Factors influencing ground lichen height in the Boreal-zone
The effects of reindeer husbandry and forestry industries in northern Sweden

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Abstract

There are indications that lichen-rich areas in northern Sweden, commonly used for winter grazing by semi-domesticated reindeer (*Rangifer tarandus*), has declined by 30-50% since the 1950s. This is mainly believed to be because of a rise in clear-cutting activities during that time period. With fewer areas for the reindeer to conduct their winter grazing it is important to know how grazing activities potentially affect the ground lichen. This report investigates what variables, such as tree density and reindeer grazing intensity, affect the height of five ground lichens; four *Cladonia* and one *Cetraria* species. The research was conducted in Norrbotten and Västerbotten, with a total of 55 sample plots, during the month of July 2015. Previous National Forest Inventory plots with a ground cover of at least 25% reindeer lichen were used. The commonly found species were *Cladonia rangiferina* and *Cladonia arbuscula/mitis*. Grazing intensity from reindeer had a low explanatory power on the variation in the mat-forming lichen height in boreal forests if considered by itself ($R^2=0.05$, $p=0.06$). Instead, reindeer grazing effects became more evident when considering an interaction with the tree density of the forest. Tree density and grazing pressure have an important role for lichen height, but there probably are more variables which, directly or indirectly, affect lichen height. Tree density also effects the amount of reindeer found in the area and seems to be of great importance when reindeer graze during the winter.
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1 Introduction

Northern Sweden is located within the boreal forest biome, which is mainly dominated by coniferous trees. The mountain area in the north-west is located outside the timberline, meaning mostly shrubs and deciduous trees manage to grow here. Around half of the boreal forests of northern Sweden are owned by forest companies (Sandström et al. 2006). The forest industry has, within the last one hundred years, become a large scale industry thanks to more efficient machinery (Sandström et al. 2006). These same forests of northern Sweden are also used for reindeer husbandry which is conducted by the indigenous people of Sweden, the Sami people (Kivinen et al. 2012). Around a century ago, reindeer husbandry changed to a more extensive method, leading to a larger distribution of the reindeer herds in the landscape (Sandström et al. 2006). This has led to conflicts between the two industries (Kivinen et al. 2012).

Reindeer husbandry is an exclusive right to the Sami people. As far as we know, the Sami people have been practicing reindeer husbandry in northern Sweden’s boreal forest since at least the 17th century and today’s method of herding reindeer can be dated back to the early 20th century (Kivinen et al. 2012). A reindeer herding district is called a “Sameby” in Swedish. In Sweden, reindeer herding is organized into 51 herding districts, covering in total about 40% of the country (Kivinen et al. 2010) (Figure 1.). During the last century, the reindeer population in Sweden has fluctuated around 225 000 individuals (Moen and Danell 2003). Thirty-three districts are classified as mountain herding districts (Lundqvist et al. 2009). These herding districts migrate their reindeer between summer pastures, which are conducted in the mountains of north-western Sweden, and winter grazing areas in the northern boreal forest, located closer to the east coast (Horstkotte and Roturier 2013). Eighteen herding districts are classified as forest herding districts (Lundqvist et al. 2009). These reindeer do not migrate long distances and spend all year (summer and winter months) in the boreal forest.

Figure 1. Reindeer herding districts in Sweden.
Semi-domesticated reindeer (*Rangifer tarandus*) are classified as grazers (Heggberget et al. 2002). During summer, reindeer graze on a wide array of plant species. However, during the winter period, the nutritional value in most of these plants declines and reindeer switch their main food intake to lichens, which reindeer reach by digging through layers of snow (Berg et al. 2008). The winter grazing areas are lichen-rich and often located within pine heath areas in the boreal forest region (Gaio-Oliveira et al. 2006). Through interviewing 14 Sami herders, Inga (2007) assessed that reindeer mainly graze lichens during the winter months (October – April/May), and the reindeer herders claim that reindeer do not feed on dried lichens. The reindeer herds are allowed to graze freely over wide areas and are only handled during certain times of the year (Kivinen et al. 2010). Reindeer have adapted to severe winter conditions and thus manage to live in cold climatic environments (Inga 2007). However, since winter pasture areas are more restricted than summer ones, the winter resources are often the limiting factor for reindeer population growth (Kivinen et al. 2010).

