures will lead to an increase in the amount of vascular plants and mosses, at the expense of the lichens in these areas. In addition, the lichens are facing challenges with more unstable winters. The lichens are very frost tolerant, but when they are encapsulated by ice, respiration is reduced, which will cause damage (ibid.). Climate change causes fluctuating temperatures and unstable snow cover during winter, which will lead to ice encapsulation on the vegetation in mountainous areas due to repeated melting and freezing processes. Intact lichen mats have a higher resistance against the establishment of vascular plants, compared to already fragmented lichen mats (Forsgren et al., 2015).

One well-documented major change in vegetation is the expansion of shrubs into the arctic and alpine areas, often described as shrubification (e.g. Odland et al., 2010, Heggberget et al, 2002). High-latitude tundra is particularly at risk of climate change-induced degradation and loss, with woody shrubs encroaching into those areas (IPCC, 2018). The biomass of *B. nana* and *E. nigrum* in particular is predicted to increase (Kullman, 2010, Heggeberget et al., 2002). The shrubs are taking advantage of the changing environmental conditions, like a change in snow distribution and higher winter temperatures, which gives less days with frozen soil. The longer growing season and warmer summers are also of significant advantage for shrub vegetation (Hallinger et al., 2010). It is possible that shrubs could become the most dominant vegetation type in areas earlier dominated by lichen.

When the range of shrub-dominated vegetation increases at the cost of lichen, the surface turns from light to darker colors, with the consequence that less of the sun radiation is reflected. The albedo of lichen cover has been measured to be markedly higher (0.31) than for other, green vegetation (0.20) (Peltoniemi et al., 2010). This may result in lower soil temperatures below lichen cover than below other vegetation. A decrease in lichen cover is therefore likely to result in an increase in soil temperatures due to a higher absorption of solar radiation, which works as a positive feedback to global warming.

In order to understand, and be able to forecast, mechanisms and changes in vegetation patterns and biodiversity, it is important to continue the research on vegetation responses to climate change. This is in particular important for many alpine plant communities, which are very sensitive to the ongoing changes.

Research on lichen communities is of extra importance for Norway, because the only wild reindeer (*Rangifer tarandus*) in Fennoscandia are found here. Norway therefore has an international responsibility for managing these animals in a sustainable way. Overgrazing of lichens may easily happen at high reindeer densities, which can have long-term effects due to lichens' slow regeneration rate (Heggeberget et al. 2002). This also has consequences for the reindeer themselves, which are dependent on lichen as the main constituent of their winter diet (ibid.).

My master project is a support to the PhD project of Peter Aartsma, who investigates the impact of lichens on local climatic conditions. One of the aims of his project is to quantify the differences in local climate conditions between lichen and shrub vegetation. The variables in focus are albedo, soil temperature, soil moisture and soil heat flux. To strengthen the PhD project, it is needed to investigate the vegetation composition in a larger number of plots, and also over an extended area.

1.5 Aim of the project

The main aim for my master project is therefore to investigate if the plots investigated in the PhD project are representative for the lichen and shrub vegetation in a larger area on Imingfjell, and to have a look at the variation in albedo within the two vegetation types. Based on this, there are three research questions I will investigate:

-1. What is the variation in vegetation in lichen- and shrub-dominated plots at Imingfjell?

-2. What is the variation in albedo in lichen- and shrub-dominated plots at Imingfjell?

-3. Is there a relationship between vegetation composition and albedo in the lichen heath- and shrub-dominated vegetation at Imingfjell?

2 Material and methods

2.1 Study area

Imingfjell is a mountainous area located in Buskerud county in south eastern Norway, at 60°1´N, 8°34´E (Figure 1). The area is chosen because of its high amount of large uniform patches of lichen, its good accessibility, and also because of good experience of other fieldwork done in this area by the Department of Natural Sciences and Environmental Health (INHM) at the University of South-Eastern Norway (Odland & Munkejord, 2008; Odland et. al., 2015; Sundstøl & Odland, 2017). The elevation of the study area ranges from 1133 to 1207 m a.s.l.. The bedrock mainly consists of the nutrient poor rock metarhyolite. Towards the outer border of the study area, it consists of nutrient rich gabbro and amphibolite (Geological Survey of Norway [NGU], 2019a). The bedrock is covered by a relatively thick layer of moraine material (NGU, 2019b).

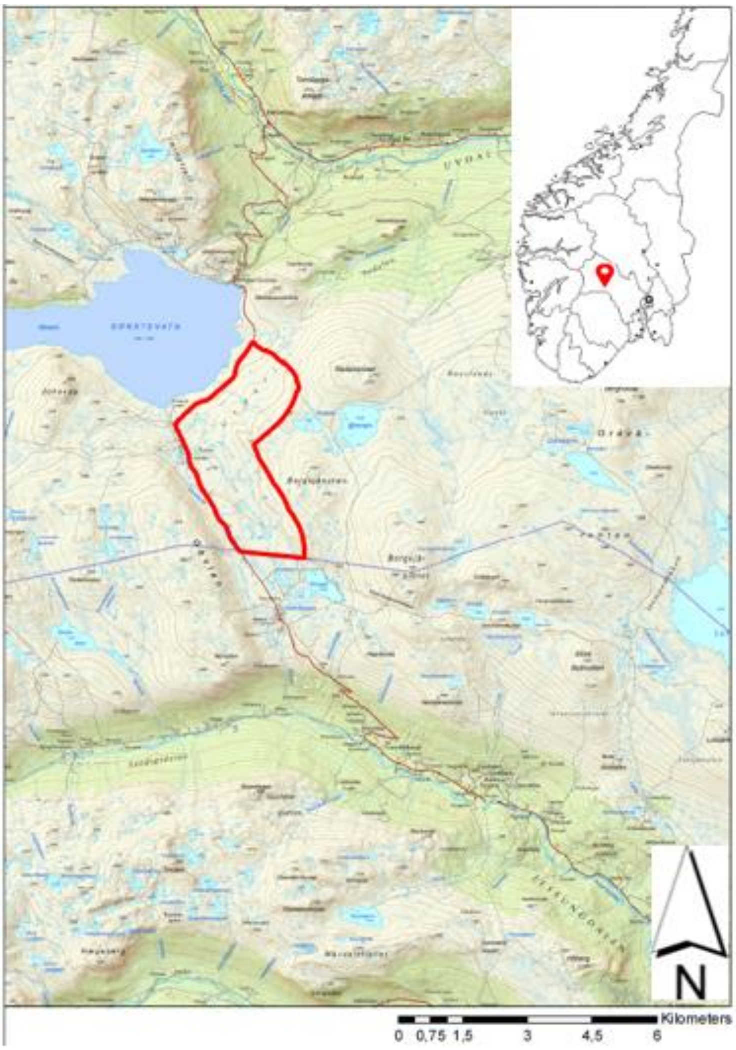

Figure1: The study site (within the red line) in the Imingfjell area, and its location in Norway (Norgeskart, 2018)

The nearby weather station at Dagali measured a yearly average amount of 550 mm of precipitation per year in the reference period 1961 – 1990 (Førland, 1993). The yearly mean temperature here was in the same period 0.5 °C. For January, the mean temperature was -10 °C, and the mean July temperature was 11 °C (Aune, 1993). The weather contitions in Norway during the field season were abnormal. The summer season (June – August) 2018 had a temperature that was 1,8°C warmer than in the normal period (1961 – 1990). For the eastern parts of the country, the deviation was largest, with 3-4°C warmer than the normal, and Dagali weather station nearby Imingfjell had a deviation of 2.5°C. In addition to the high temperatures, the eastern parts of Norway received very little precipitation, some places only got 40% of the normal (Grinde, Heiberg & Mamen, 2018).

The Imingfjell area is classified within the indifferent vegetation section, which covers most of the central part of southern Norway (Moen, 1999). The indifferent section is characterized by neither being dominated by oceanic nor continental climate. The area is also located in the low alpine vegetation zone, which is altitudinally above the northern boreal zone. The low alpine zone can be characterized by an alternation between alpine ridge, lee-side and snow-patch vegetation (Moen, 1999). Ridge vegetation consists of species that are adapted to low winter temperatures due to thin snow cover and windy conditions. Examples of this are the lichens *F. nivalis* and *A. ochroleuca*, and the vascular plants *L. procumbens* and *A. alpinus*. The leeside juniper- and dwarf birch heath vegetation has a stable, relatively thick snow cover in winter time. Dominating species are *B. nana*, *E. nigrum* and *Cetraria islandica* (Fremstad, 1997). There is a low level of disturbance on the vegetation other than grazing. Grazing by sheep occurs, and this year also some disturbance by reindeer was observed. In addition, there are some footpaths and cabins in the area.

2.2 Study design and field work

The PhD-project includes measurements on ten lichen-, and ten shrub plots. The plots were measured pairwise; one lichen plot always has a corresponding shrub plot within a radius of 50 meters. This means that one sample location represents two different plots. The study site covers an area of approximately 7.5 km^2 on the east side of the road, Fv-124, that crosses the area. The site consists of two zones: zone 1, 0-200 m distance from the road (approx. 0.8 km^2), and zone 2, 200-1500 m distance from the road (approx. 6.7km^2) . Three different groups of plots were investigated within the area. The plots in the PhD project, PhD200 (blue points, Figure 2), were limited to be located within zone 1, due to restrictions from the landowner. In addition to the plots covered by the PhD project, ten plots were established for vegetation analysis within this area (red points, Figure 2). These represent the second plot group; MSc200 (red points, Figure 2). It was also decided that I should analyze as many plots as possible between 200 and 1500 meters from the road (zone 2) within the time of the field season, to increase the validity of the PhD study. This resulted in 17 analyzed plots in this zone; the MSc1500 plots (green points, Figure 2). In total, vegetation analysis was thus performed at 74 plots (for plot coordinates, see appendix 1).

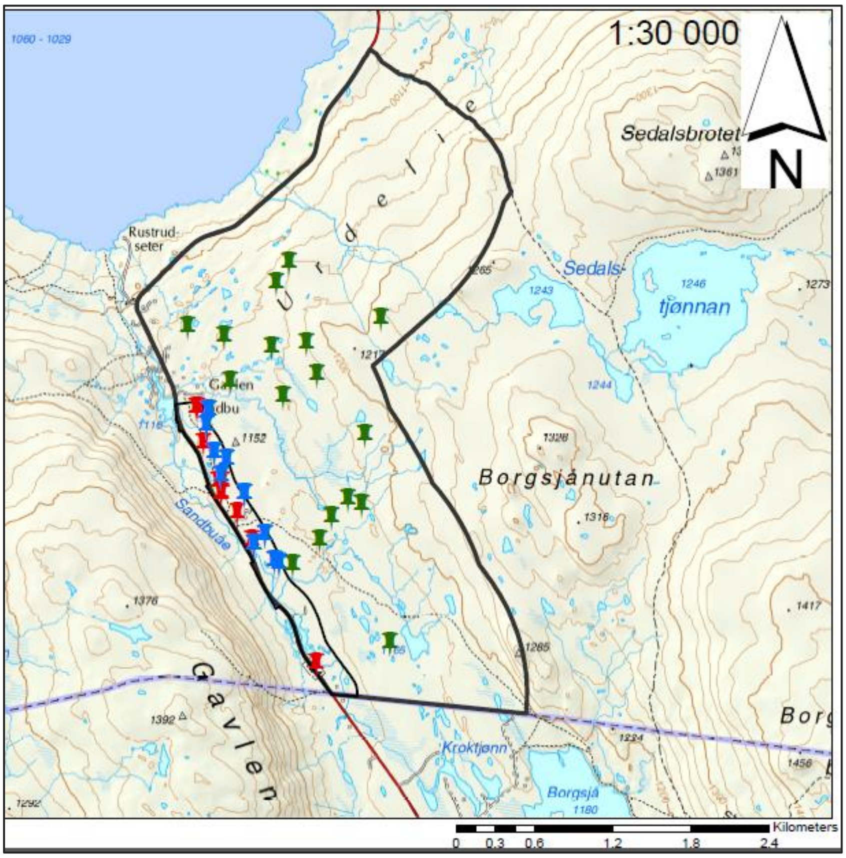

Figure 2: Study site with sample locations. PhD200 (blue) and MSc200 (red) in zone 1. MSc1500 plots (green) in zone 2

To make randomized samples, all large lichen patches in the area were mapped with the software ArcMap, based on aerial photographs from 2016 (Geonorge, 2018). The two zones were established, and 120 random sample points were drawn with the "random sample" tool in the ArcMap software. One sample site always represents two plots; one dominated by lichen and one dominated by shrub vegetation. The high number of samples were made to make sure to have enough in case of having to omit some of the sites. To locate and establish plots in the field, a computer with a map over the sample sites was used.

Since this study compares plots from the PhD project with other plots, it was decided to use the same plot size and determination criteria for both projects. If there was lack of either lichen or shrub plots meeting the criteria, the sample location would be omitted. This was the case for five of the pre-sampled locations. For the determination of suitable plots in the field, the following criteria were established:

Table 1: Criteria for plot determination

Criteria lichen plot:	Criteria shrub plot:
We choose the plot with the highest percentage of light lichens within a radius of 50 meters from the randomly drawn sample location	The plot with the highest percentage of shrubs within 50 meters of the lichen plot
Size: 4 m^2, radius 112 cm	Size: 4 m^2, radius 112 cm
≥ 50% of light lichens	≥ 90% shrubs
< 10% non-vegetation surface	< 10% non-vegetation surface
< 10 degrees slope	< 10 degrees slope
At least 50 meters away from houses	At least 50 meters away from houses
Soil available (no epilithic lichens)	Soil available
No overlap with an already chosen plot	No overlap with an already chosen plot
Undisturbed (i.e. no grazing)	Undisturbed (i.e. no grazing)
	No *Juniper*, no *Salix*
	Aspect within ±10 degrees of the aspect of the lichen plot
	If multiple plots are equally qualified, the one closest to the lichen plot will be chosen

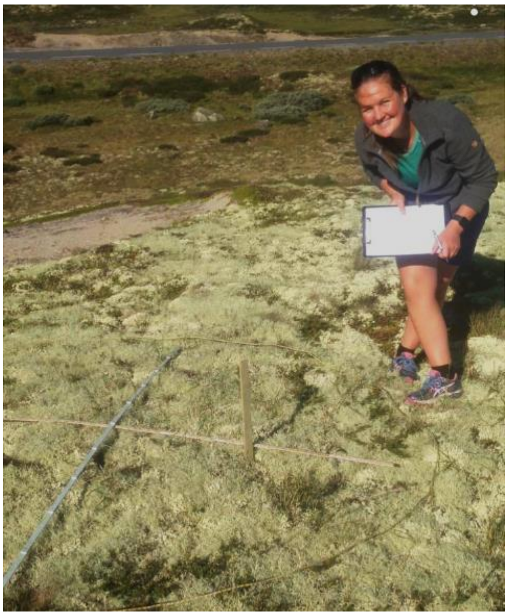

Figure 3: Analysis of a lichen dominated plot

Field work was performed from 7th of July to 5th of August 2018. The data collected for vegetation analysis consist of the following variables; species cover percentages, vegetation layer percentages, coordinates, altitude, slope, aspect and vegetation height (field form for data sampling, see appendix 2). Species nomenclature followed Artsdatabanken (2015) for both vascular plants and lichens. Floristic data were collected as visual estimations of cover percentage (Figure 3). The percentage values were registered in 5%-intervals (5, 10, 15, 25, 30 etc.). If the species were only present with one branch at one site in the plot, it was registered as 1%. If there were more than one specimen, it would be registered as 5%. Vegetation height was measured every 10 centimeters along both a north-south transect and an east-west transect in each plot.

Albedo measurements were implemented at all plots within zone 1. For the plots covered by the PhD project, albedo was one of several variables that was measured over two days at each plot. Data was sampled every five minutes. At the MSc200 plots, the albedo in all plots was measured within two days in the middle of the field season, the 26th and 27th of July. Over this two-day period the equipment was set up in one lichen plot and the related shrub plot at the same time for half an hour of measuring, sampling once per minute.

Two Kipp & Zonen CNR4 net radiometers were used for the albedo measurements. The radiometers measure the four components of the radiation balance: incoming and outgoing shortwave and incoming and outgoing longwave radiation (shortwave: 0.3 to 2.8 µm, longwave: 4.5-42 µm). The albedo is obtained by dividing the outgoing shortwave by the incoming shortwave radiation.

In order to get comparable weather and light conditions, albedo was measured over the lichen- and shrub dominated vegetation at the same time. When placed 30 cm above the ground, the radiometers' measuring range covers a circle with a radius of 112 cm, and an area of approximately 4m^2. This is the reason why all plots were set to be this size. A metal pole with a radiometer was placed inside the plot with a 45 cm distance from the northern border, with the albedo sensor situated over the center of the plot. The distance between the sensor and the vegetation was 30 cm, and the sensor was adjusted to be horizontal (Figure 4). For overview of the setup, see appendix 3.

Cloud cover was estimated at the start and end of each measuring session, because this affects the incoming sun radiation to a plot, and maybe also the albedo. This was registered on a standard scale of oktas from 0/8 to 8/8 (The Norwegian Meteorological Institute, 2017). No data was collected when it was raining, because raindrops cause disturbance on the sensor for incoming radiation.

Figure 4: Setup for albedo measurements at one lichen plot (left) and one shrub plot (right)

2.3 Statistical methods

All statistical testing was conducted in the program R version 3.3.2 (R Development Core Team, 2016). The R-package Vegan, version 2.5-3 was used for ordination (Oksanen et al., 2018). Some of the graphics were produced in Microsoft Excel.

In order to get an overview of the variation in vegetation composition, the ordination method detrended correspondence analysis (DCA) was used. The function of ordination is to compare samples in relation to each other and extract main gradients from the floristic composition in the plots. Differences between the sampling units and species

optima are plotted along axes (gradients), given in standard deviation units (Lepš & Šmilauer 2003). To test for a significant difference in vegetation composition between the three different data sets (PhD200, MSc200 and MSc1500), the plot scores from the DCA-axis 1 were used as variables for further testing. This is because the first axis has the highest eigenvalue, which means that it explains the largest part of the variability of the data (ibid.). The variation in vegetation composition was also determined by comparison of the species richness and -diversity in the three plot groups.
When large groups of data from the plots was going to be analyzed, the data were tested for normality, and statistical test was chosen based on the outcome. When comparing groups consisting of only 10-17 samples, Mann Whitney U-test (MWU) was chosen considering the small sample sizes.

To identify the species that represent the largest differences in the vegetation composition, box plots were created for all species with values ≥20% of cover percentage in one or more plots. These statistics compare species percentages from the three plot groups. The species showing the biggest differences was *F. nivalis, A. ochroleuca, C. stellaris, B. nana* and *E. nigrum.* These were further statistically tested for significant difference between the three plot groups PhD200, MSc200 and MSc1500.

Variation in albedo was analyzed by comparing data from the PhD200 and the MSc200 plots. The albedo data from the PhD200 and the MSc200 plots were collected differently. In order to use comparable data, half-hour measurements from the data sampled in the PhD project was extracted from each two-day series. These were compared to the whole PhD200-dataset to check if representative data was extracted. Further, these data were compared to the half-hour albedo measurements from the MSc200-plots. For the albedo data as for the vegetation data, the datasets were tested for normality, and if the outcome did not meet the assumptions of a normal distribution, MWU-test was chosen. For normally distributed data, two-sample t-test was used. Because a two-sample t-test is a poor choice for relatively small sample sizes (Whitlock and Schluter, 2015), a MWU-test was also here used for the groups consisting of 10-17 samples.