According to the Sami, the lichen genus *Cladonia* is the first choice of food for reindeer during winter foraging, with a preference for *C. rangiferina*, *C. arbuscula* and *C. stellaris* (Inga 2007). The genus *Cetraria* is also consumed during the winter months (Kivinen et al. 2010). These species, together with *C. stygia* and *C. mitis*, are commonly referred to as mat-forming, or reindeer lichens, and are important in northern ecosystems (Gaio-Oliveira et al. 2006). During early spring (March/April), snow can become too hard for reindeer to dig, and reindeer switch to eating more arboreal lichens (Inga 2007). The lichens of the genus *Cladonia* preferred by reindeer are ground lichens. In the boreal and arctic zones they can form extensive mats that cover the ground (Boudreault et al. 2013). These lichen mats can be up to 10-12 cm deep (Jonsson et al. 2008). The *Cladonia* genus is an important forage for reindeer, has the ability to fixate carbon dioxide and can store nutrients, indicating that they have a great ecological importance within boreal and arctic ecosystems (Boudreault et al. 2013). There are indications that winter grazing grounds with a lichen-rich ground cover have declined by 30-50% since the 1950s (Berg et al. 2008). This is mainly believed to be because of a rise in clear-cutting activities during that time period (Sandström et al. 2006). Additionally, the remaining lichen-rich areas have undergone a reduction in quality (Berg et al. 2008).

Mat-forming lichens constitute 15-90% of the total food intake for the reindeer during winter grazing, depending on snow conditions (Gaio-Oliveira et al. 2006). Depending on weather conditions, the reindeer diet can consist of up to 80% lichen into the early spring period (Berg et al. 2008). Ideal winter grazing areas for reindeer consists of high abundancies and easy access of both ground and arboreal lichens (Kivinen et al. 2010). Reindeer have a specialized microbial flora in their digestive system which allow them to digest lichens (Berg et al. 2008). This allows them to digest over 50% of the dry lichen matter (Heggberget et al. 2002). Reindeer grazing is dependent on access to many different types of pastures, and defining optimal pastures depends on biological, geographical and climatic variables. The Sami herders have a word which defines the ideal pasture including all those variables: *Guohtun* (Roturier and Roué 2009) (Figure 2.).

![Figure 2. Variables which influence the Guohtun (depicted by the dark grey box, adapted from Roturier and Roué 2009).](image-url)
Guohtun also incorporates space and time due to the fact that it is based on the accessibility of grazing grounds, which is defined by tree cover, understory vegetation and snow conditions (Roturier and Roué 2009). Sami herders want to preserve as many lichen-rich areas as possible, because the snow conditions are different from year to year (Roturier and Roué 2009). The available food resources during the winter grazing months are determined by two main factors: first, the standing biomass of lichen in the area, and secondly, the lichen accessibility due to snow conditions (Heggberget et al. 2002).

Because of the importance of lichens for reindeer as food resource in the winter, a key factor when organizing grazing management plans for reindeer husbandry is to ensure the accessibility to lichens during winter (Moen et al. 2007). Conflicts with reindeer husbandry arise when other land users, such as the forest industry, use the winter grazing areas (Inga 2007). Forestry activities have led to limitations in winter grazing grounds for the reindeer husbandry in Sweden in the last century for instance through fragmentation of the forest and hindrances such as logging residues and mounds from soil scarification (Berg et al. 2008, Kivinen et al 2012).

When reindeer graze mat-forming Cladonia-lichens, the carpet becomes thinned and fragmented (Gaio-Oliveira et al. 2006). The abundance and growth of mat-forming lichens might be strongly dependent on the grazing pressures from reindeer (Gaio-Oliveira et al. 2006). This indicates there is a need for a high quantity of suitable lichen rich areas for reindeer husbandry, so that the herders can practice a rotational system that is sustainable. Overgrazing of the lichen mats is also believed to alter the regeneration capacity, which is dependent on the quality of the remaining lichen thallí (Gaio-Oliveira et al. 2006). With this in mind, it is of great importance to understand the regeneration capacity in relation to other environmental factors, as this will in turn affect the appropriate rotational scheme.