3 Results

3.1 Variation in vegetation composition

The DCA over all plots gives a clear indication of two separated groups - the lichen- and the shrub-dominated vegetation (Figure 5). Statistical testing confirms that the difference in composition is significant (p-value: < 0.01) when comparing the lichen-dominated plots to the shrub-dominated plots. The first axis in the DCA is suggested to represent the transfer from leeside to exposed ridge, and the second axis might be explained as a gradient of moisture. The length of DCA axis 1 is 2.4 units (SD), indicating that there is no total shift of species, even between the two most separate plots.

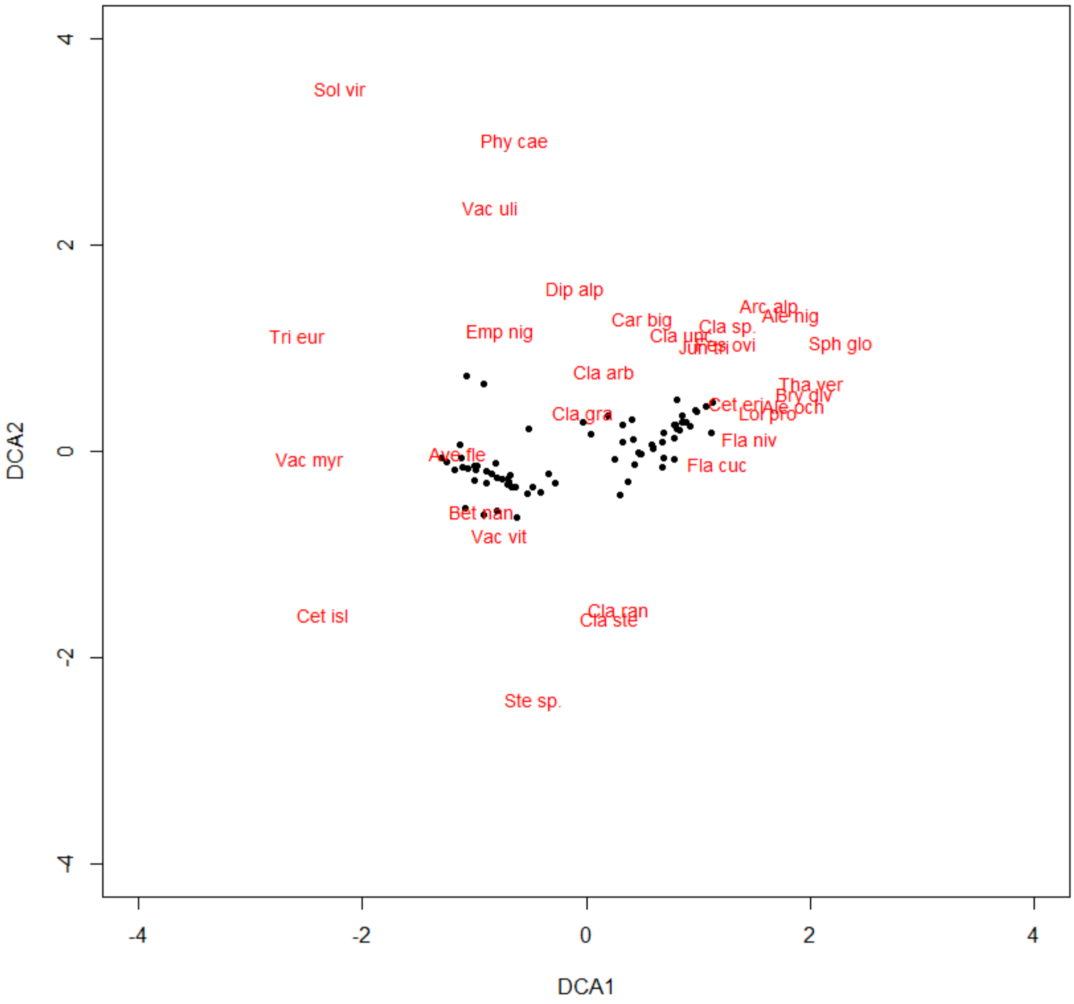

Figure 5: DCA of all plots (black circles) and species in the study. Left cluster: shrub plots. Right cluster: lichen plots. For species abbreviations, see appendix 4.

Further, the variation within each of the two vegetation types was investigated. The lichen vegetation showed no significant difference (p-value: 0.853) between the two groups within 200 meters from the road (PhD200 and MSc200). These two plot groups were therefore merged and used as one group for comparison to the MSc1500 plots. When comparing the lichen-dominated vegetation in the two zones (zone 1: 0-200m and zone 2: 200-1500m), a significant difference was found (p-value: < 0.01). For overview of statistical testing, see table 2. The DCA (Figure 6) shows that the MSc1500 plots are skewed towards the right side of the plot, which can indicate a relation to the *Cladonia* species. Shrub vegetation shows the same pattern, with no significant difference between the PhD200 and MSc200-plots, and significant difference between the shrub plots in zone 1 versus zone 2. Figure 7 shows that the MSc1500-plots are skewed towards the left side of the DCA-plot, where we also find the species *E. nigrum* and *Vaccinium myrtillus*.

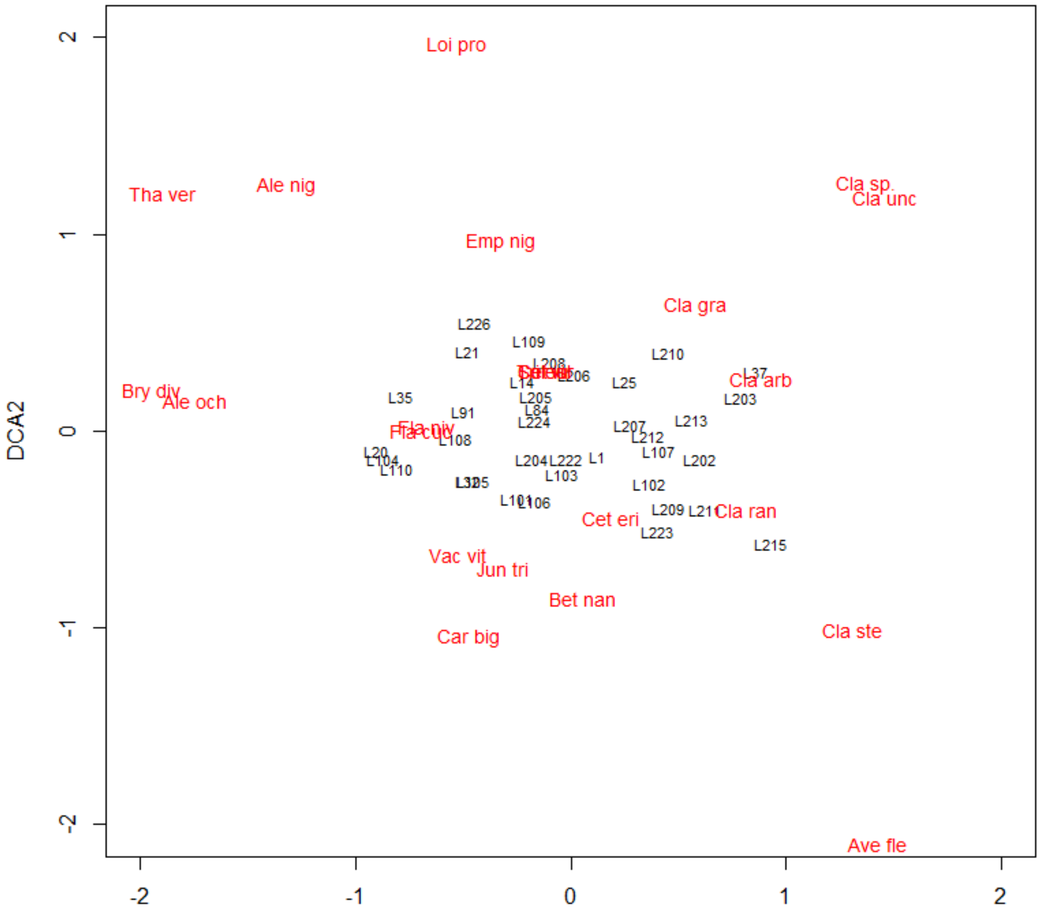

Figure 6: DCA of all lichen-dominated plots (black labels) and species (red labels). Labels: PhD200-plots: "Lxx", MSc200-plots: "L1xx", MSc1500-plots: "L2xx"

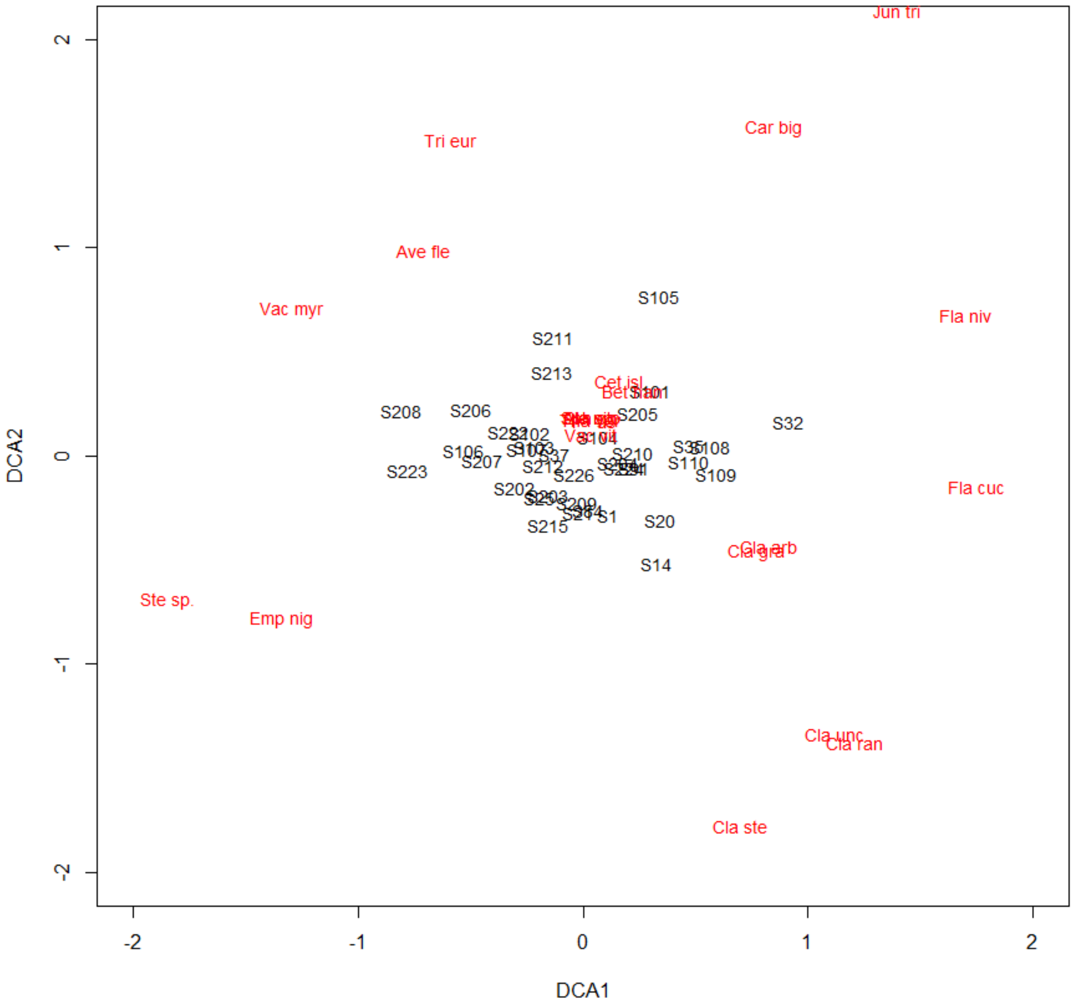

Figure 7: DCA of all shrub-dominated plots (black) and the species found here (red). Labels: PhD200-plots: "Sxx", MSc200-plots: "S1xx", MSc1500-plots: "S2xx".

Table 2: Overview of statistical tests used, including outcome (continues on next page).

	PhD200 versus MSc200	**(PhD + MSc)200 versus MSc1500**	**Lichen versus shrub**
Lichen-dominated vegetation	Mann-Whitney U-test No significant difference p-value: 0.853	Two-samples t-test Significant difference p-value: < 0.01	

Shrub-dominated vegetation	Mann-Whitney U-test No significant difference p-value: 0.796	Two-samples t-test Significant difference p-value: < 0.01	
All plots			Two-samples t-test Significant difference p-value: < 0.01

Species richness and diversity were investigated and compared for the vegetation data. The analysis showed that the shrub-dominated plots had a significantly lower score in both richness and diversity than the lichen-dominated plots (p-value richness: < 0.01, p-value diversity: < 0.01). When looking further into only the lichen-dominated plots, no significant difference was found between the PhD200 and MSc200 plots (p-value richness: 0.078, p-value diversity: 0.165), and the PhD200+MSc200 versus the MSc1500 plots (p-value richness: 0.404, p-value diversity: 0.821) in neither species richness nor diversity. The same trends were found for the shrub-dominated vegetation. For statistical tests, see appendix 5.

3.1.1 Differences between PhD200, MSc200 and MSc1500 plots at the vegetation species level

In this section, we analyse what vegetation species have specifically contributed to the significiant differences in vegetation composition in the MSc1500 plots relative to the MSc200+PhD200 plots. To have a first overview, pie charts over the percentage that each species represents are made (Figure 8).

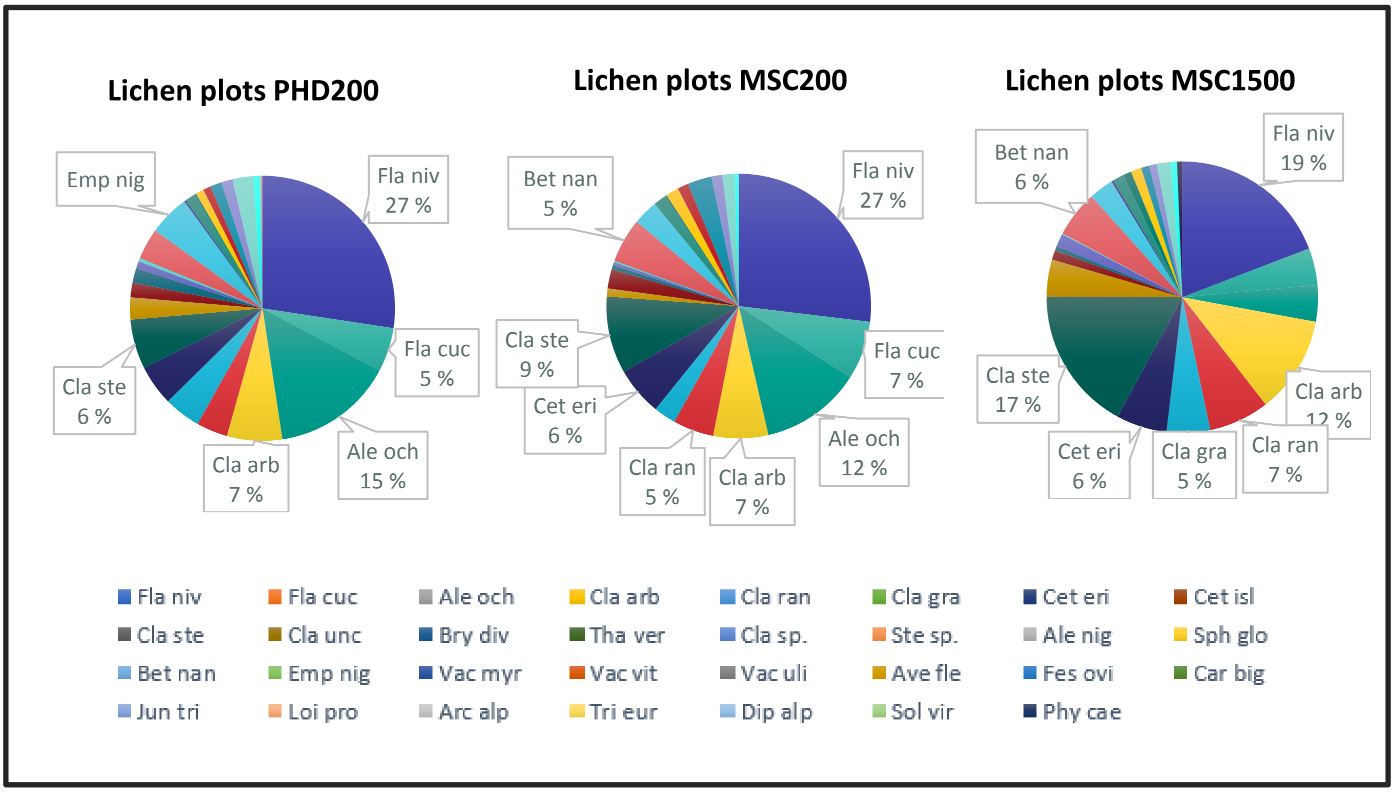

Figure 8: Pie charts over relative abundance of the species in the lichen-dominated plots.

This is not the actual cover percentage of the species, as the vegetation cover at each plot exceeds 100% due to the vegetation layers and overlap. The pie charts show that *F. nivalis* and *A. ochroleuca* have the highest abundance in the PhD200 and MSc200 **lichen** plots. *F. nivalis* reaches 27% in both cases, whereas *A. ochroleuca* covers 12% and 15% for MSc200 and PhD200 plots, respectively. For the MSc1500 plots, *F. nivalis* still is the largest component, but the percentage of *A. ochroleuca* is notably smaller with only 4%. On the other hand, *Cladonia arbuscula* and *Cladonia stellaris* are bigger in the MSc1500 plots, with 12% and 17%, respectively, whereas these species do not reach 10% in either the MSc200 or the PhD200 plots. The difference in abundance for these species between the plot groups are shown in the box plots in figure 9a, b and c. When comparing the actual cover percentages of each species, a significant difference is found between the PhD200+MSc200 plots versus the MSc1500 plots in both *A. ochruleuca* (p-value = 0.016) and *C. stellaris* (p-value < 0.01)*,* whereas no significant difference was found for *F. nivalis* (p-value = 0.13). For statistical tests, see appendix 6.