In this study, I first assess if there is any difference in abundance between the mat-forming lichen species in the Swedish boreal forest. My null hypothesis for this question is that all species have the same abundance within the study areas. I will also investigate if, and how, reindeer grazing affects lichen height and if the tree density of the forest has any effect on the height of the lichens. My null hypotheses for these questions is that lichens are shorter in forest with higher tree densities, and within areas where reindeer grazing is strongest.

2 Methods

2.1 Sample plots

A total of 55 sample plots were visited in Norrbotten and Västerbotten during the month of July 2015. All plots were located within the Boreal forest zone. The overall landscape of the visited plots consisted mainly of coniferous forests with Scots pine (Pinus sylvestris) as the dominant species, but also including Norway spruce (Picea abies) and deciduous trees (mainly Betula spp.). I visited both forest herding districts (winter and summer pastures within the boreal forest) and mountain herding districts (only winter grazing in the boreal forest). I selected the sample plots among those visited by the National Forest Inventory (NFI) between 2010 and 2014, using ArcGIS version 10.2.1 (ESRI 2014). Only NFI plots with a ground cover of at least 25% reindeer lichen were used. In total 65 where 10 plots was impossible to visit due to military zones. The other NFI plots with lichen ground cover (>25%) were fixed plots and prohibited for me to visit. The original NFI plots had a diameter of 20m (SLU 2013). Each plot had its own geographic coordinates and was located with a Garmin Oregon 600t GPS device, with an accuracy of 5 to 10 meters. In many cases, a wooden marking stick could be found which indicated the exact centre of the NFI plot. In cases where the marking stick from NFI could not be found, a new centre was marked with a temporary plastic marker.

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2.2 Recorded variables

2.2.1 Lichen height and lichen species

I measured lichen height using a device with a circular plate that rests on top of the lichen podetia (“body” looking part) during measurement (following Olofsson et al. 2011) (Figure 4A). The measuring device is constructed by two separate parts. The first part is a metal rod with a ruler on it, the second part is a plastic circular plate with a diameter of 8cm and a weight of 10g (Olofsson et al. 2011). The circular plate moves freely up and down the metal rod and because of its light weight can be held up by the lichen podetia during measurement (Olofsson et al. 2011). By placing the rod in the lichen-mat and resting the plate on top of the lichen podetia the lichen height could be measured without damaging the lichens, compared to pulling them up and measuring the lichen podetia. In each plot the lichen height was measured in 1m intervals starting from the centre of the NFI plot and moving in the direction of the cardinal (north, south, west, and east) and the half-cardinal (northwest, southeast, northeast, southwest) directions, following Uotila et al. (2005).

At each measuring point, lichen were identified to species. Lichen species of interest were the Cladonia species C. stellaris, C. rangiferina, C. stygia, C. arbuscula and C. mitis and Cetraria islandica. Those Cladonia species are defined in Swedish as “reindeer lichens” (renlavar) and are all eaten, together with Cetraria islandica (Moen et al. 2007), by reindeer during winter grazing (Hylander and Esseen 2005). C. arbuscula and C. mitis are impossible to distinguish without chemical treatment and no attempt to distinguish between the two was made for the purpose of this study. To distinguish C. rangiferina (Figure 4B) from C. stygia (Figure 4C), 3-4 podetia were removed and the colour of their necrotic part, the lower inner part of the podetium, was checked. C. stygia has coal black necrotic podetia, while in C. rangiferina the necrotic podetium has a browner tone (Ahti et al. 2013). At first glance, C. arbuscula (Figure 4D) can sometimes have a shape similar to C. stellaris (Figure 4E). The way to tell the difference between the two is to lightly try to separate the podetia. In C. stellaris it is impossible to separate them without breaking them, because the main axes (isotomous) is absent in this species (Ahti et al. 2013). C. uncialis can also have a shape similar to the reindeer lichens. However, C. uncialis upper parts do not bend in the same fashion as in the reindeer lichens. Cetraria islandica has completely different morphological traits compared to the reindeer lichens. It has a brown thallus with a high amount of wide lobes and is irregularly branched. Traits are similar to Cetraria ericetorum, however, the latter has smaller lobes (Hylander and Esseen 2005).