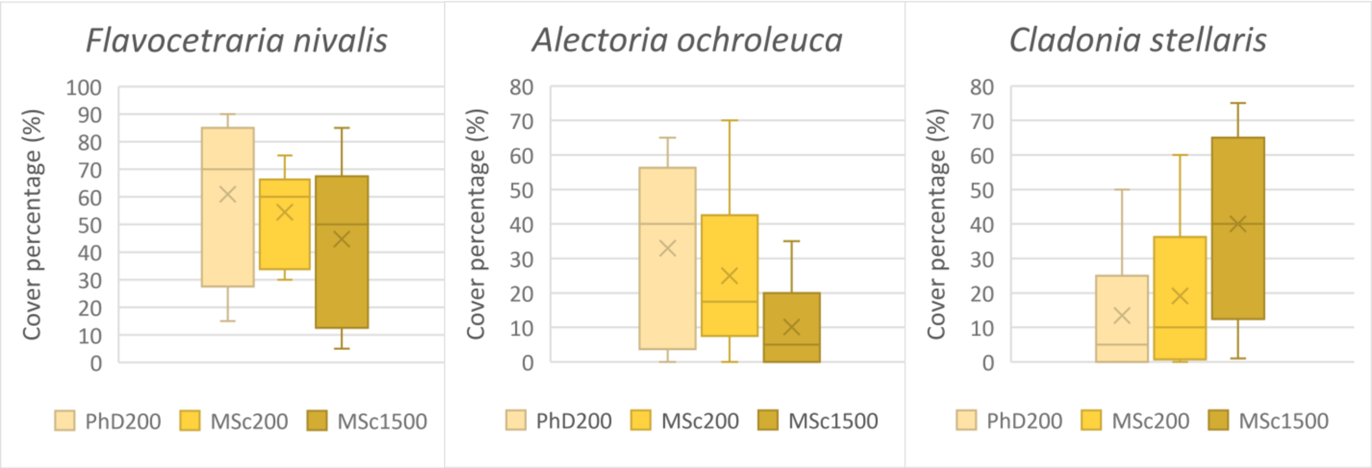

Figure 9: Box plots showing differences in species abundance of F. nivalis *(a),* A. ochroleuca *(b) and* C. stellaris *(c) in the lichen-dominated plots.*

The species showing the largest differences in the **shrub** plots are the two most dominating shrubs; *E. nigrum* and *B. nana* (Figure 10). In all three plot groups, these two species represent between 55% and 60% of the total species abundance. We see that *B. nana* represents 41% of the vegetation in the PhD200 plots and 47% in the MSc200 plots. For the MSc1500 plots, the value for *B. nana* is 36%. For the *E. nigrum,* the trend is different, as it reaches 17% and 12% in the PhD200 and MSc200 plots, and is higher in the MSc1500 plots, with 20%.

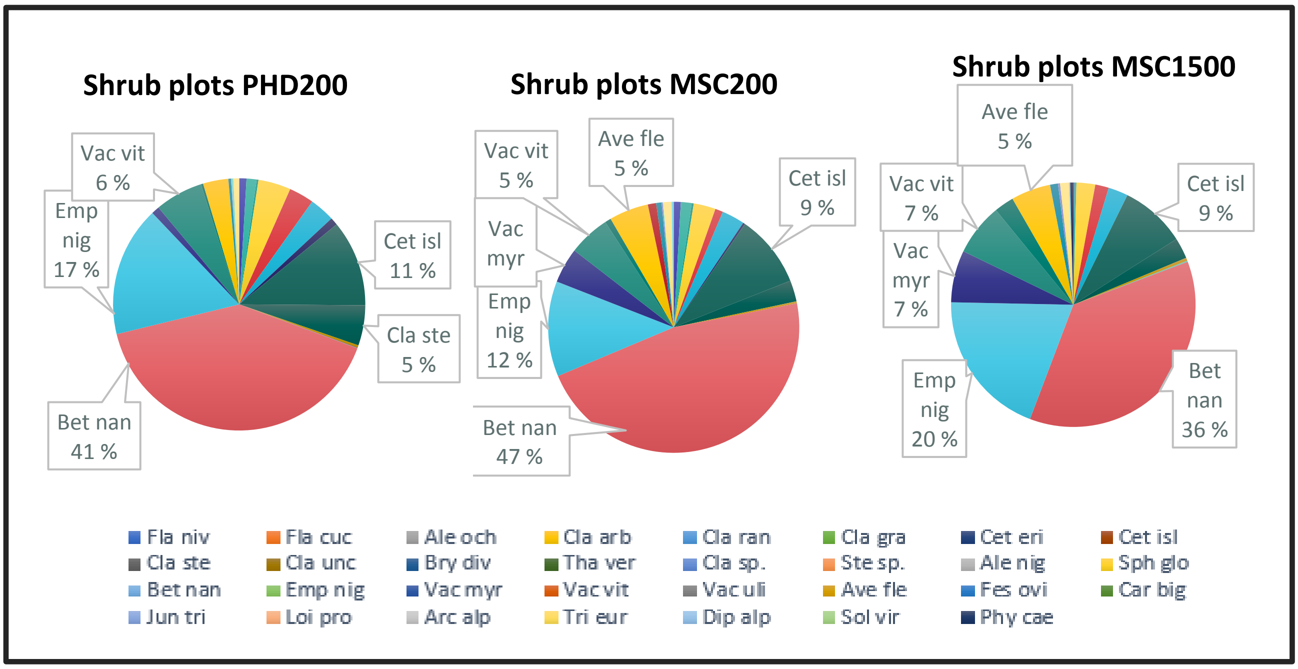

Figure 10: Pie charts over relative abundance of the species in the shrub-dominated plots

When we look at the actual cover percentages, the same trends are found (Figure 11). *B. nana* has a significantly lower cover percentage in the MSc1500 plots than in the PhD200+MSc200 plots (p-value = 0.03). The difference is not significant in *E. nigrum* (p-value = 0.12), but the highest values are found in the MSc1500 plots.

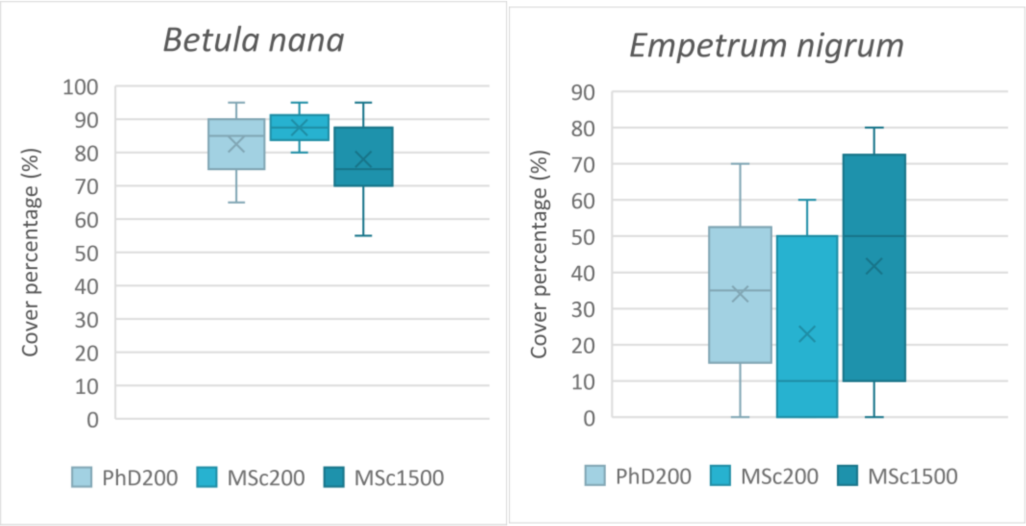

Figure 11: Box plots of the percentage abundance of B. nana *(a) and* E. nigrum *(b) in the shrub-dominated vegetation.*

3.2 Variation in albedo

The albedo data are sampled at the PhD200 and MSc200 plots, and we compare the half hour measurements from the MSc200 plots to randomly extracted half hour measurement from the PhD200 plots. Figure 12 gives a clear indication that the lichen plots have a higher albedo than the shrub plots. All lichen-dominated plots are situated between albedo 0.2 and 0.3, and the shrub plots have an albedo of 0.1 to 0.2. The difference in albedo between the two vegetation types is confirmed by statistical testing (p-value < 0.01). Further, the figure indicates that the PhD200 and MSc200 plots are quite similar within each vegetation type (Fig 12). The standard deviation is larger for the PhD200 plots because of larger data series.

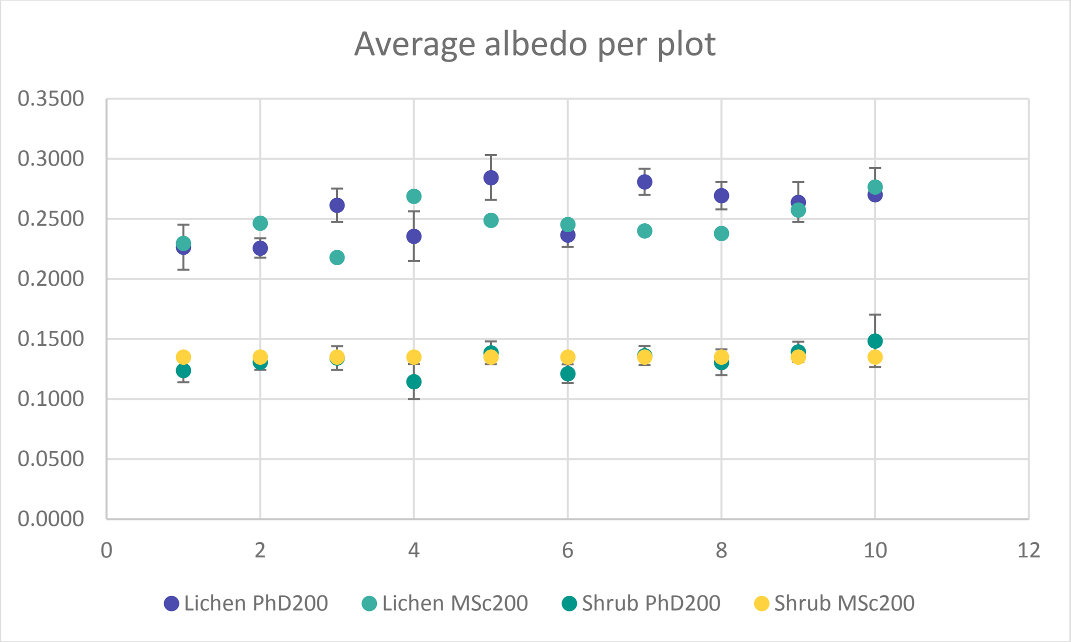

Figure 12: Average albedo per plot.

For the albedo measurements of the lichen plots, the PhD200 data show a slightly larger spread than the MSc200 data (Figure 13a). The mean value for the PhD200 plots is 0.255, and the mean value for the MSc200 plots is 0.247. Statistical testing shows that these two datasets are not statistically different (p-value = 0.63). For the shrub plots, figure 13b indicate that the albedo at the PhD200 plots is spread over a wider specter, but is generally lower than for the MSc200 plots. This difference in confirmed by statistical testing (p-value < 0.01).

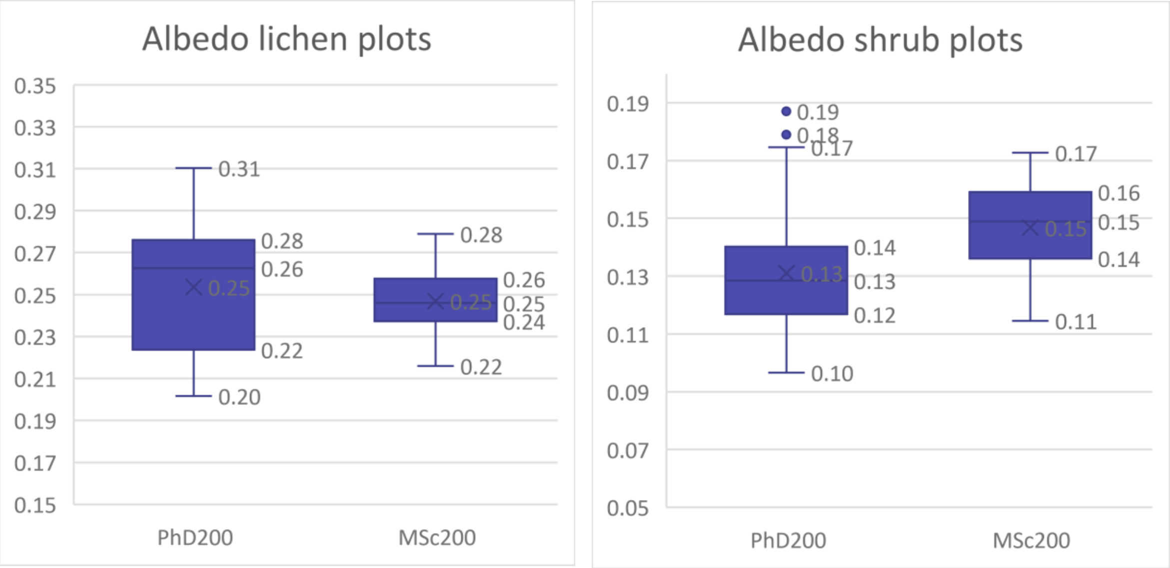

Figure 13: Box plots for albedo at lichen plots (a) and shrub plots (b). The given values are: Max and min values, first quartile (Q1) and third quartile (Q3) mean (x) and median (line). Note the different scales on the y-axis.

4 Discussion

Alpine vegetation, with lichen heaths and exposed ridge vegetation in particular, is very vulnerable to climate change (Joly et al., 2009). As the yearly mean temperatures increase and the precipitation patterns change, it is likely that shrubification occurs and threatens both intact and fragmented lichen mats. As changes in species composition and biomass increase among others can influence permafrost thaw rates, small scale patterns should be considered in assessments of climate-vegetation-permafrost feedbacks. (Juszak et al., 2016). Reduction of lichen can also have dramatic consequences for reindeer that are dependent on lichen for winter forage (Heggeberget et al. 2002). The plots in this study give insight into the lichen- and shrub-dominated vegetation at Imingfjell, both in composition and at species level. The albedo measurements, in addition to presented information from Imingfjell, emphasize the difference between the light lichen and the dark shrub-dominated vegetation (Peltoniemi et al., 2010).

We found a mean albedo of lichen-dominated vegetation cover of 0.25, whereas the mean albedo of shrub-dominated vegetation was 0.13. The lichens' high albedo due to its light-colored surface contributes to lowering of the temperature under the lichen cover compared to other vegetation cover (Stoy et al., 2012). This can keep the soil under the lichen cover frozen longer, which makes it more challenging for vascular plants to establish. Intact mats of light lichen with a high albedo is preferable because they can keep the direct environments cool, and thereby contribute to slowing down the enhanced greenhouse effect. This makes it is highly relevant to study the relationship between light-colored lichens and other, darker vegetation.

4.1 Vegetation composition

The Imingfjell area with its alpine vegetation has been an object of several scientific studies, where the exposed ridge-vegetation with a high amount of lichens plays an important role (Sundstøl & Odland 2017, Odland & Munkejord 2006, Odland et al. 2015). Alpine vegetation is situated above the tree line and in this case it can be divided into three main groups; exposed ridge vegetation, leeside vegetation and snowbed vegetation (Fremstad, 1997). The results in this study give an overview of the present species in both exposed ridge-, and leeside-related vegetation in the low alpine zone. From the lichen-dominated plots sampled at exposed ridges, some of the most abundant lichen species are *F. nivalis* and *A. ochroleuca*. These are very characteristic species for the vegetation type (ibid.). The clearly most abundant species in the shrub-dominated vegetation is *B. nana*, followed by *E. nigrum.* The detected species and the vegetation composition correspond well with descriptions of alpine vegetation in the low alpine zone.

The lichen-dominated plots had a significantly higher score in both richness and diversity than the shrub-dominated plots. This indicates that lichen heaths and exposed ridges are valuable communities for biodiversity, and it emphasizes the importance of investigating these areas and vegetation types. Further, the results show that the lichen plots in zone 1 are closely related to the characteristic exposed ridge-species, *F. nivalis* and *A. ochroleuca*. However, with bigger distance from the road, the vegetation composition is found to be different, as a higher percentage of the *Cladonia*-species *C. stellaris*, *C. rangiferina* and *C. arbuscula* is registered. These species can be found at less exposed sites. Snow depth and snow layer duration can vary markedly on short distances and between terrain formations in the mountains. The distribution of snow is one of multiple environmental factors that influences the distribution of mountain plants (Odland et al., 2008, Heegaard, 2002). Odland et al. (2008) have established snow indicator values (SI-values) ranging from 1-9 for alpine plants, as a parallel to Ellenberg's indicator values (Ellenberg et al., 1991). Values close to 1 are assigned to plants growing at locations without snow cover during most of the year, and values close to 9 are assigned to plants growing at locations with a long lasting snow cover. Both *F. nivalis* and *A. ochroleuca* have a SI-value of 1, whereas the *Cladonia*-species mainly score around 2 on the scale (ibid.). From this we see that *Cladonia*-species are slightly more adapted to a longer snow cover duration. Based on these species' SI-values and abundance patterns, some of the variation in vegetation composition could be explained by variation in terrain formations, which is closely related to snow layer duration. Based on subjective observations, the elevation increases further away from the road, and the terrain is less dominated by the very expressed exposed ridge-terrain that is found near the road. Still, the results show little variation in species richness and diversity, and the shift of species is low, even between the most different plots (Figure 5).

4.2 Weather conditions

The weather conditions in Norway the summer of 2018 should be considered when understanding the results. The extremely warm and dry period this summer started in May and lasted until August, hit hardest in Southern-Norway and lasted the longest in eastern parts of the country (Skaland et al., 2019). The mean temperature for Norway was 3.1 °C above normal, and the country only had 74% of the precipitation compared to a normal year (ibid.). Due to the high temperatures and drought, vegetation composition could deviate from a normal situation. Exposed ridge-vegetation is adapted to challenging conditions, like frost and drought (Ives and Barry, 1974). It can therefore be assumed that the drought did not affect the vegetation composition at the exposed ridges to the same degree as the vegetation growing on the slopes or snow beds. Still, the drought was severe, and might have affected the abundance of certain species, also on the ridges. It should be considered that the results both regarding vegetation composition and albedo might have been affected by this. It would have been interesting to have a time series of data, to see how much impact the drought had on the vegetation this year. This project only included one field season, but other, longer lasting studies might give an indication to if the unusual weather conditions of the summer of 2018 had an impact on the vegetation composition.

4.3 Albedo

The results show a significant difference in albedo between lichen- and shrub-dominated vegetation (Figure 12). These results support the findings of Peltoniemi et al. (2010), who measured a markedly higher albedo for lichen cover (0.31) than for other, green vegetation (0.20). The albedo values for the lichen-dominated vegetation ranges from 0.21 to 0.29 in our study. Petzold and Rencz (1975) have found an albedo of 0.22 of dry *C. stellaris*-dominated cover, which corresponds well with our results. Heim and Lundholm (2014) collected only reindeer lichen (*Cladonia* sp.) and measured the albedo to be 0.33. When our study shows a lower mean albedo value of lichen cover than what they found, it is because we measured albedo in field with natural vegetation composition which contains fractions of darker vascular plants within the lichen cover.

From the results we see that the albedo in the shrub-dominated vegetation is higher in the MSc200 plots than in the PhD200 plots. This indicates that the vegetation in the PhD200 plots is darker than in the MSc200 plots. There are two possible explanations for this difference. The first explanation is species dependent; the two groups contain the same cover percentage of shrubs, but there might be a higher percentage of darker shrub species in the PhD200 plots which gives a significant contribution to lowering the total albedo. The other explanation is, as earlier mentioned, that it is possible that the most favorable plots were chosen for the PhD project. A combination of these two explanations is a possibility, but strict criteria were made and followed in order to secure equal plots. It is therefore most likely that the combination of different colored shrub species influences the albedo enough to give the significant differences we see in the results.

The albedo was not measured at the MSc1500 plots. The vegetation composition was found to be different between the MSc1500 and PhD200 + MSc200 plots. Surfaces of different species composition give different albedo values (e.g. Petzold and Rencz, 1975 and Juszac et al., 2016). This makes it likely that a difference in albedo could have been found if this had been measured. The MSc1500 plots represent the surrounding landscape at Imingfjell, so it is possible that the measurements from the PhD200-plots either overestimates or underestimates the albedo for the lichen and shrub dominated vegetation at a larger scale.