Figure 3. A: Device used for measuring lichen height. B: C. rangiferina. C: C. stygia. D: C. arbuscula/C. mitis. E: C. stellaris. Note that all figures have different scales and lighting, B-E background squares are 0.5cm².
2.2.2 Tree density

The density of the forest was estimated at each study site by measuring the stem basal area (m²/ha) with a relascope, an angle gauge commonly used in forest inventory (Olofsson et al. 2011). Measurements were taken at each plot centre and the furthest points on the north and south cardinals. This method gives a mean estimate of the tree density of the whole sample area. Tree width smaller than the set spacing marker at the end of the relascope was not counted and trees with a wider width than the spacing marker were counted as one, trees which just filled the relascope spacing marker were counted as 0.5.

2.2.3 Reindeer grazing intensity

Reindeer abundance was estimated by counting reindeer pellet groups in each sampling plot. Because the fieldwork was only conducted during one summer (2015) the Faecal Standing Crop technique was used (Campell et al. 2004). This involved counting both fresh and old pellets. The abundance of reindeer indicates whether there has been reindeer in the area and grazing is assumed at the visited study sites.

In each plot, the pellet groups were counted in five circular subplots, one in the centre and one at the end of each cardinal direction (north, south, east, and west) (Figure 3). Each subplot had an area of 7.065 m² (r=1.5m). Pellet groups which only had their centre inside the subplots were included in the count and since reindeer sometimes defecate when moving only clear groups of 50 or more pellets were counted (Skarin 2007). Reindeer faeces have different morphological shape during the year and are easily distinguishable. During winter, pellets are drier and occur separated in the faeces piles. Summer faeces are wetter and the individual pellets are clumped together. Only reindeer winter faeces were counted in this study.

![Sampling design for the pellet count.](image-url)
2.3 Data analysis

I entered and organized the data collected in the field in Microsoft Excel 2013 (Microsoft 2013), and performed data analysis in R version 3.1.2 (R core team 2015). Significant levels were set at 0.05. I used analysis of variance (ANOVA) to check for variance among species in lichen abundance and Tukey’s Honest Significant Differences (Tukey’s HSD) to detect which species differed from the others. I created a regression model with lichen height (averaged within each plot) as the response variable and amount of pellets and tree density as explanatory variables. I noticed and removed one sample that had an extreme Cooks distance value, which had an unproportioned effect on the results compared to the other samples (See appendix Figure A1). I checked if the response variable (lichen height) was normally distributed visually, using a histogram. I then created four different models. I used regression analysis when creating the two first models. The first model had tree density as a predictor variable and the second model had pellet count as a predictor variable. The third and fourth models were created with multiple regression analysis. The third model was made with both the variables tree density and counted pellets and an interaction term between these two variables. The fourth model was created by removing the non-significant term (pellet count) from model three. Finally, I compared the models based on Akaike Information Criterion value (AIC). The models residuals were checked for normality and heteroscedasticity. No regression assumption was violated. I used regression analysis to create univariate models to visualize the relationship between tree density and lichen height. The same was done for amount of pellets and lichen height. When regressing tree density on the amount of pellets found (both count data) I assumed a quasipoisson distribution to account for overdispersion.

3 Results

Of the 55 plots, 10 were in clear-cuts, with tree height lower than 0.5m. 35 plots were dominated by P. sylvestris and 10 plots were in mixed forest. The average lichen height for all plots was 3.1cm (± 2.5). The tallest lichens measured (15 cm) were C. rangiferina and C. arbuscula in a mixed forest location.