4.4 Methods

The sampling area for the PhD200 plots covers the area 0-200 meters from the road (zone 1, see figure 2), which is a small fragment of the Imingfjell area. The original plan was to sample all plots within 0-1500 meters east of the road, but as earlier mentioned some restrictions were set by the landowner. We still decided to keep this study area because it contains large, uniform patches of light lichens, with potential for establishment of numerous plots. This is particularly expressed close to the road, where we find many exposed ridges with the typical, lichen-rich vegetation cover. In addition, there is a high abundance of shrub-dominated vegetation in short distance from the exposed ridges.

In addition to the PhD200 plots, the MSc200 plots are located within zone 1. This results in a rather high concentration of plots within this area. The procedure of locating and establishing plots in the field was first implemented for the PhD200 plots. Some of the locations fulfilling the criteria were therefore already taken when the MSc200 plots were to be established. One criterion was that the plot with the highest percentage of light lichens or shrubs within 50 meters from the sample location should be chosen, which makes it very likely that an overlap of the searching areas occurs within the 200 meter-zone. A consequence can be that the PhD200 plots are the most preferable areas concerning the criteria. This can have an impact on both the registered differences in vegetation composition and the measured albedo between those two plot groups. On the other hand, we can argue that the criteria for determination of plots were the same for all plots, with the intention to choose as similar plots as possible. Either the plot met the criteria or not, and if it did not meet the criteria it was omitted. This gives more reliable results, because the strict criteria led to sampling of only representative plots for the vegetation types we wanted to investigate. The strict criteria limit the variation in vegetation in total, but capture the variation within each of the two vegetation types, both in composition and albedo.

A factor that also should be discussed is how the albedo data were collected. We only had access to two radiometers, because these are very expensive devices. This means that only one pair of lichen and shrub plots were measured at the same time. An ideal situation would have been to have a constant setup at two control plots (lichen and shrub) through the whole field season. When comparing the data series with the present set-up, no control data exist, so differing weather conditions and zenith angle of the sun is not corrected for. These conditions differ through the measuring series, and could have an impact on the measured albedo values. To reduce the error due to changing zenith angle, the MSc200 measurements (that were taken over two days) was done in the middle of the field season. The average zenith angle of the PhD200 plots would therefore be similar to the zenith angle of the two measuring days at the MSc200-plots. In this way, we argue that it is defendable to compare albedo from the two plot groups. Furthermore, the data was collected by the same people, doing the same procedure with the same equipment at every plot, which strengthens the study's reliability.

5 Conclusion

This thesis presents vegetation- and albedo data from an alpine area in Southern Norway. Research on alpine vegetation, and particularly lichens, is highly relevant because this vegetation is very sensitive to the ongoing changes in climate. This changes the growing conditions and gives already vulnerable vegetation even more challenges.

Analyses of the vegetation at Imingfjell show a significant difference between the lichen- and shrub-dominated vegetation, the two vegetation types that are objects of this research project. The results further show that the vegetation composition is not significantly different within zone 1, but a difference is found between the vegetation in zone 1 and zone 2. This is the situation in both the lichen- and the shrub-dominated plots, and the same trends are found for some of the investigated species.
When looking closer at the species composition within the three groups (PhD200, MSc200 and MSc1500), *F. nivalis*, *A. ochroleuca* and *C. stellaris* represent some of the largest fractions in the lichen-dominated plots of the three groups. For the shrub-dominated vegetation, *B. nana* and *E. nigrum* are the dominating species. None of these species show a significant difference in cover percentage when comparing data from the PhD200 plots to the MSc200 plots. Further comparison of cover percentage in the PhD200- and MSc200-plots to the MSc1500-plots reveals significant differences for *A. ochroleuca* (PhD200: 33%, MSc200:25% and MSc1500: 10%) and *C. stellaris* (PhD200: 13%, MSc200: 19% and MSc1500: 40%) in the lichen dominated plots. These differences can be explained by the characteristics of the terrain, with a higher density of exposed ridges in zone 1. Significant difference is also found between the PhD200 + MSc200 plots compared to the MSc1500 plots for *B. nana* (PhD200: 83%, MSc200: 87% and MSc1500: 78%) in the shrub dominated vegetation.

The results also show a significant difference in albedo between lichen- and shrub-dominated vegetation (albedo lichen: 0.25, albedo shrub: 0.13). The lichen-dominated vegetation in the PhD200- and MSc200-plots show no significant difference in albedo. A significant difference is found between the shrub-dominated plot groups, whereas the MSc200-plots have the highest mean value (albedo PhD200 shrub: 0.13, albedo MSc200 shrub: 0.15). This might be caused by the different colors, and thereby albedo, of shrub species, even with plots containing a similar total cover percentage of dark shrubs.

This study is a contribution to understanding how alpine ecosystems are affected by climate change, with particular focus on the interaction between lichen- and shrub-dominated vegetation. In order to have a sustainable management of alpine areas, further research is needed to monitor the vegetation’s responses to a changing climate.

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7 Appendix

Appendix 1 – plot coordinates

UTM zone 32 V (east, north).

Site nr	Coordinates lichen plot	Coordinates shrub plot
1	0476416 6672874	0476359 6672884
25	0476552 6673263	0476628 6673267
14	0476229 6672946	0476259 6672923
37	0476311 6672892	0476357 6672885
21	0476283 6672726	0476261 6672750
84	0476484 6672634	0476509 6672601
35	0476645 6672335	0476599 6672355
91	0476705 6672136	0476728 6672180
32	0476566 6672265	0476560 6672272
20	0476731 6672807	0476718 6672091
103	0476124 6673307	0476120 6673336
109	0476060 6673301	0476053 6673295
101	0476279 6672637	0476312 6672606
105	0476163 6672979	0476164 6672971
107	0476319 6672740	0476324 6672728
106	0476281 6672734	0476285 6672689
102	0476281 6672646	0476280 6672638
104	0476398 6672491	0476377 6672506
110	0476531 6672255	0476559 6672256

108	0477014 6671317	0477015 6671309
202	0477175 6672423	0477183 6672387
208	0477361 6672530	0477393 6672511
209	0477047 6672264	0477061 6672272
211	0477575 6671437	0477550 6671419
215	0477243 6672534	0477262 6672534
213	0476798 6673398	0476848 6673400
210	0477374 6673063	0477410 6673090
204	0476679 6673749	0476688 6673747
212	0476981 6673778	0476999 6673796
205	0476276 6673841	0476317 6673867
206	0476811 6674365	0476781 6674327
203	0477494 6673970	0477490 6673937
207	0476721 6674245	0476721 6674225
222	0476329 6673468	0476300 6673495
224	0476813 6672039	0476836 6672043
226	0476047 6673904	0476063 6673895
223	0477031 6673504	0477066 6673486

Appendix 2 – field form

Plot nr:

Date: Coordinates: Mean height:

Altitude: Aspect: Slope:

Dark vegetation (%) : Light lichens (%):

TA (shrubs) (cover percentage):

TB (field):

TC (ground - lichen):

TD (ground - moss):

TE (soil):

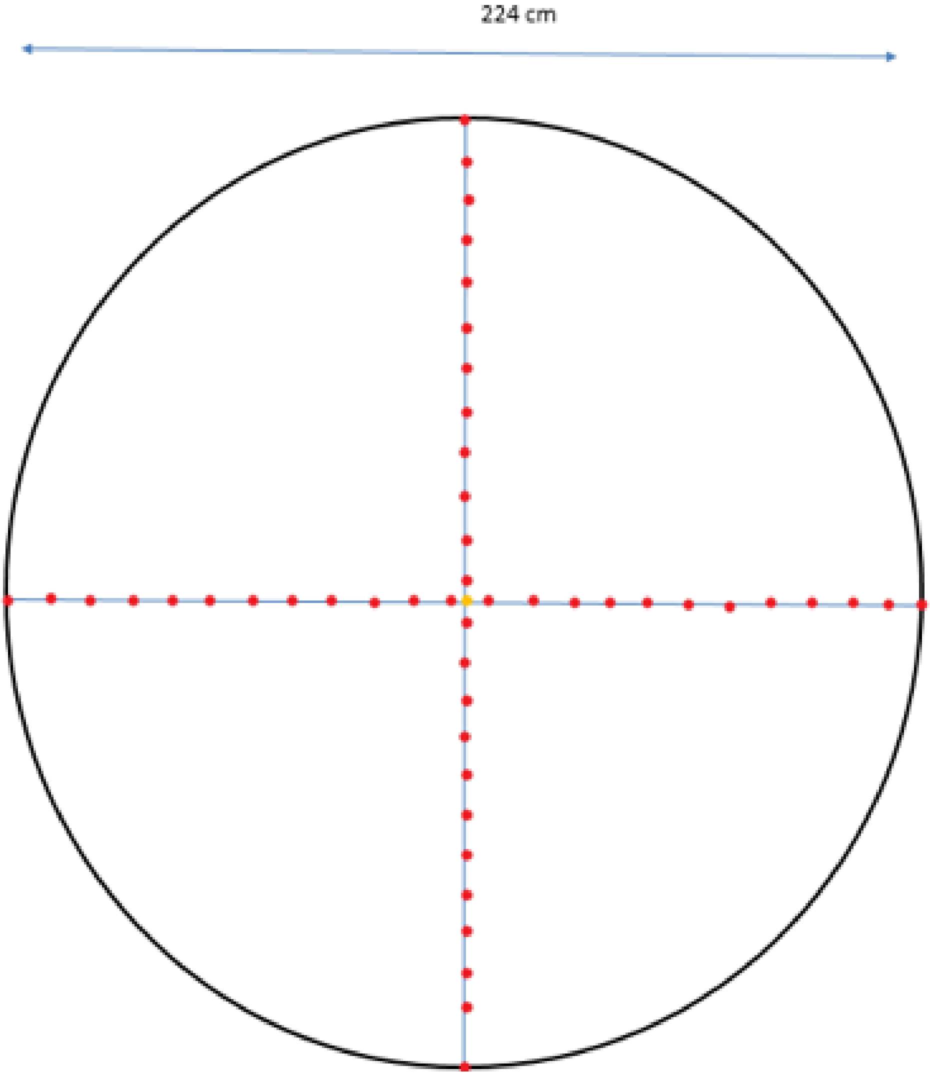
TF (stones):