3.1 Lichen species

There was a significant difference in frequency among the lichen species in the visited plots ($F_{4,}=253.8, p<0.01$). There was no significant difference between C. rangiferina and C. arbuscula/C. mitis ($p=0.25$). Both species were significantly different from the other species Cetraria islandica, C. stellaris and C. stygia ($p=0.00$, see appendix B) indicating that the most common mat-forming lichen species in my study were C. rangiferina and C. arbuscula/C. mitis (Figure 5).

![Figure 5. Lichen species occurrence in visited plots.](image)
3.2 Effect of reindeer grazing intensity and tree density on lichen height

33 of the 54 plots had reindeer pellets (61.1%). I chose the model with the lowest AIC (for further explanations of the models see appendix B3). This model was a multiple regression analysis with lichen height as response variable and explanatory variables were tree density and an interaction between tree density and the amount of pellets. The explanatory power of this model was reasonably high (adjusted $R^2=0.22$). The interaction between tree density and amount of pellets showed a negative effect on lichen height (estimate=-0.03, $p<0.05$). This means that the relationship between the amount of reindeer pellets and lichen height was different depending on forest density. Tree density showed a positive effect (estimate=0.13) on the lichen height ($p<0.001$) (Table 1, Tree Density).

Table 1. Summary of model with lichen height as the response variable and explanatory variables tree density and amount of pellets with interactions. (Intercept)= where the models line starts (y). Estimate = estimate of the coefficient Std.Error= standard error, estimate of the variance of the strength of the effect. t value=t value for testing whether the corresponding regression coefficient is different from zero. $pr(>|t|)= p$ value, an estimate of the probability of seeing a t-value as extreme.

|                      | Estimate | Std.Error | t value | $pr(>|t|)$ |
|----------------------|----------|-----------|---------|------------|
| (Intercept)          | 2.46     | 0.27      | 9.04    | <0.001     |
| Tree Density         | 0.13     | 0.03      | 3.85    | <0.001     |
| Tree density: Amount of Pellets | -0.03   | 0.01      | -2.06   | <0.05      |

The univariate graph for amount of pellets shows indications that the lichen height could potentially decline with higher amount of reindeer pellets in a linear relationship. The linear effect ($R^2=0.05$; $F_{52}=3.616$, $p=0.063$) best explained the relationship between the two variables (Figure 6, A). However the explanatory line is non-significant and has little explanatory power. The graph showing the effect of tree density (basal area) on the height of the lichens shows a significant positive effect ($R^2=0.17$; $F_{49}=11.2$, $p<0.01$) (Figure 6, B). The plot for how tree density might potentially affect the amount of reindeer pellets found in the area shows a potential negative trend of number of pellets with higher tree density (Figure 7.)

![Image A](image_a.png)

**Figure 6.** Scatterplot representing the relationship between: A- Amount of counted pellet groups and lichen height, redline showing negative linear relationship; and B- Linear relationship between tree density and lichen height, redline showing a positive linear relationship.
4 Discussion

4.1 Lichen species

In my visited study areas, *C. arbuscula/C. mitis* and *C. rangiferina* were the most significantly abundant species. This shows that there is a difference among species in occurrence in the landscape. All species except the *C. arbuscula/C. mitis* group had extreme outliers, which could indicate that with more sampling the difference between the species might become smaller (or greater). The reason for this is probably that the visited plots were of similar quality, which benefit lichens. All lichens need moisture and solar radiation to grow (Jonsson et al. 2008). These factors, although not tested, were probably similar in most of the visited areas because lichens managed to grow there. Boudreault et al. (2013) showed that *C. stellaris, C. rangiferina* and *C. mitis* all have the ability to grow well within clear-cut areas and areas with lower tree densities in Finnish boreal forests. The morphological differences between *C. rangiferina* and *C. stygia* are small, and because I only checked 3-4 necro podelia every time *C. rangiferina* was found, the actual occurrence of *C. stygia* might be slightly underestimated. However, I believe that this would not affect the variation between the two species. Even though *C. arbuscula/C. mitis* was one of the most common lichen groups, there is no way to determine which species was more abundant out of the two. This indicates that *C. rangiferina* is the most common of the species counted, however further research is needed to conclude such a statement.