Height measurements (cm)									
1		11		21		31		41	
2		12		22		32		42	
3		13		23		33		43	
4		14		24		34		44	
5		15		25		35		45	
6		16		26		36		46	
7		17		27		37		47	
8		18		28		38		48	
9		19		29		39		49	
10		20		30		40			

Species	Cover percentage

Notes:

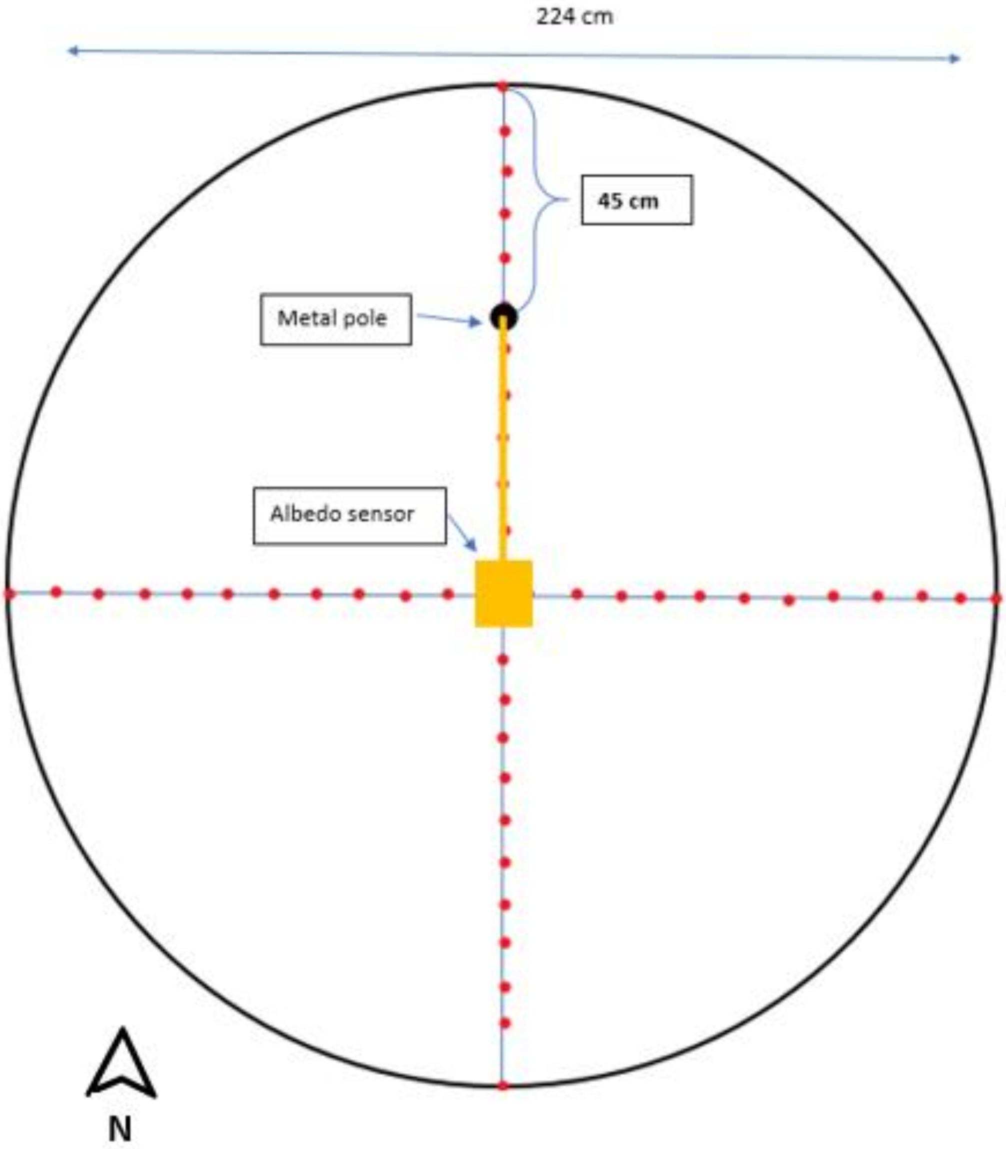
Transect for height measurements. (North-south and east-west)



Nr	Cm
1	0
2	10
3	20
4	30
5	40
6	50
7	60
8	70
9	80
10	90
11	100
12	110
13	112
14	114
15	124
16	134
17	144
18	154
19	164
20	174
21	184
22	194
23	204
24	214
25	224

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
0	10	20	30	40	50	60	70	80	90	100	110	114	124	134	144	154	164	174	184	194	204	214	224

Appendix 3 – Setup for albedo measurement



Appendix 4 – species abbreviations

List of species found in the study site. Abbreviations were used in the ordination diagrams and pie charts.

Species name (latin)	**Abbreviation**
Alectoria nigricans	Ale nig
Alectoria ochroleuca	Ale och
Arctous alpinus	Arc alp
Avenella flexuosa	Ave fle
Betula nana	Bet nan
Bryocaulon divergens	Bry div
Carex bigelowii	Car big
Cetraria ericetorum	Cet eri
Cetraria islandica	Cet isl
Cladonia arbuscula	Cla arb
Cladonia gracilis	Cla gra
Cladonia rangiferina	Cla ran
Cladonia sp.	Cla sp.
Cladonia stellaris	Cla ste
Cladonia uncialis	Cla unc
Diphasiastrum alpinum	Dip alp
Empetrum nigrum	Emp nig
Festuca ovina	Fes ovi
Flavocetraria cucullata	Fla cuc
Flavocetraria nivalis	Fla niv
Juncus trifidus	Jun tri
Loiseleuria procumbens	Loi pro
Phyllodoce caerulea	Phy cae
Solidago virgaurea	Sol vir
Sphaerophorus globosus	Sph glo
Stereocaulon sp.	Ste sp.
Thamnolia vermicularis	Tha ver
Trientalis europaea	Tri eur
Vaccinium myrtillus	Vac myr
Vaccinium uligunosum	Vac uli
Vaccinium vitis-idaea	Vac vit

Appendix 5 - Statistical testing: Species richness and diversity

		Lichen vs shrub	PhD200 vs MSc200	Zone 1 vs zone 2
SPECIES RICHNESS	All plots	MWU-test p-value < 0.01		
	Lichen-dominated		MWU-test p-value = 0.078	MWU-test p-value = 0.404
	Shrub-dominated		MWU-test p-value = 0.378	MWU-test p-value = 0.3945
SPECIES DIVERSITY	All plots	Two-sample t-test p-value < 0.01		
	Lichen-dominated		MWU-test p-value = 0.165	MWU-test p-value = 0.821
	Shrub-dominated		MWU-test p-value = 0.315	MWU-test p-value = 0.916

Appendix 6 – statistical testing of species abundance

Differences in abundance of the species *F. nivalis, A. ochroleuca, C. stellaris, B. nana* and *E. nigrum* between the plot groups PhD200, MSc200 and MSc1500.

Green color: P-value < 0.05 (Significant difference)

	F. nivalis (Lichen plots)	*A. ochroleuca* (Lichen plots)	*C. stellaris* (Lichen plots)	*B. nana* (Shrub plots)	*E. nigrum* (Shrub plots)
PhD200 vs MSc200	W = 37, p-value = 0.341 Median: MSc200: 60 PhD200: 70	W = 40.5, p-value = 0.494 Median: MSc200: 17.5 PhD200: 40.0	W = 58, p-value = 0.565 Median: MSc200: 10 PhD200: 5	W = 66.5, p-value = 0.215 Median: PhD200: 85 MSc200: 87.5	W = 39, p-value = 0.419 Median: PhD200: 35 MSc200: 10
PhD200 vs MSc1500	W = 51.5, p-value = 0.096 Median: MSc1500: 50 PhD200: 70	W = 40.5, p-value = 0.025 Median: PhD200: 40 MSc1500: 5	W = 142.5, p-value = 0.004 Median: PhD200: 5 MSc1500: 40	W = 64, p-value = 0.296 Median: PhD200: 85 MSc1500: 75	W = 102, p-value = 0.405 Median: PhD200: 35 MSc1500: 50
MSc200 vs MSc1500	W = 71.5, p-value = 0.511 Median: MSc200: 60 MSc1500: 50	W = 51.5, p-value = 0.092 Median: MSc200: 17.5 MSc1500: 5.0	W = 129.5, p-value = 0.026 Median: MSc200: 10 MSc1500: 40	W = 40, p-value = 0.023 Median: MSc200: 87.5 MSc1500: 75	W = 118.5, p-value = 0.0937 Median: Msc200: 10 MSc1500: 50
PhD200+MSc200 vs MSc1500	**Two-sample t-test** t = -1.5292, df = 31.229, p-value = 0.136	**MWU-test** W = 92, p-value = 0.016 Median: PhD200+MSc200: 25 MSc1500: 5	**MWU-test** W = 272, p-value = 0.001 Median: PhD200+MSc200: 7.5 MSc1500: 40	**Two-sample t-test** t = -2.2656, df = 28.199, p-value = 0.031	**MWU-test** W = 220.5, p-value = 0.1241 Median: PhD200+MSc200: 27.5 MSc1500: 50