4.2 Effect of reindeer grazing intensity and tree density on lichen height

My results indicate that reindeer do affect lichen height, and tree density affect the reindeer density and the lichen height. The effect of grazing intensity from reindeer on mat-forming lichen height in boreal forests was only marginally significant if considered by itself. Instead, its effect became evident when considering an interaction between the amount of pellets and tree density. My fairly simple model managed to have an explanatory value of 22% ($R^2=0.22$). This indicates that tree density and grazing pressure have an important role but that there probably are also other variables which, directly or indirectly, can affect lichen height. I found a positive relationship between tree density and lichen height, which is confirmed by Jonsson Čabrajić (2009) for low tree densities. Indeed, my highest measured tree density was (15.7
9
m²/ha). Olofsson et al. (2011) showed that forest densities within 0-17 m²/ha have a positive effect on the height of mat-forming lichens.

The significant interaction that I detected between reindeer grazing and tree density indicates that the effect of reindeer pellets on lichen height is different for different values of tree density. The interaction term was negative (Table 1. Estimate) indicating that lichen with more reindeer pellets tend to be shorter at both high and low tree densities, but the relationship is much more dramatic in high than in low forest densities. This can be seen in the negative effect of the amount of pellets have on the lichen height in the absence of an interaction (Figure 6, A) and the potential negative effect of tree density on the amount of reindeer pellets (Figure 7). Without interactions there were still a negative effect of the amount of pellets on the lichen height (Figure 6, A). These linear effects were marginally significant and had low explanatory value. This indicates that the tree density, and maybe additional factors, affect the height of the ground lichens. It is interesting to think that there might be a hyperbolic relationship between reindeer grazing intensity and lichen height (Figure 6, A). This would mean that in favorable growing conditions the lichen height is only affected to a certain height. This could explain why tree density had a strong effect on reindeer pellets at higher than lower forest densities. For example, if there is a hyperbolic relationship between the grazing pressure and the height of the lichens, there could be a potential height which even if grazed upon will fluctuate around a threshold height. Theoretically, in forests with higher tree densities it is farther from this level than in less dense forests which could explain what my model is indicating (Figure 8). From simply looking at the graph (Figure 6, A) it seems this threshold level could be around 2-3cm. This would be interesting to investigate further and I would recommend having a sample plot of 100 or more with a lot more areas with reindeer pellets when investigating this effect, since the places where there are no reindeer will highly affect the result.

![Figure 8](image.png)

Figure 8. Visualization of theorized potential interaction between tree densities and hyperbolic grazing intensity. Counted pellet groups high to low, Tree density low to high.

The high observation in Cooks test, which was later removed, was due to a high pellet count with very high lichen height compared to the other samples (Figure 1A in appendix). This effect is probably because certain areas within this specific sample plot contained thicker mats of moss with shrubs creating a landscape matrix within the plot of open areas with shorter lichen and moss and shrub dominated areas (Figure 2A in appendix). Lichen growing in moss seems, in general, to have a greater height (pers. observation). The few lichen which manage to grow in areas with moss and shrubs could potentially change the average height...
for the whole sample area. This could be the reason for the outlier and this might slightly interfere with the reindeer pellet counts effect on lichen height. To be able to account for these errors, a higher amount of sample plots than 55 is recommended.

Differences in the rate of pellet decomposition among the different forest types was not accounted for in this experiment but is recommended for future studies with a wider array of forest types. Even though the exact decomposition rate of reindeer pellets in mixed forests and clear-cuts is unknown, I assume that the decomposition rate in the visited experiments had around the same reindeer pellet decomposition rate. This is because we only selected NFI plots that were expected to offer good lichen habitat since they were defined as “lichen type and lichen rich” (more than 50 % and 25 % lichen cover, respectively) by the NFI. In a pine heath, the decomposition rate of the reindeer pellets can take up to five years (Helle et al. 1990) and the decomposition rate of reindeer pellets in mixed forests and clear-cuts is unknown. That being said, most of the plots visited were dominated by P. sylvestris so the estimates for the pellet count were probably not affected in this study.

Based on a visual assessment and the interaction term in my model, tree density also seems to affect the amount of reindeer pellets found in the area (Figure 7). The higher the tree density, the less pellets were found. However, there seems to be a large variance within the plotted data. This result could be explained by the relationship between reindeer and snow. Areas that did not have any reindeer pellets may have not been visited by the reindeer because snow conditions hindered them from reaching the lichens (Moen et al. 2007). This is of great importance when understanding reindeer grazing activities in the landscape. I would recommend thinking in the way of the Guohtun, there are several factors that determine where the reindeer can graze and where they will be located during winter months. I would like to suggest an improvement to the previous figure of the Guohtun (Figure 2, page 2). I think that adding a forest characteristic effect on snow, which later affects the reindeer forage, could be an improvement to the figure of the Guohtun. This is because one important factor that alters the snow condition is tree density, which is a characteristic of the forest. For example, snow becomes too densely packed in clear-cut areas for the reindeer to dig through (Roturier and Roué 2009). The type of forest management conducted will also affect the forest characteristics and small things such as logging residues left from forestry activities can make it harder for a reindeer to reach the lichen when digging through snow (Sandström 2006). The snow factor will change with different weather conditions. Warmer periods during the winter season will lead to snow melting and dropping around the tree stems, which packs the snow around the trees. In these cases, snow in dense mature forests may become hard packed, making it impossible for reindeer to dig (Roturier and Roué 2009). The average temperature in Sweden last winter (2014) was -0.9°C. This is higher than the average winter temperature the previous four years (2009-2013) (SMHI 2015). Warmer weather conditions during the winter period will lead to areas with lower tree density having softer snow left between the trees, where the reindeer will be able to dig (Roturier and Roué 2009).

The forest industry undoubtedly affects the tree density within the landscape and reindeer husbandry uses the forest resources in a completely different way compared to the forestry industry. They also operate within different spatial scales, because forestry works on a stand scale whilst reindeer husbandry operates at a wider landscape level, because of the Guohtun. This means that any changes to the landscape mosaic, different types of forest stands with different tree densities in the landscape, will affect the reindeer during winter grazing (Kivinen et al. 2010). Hypothetically, this could protect the lichens from overgrazing by reindeer. However, with fewer lichen rich areas for reindeer to graze on, the risk of overgrazing could become a problem in the future. During warmer winters with frequent thawing and freezing, the Sami herders used patches which normally would be considered poorer quality for grazing activities. These areas are characterized by patches of lichens on a moss-dominated soil (Roturier and Roué 2009).
Climate change is a factor which could change the snow conditions in the future leading to even fewer areas compatible for reindeer winter grazing activities. This could potentially affect lichens in forests with low tree density. Under the present climate conditions in northern Sweden when the first snow falls in autumn, in forests with lower tree densities, most of the snow will reach the ground and melt, and possibly re-freeze (Roturier and Roué 2009). This would lock, and protect, the mat-forming lichens from being accessed by reindeer (Roturier and Roué 2009). This would lead the reindeer to forests with higher tree density, because forest with low tree density traps less snow than forest with higher tree densities (these were the forests with lowest lichen height according to my results). This effect can, however, benefit the reindeer herds during the thawing periods because there is a smaller amount of snow falling from the tree crowns in areas with lower densities of trees (Roturier and Roué 2009). Further research is recommended to understand how the snow conditions will change with climate change and how that will affect where the reindeer graze in the landscape. This, together with how many suitable areas there are left for winter grazing, could possibly lead to a damaging overgrazing effect on the mat-forming lichens. However, more investigation is needed to investigate if the reindeer grazing intensities have a hyperbolic effect on the height of ground lichens.
6 Acknowledgements

I would like to thank my supervisors Alessia Uboni and Jon Moen for their guidance and support in writing this thesis. Special thanks to Alessia Uboni for always being available to have a discussion and answer questions about statistics and general stuff. Also, thanks to Maria Johansson and Danijela Kodnik for helping create maps to find the sample plots and conducting field work with me. And finally, thanks Magnus Larsson for reading the report and giving helpful suggestions.
References


Microsoft. 2013. Microsoft Excel [computer software]. Microsoft: Redmond, USA.


Appendix A

Figure A1. Outlier (36, Plot=2022-1150), extreme outlier which was removed. Lichen height = 5.9, pellet count = 9 and tree density = 6.7. Modelled with lichen height as response variable and tree density and reindeer pellet count as explanatory variables.

Figure A2. Sample area matrix with moss and shrub (red circles) and mat-forming lichens (white).
Appendix B

Table B1. Lichen species Tukey HSD. diff= difference in the observed means. lwr= the lower end point of the interval. upr= the upper end point of the interval. p adj= p-value after adjustment for the multiple comparisons.

<table>
<thead>
<tr>
<th>Lichen species</th>
<th>diff</th>
<th>lwr</th>
<th>upr</th>
<th>p adj</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cetraria islandica</em> - <em>C.arbuscula/C.mitis</em></td>
<td>-54.64</td>
<td>-61.99</td>
<td>-47.28</td>
<td>0.00</td>
</tr>
<tr>
<td><em>C.rangiferina</em> - <em>C.arbuscula/C.mitis</em></td>
<td>5.45</td>
<td>-1.90</td>
<td>12.81</td>
<td>0.25</td>
</tr>
<tr>
<td><em>C.stellaris</em> - <em>C.arbuscula/C.mitis</em></td>
<td>-51.18</td>
<td>-58.53</td>
<td>-43.83</td>
<td>0.00</td>
</tr>
<tr>
<td><em>C.stygia</em> - <em>C.arbuscula/C.mitis</em></td>
<td>-50.64</td>
<td>-57.99</td>
<td>-43.28</td>
<td>0.00</td>
</tr>
<tr>
<td><em>C.rangiferina</em> - <em>Cetraria islandica</em></td>
<td>60.09</td>
<td>52.74</td>
<td>67.44</td>
<td>0.00</td>
</tr>
<tr>
<td><em>C.stellaris</em> - <em>Cetraria islandica</em></td>
<td>3.45</td>
<td>-3.90</td>
<td>10.81</td>
<td>0.70</td>
</tr>
<tr>
<td><em>C.stygia</em> - <em>Cetraria islandica</em></td>
<td>4.00</td>
<td>-3.35</td>
<td>11.35</td>
<td>0.57</td>
</tr>
<tr>
<td><em>C.stellaris</em> - <em>C.rangiferina</em></td>
<td>-56.64</td>
<td>-63.99</td>
<td>-49.28</td>
<td>0.00</td>
</tr>
<tr>
<td><em>C.stygia</em> - <em>C.rangiferina</em></td>
<td>-56.09</td>
<td>-63.44</td>
<td>-48.74</td>
<td>0.00</td>
</tr>
<tr>
<td><em>C.stygia</em> - <em>C.stellaris</em></td>
<td>0.55</td>
<td>-6.81</td>
<td>7.90</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Table B2. Lichen species ANOVA

<table>
<thead>
<tr>
<th>Lichen</th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lichen</td>
<td>4</td>
<td>200107</td>
<td>50027</td>
<td>253.8</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Residuals</td>
<td>270</td>
<td>53225</td>
<td>197</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table B3. Models with lichen height as the response variable, showing degrees of freedom (df) and the Akaike Information Criterion value (AIC). Models 1 and 2 - regression analysis, models 3 and 4 – multiple regression analysis. Model 4 was the final model.

<table>
<thead>
<tr>
<th>Models</th>
<th>df</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tree density</td>
<td>3</td>
<td>162.96</td>
</tr>
<tr>
<td>2 Pellet count</td>
<td>3</td>
<td>169.62</td>
</tr>
<tr>
<td>3 Tree density + Pellet count + interaction (Tree density: Pellet count)</td>
<td>5</td>
<td>162.64</td>
</tr>
<tr>
<td>4 Tree density + interaction (Tree density: Pellet count)</td>
<td>4</td>
<td>160.66</td>
</tr>
</tbody>
</table>