Estimating ground lichen biomass and reindeer grazing days

- a case study from Vilhelmina norra reindeer herding community

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Rapportnummer | **Datum**

Background and study area

The work and analysis presented in this report were financed by Nestlé via the Earthworm Foundation (EF) as part of the project Sami Reindeer Herder Community Wellbeing & Sustainable Forest Management Indicators Pilot, a recommendation from the Västerbotten Healthy Forest Landscape Assessment (Earthworm Foundation 2023). The aim of the project is to develop a set of indicators for the wellbeing of Sami Reindeer Herding Communities (RHC), particularly those related to interactions between reindeer herding and commercial forestry as part of the co-planning process. The project is managed by Sámiid Riikkasearvi (SSR) — the National Association of the Sámi People in Sweden — with coordination from EF. The work was carried out in cooperation with the Vilhelmina Norra Reindeer Herding Community, and the fieldwork was conducted on their grazing grounds.

Among the indicators SSR, have identified ground-lichen volume/biomass as a priority indicator, to use for:

1. Estimation of available lichen as a key component of 'grazing days'
2. 'Validation' of estimates of grazing days based on traditional knowledge, in the context of co-planning with forest companies
3. Informing discussion with forest companies about the need for, and design of, appropriate forest management adjustments to ensure that volumes of available lichen are sustained or increased.

Based on this, we have suggested and tested methods to estimate lichen volume and biomass, and to estimate reindeer grazing days. By doing so we have also created a baseline to enable monitoring of lichen in the area over time to determine the impact of forest management adjustments. The methods and the results from the field tests are presented in this report, along with suggestions for further development.

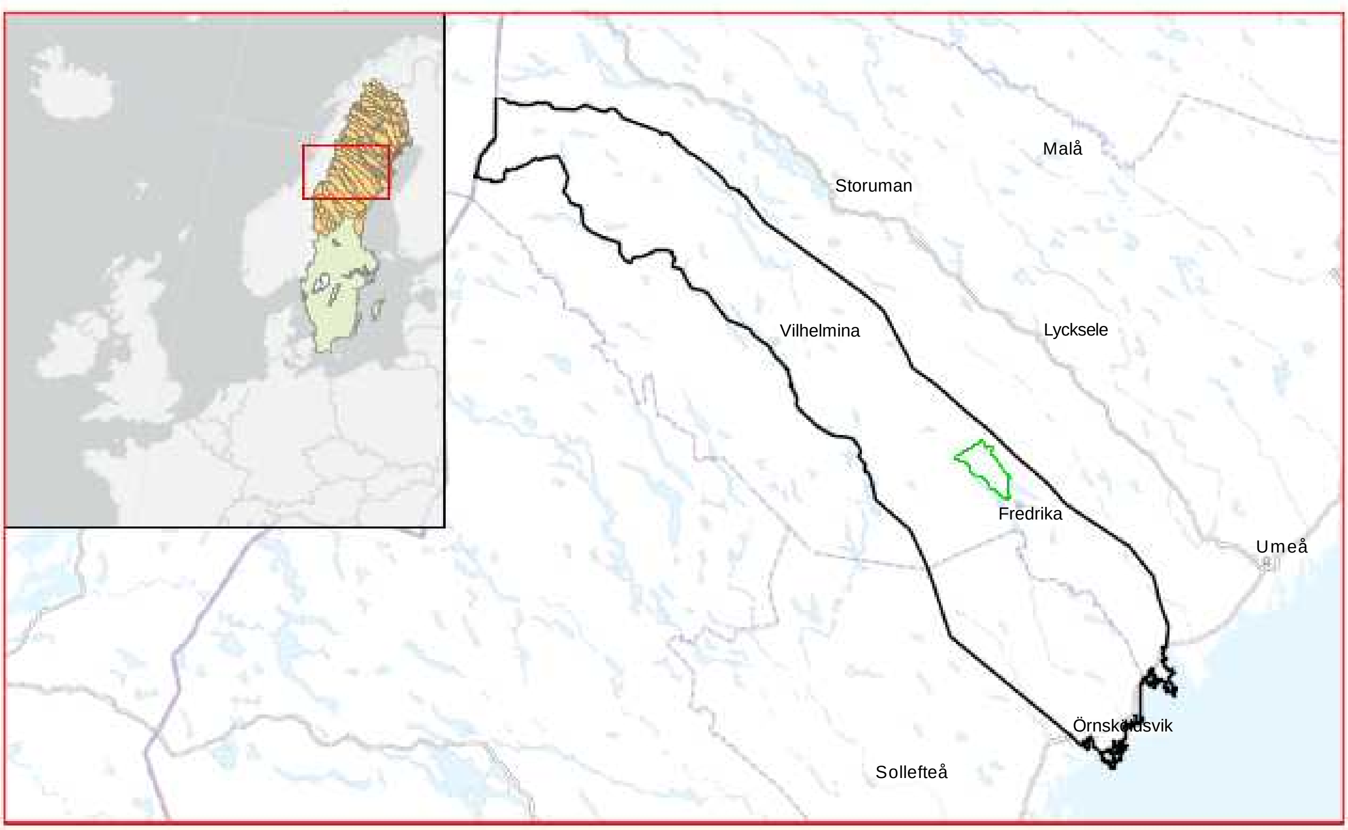

Figure 1. The overview map in the upper left shows Sweden, with the Reindeer Husbandry Area (orange) divided into 51 Reindeer Herding Communities. The larger map shows the Vilhelmina Norra reindeer herding community (black) and the Betsarn pre-winter grazing area (green).

Study area

The main study area was the Betsarn pre-winter grazing area within Vilhelmina Norra reindeer herding community (Figure 1). Reindeer husbandry in Sweden is permitted on about 55% of the northern part of the country's land area. This region includes more than half of Sweden's productive forest land and encompasses the majority of the boreal and alpine biomes. The reindeer husbandry area is divided into 51 reindeer herding communities. Vilhelmina norra is one of 33 mountain herding communities, that generally have their summer grazing areas in the western mountain regions and their winter pastures in the boreal forests to the east.

The Betsarn area is located north-west of the city Fredrika in the county of Västerbotten. It covers more than 18,000 hectares. and according to the Swedish National Land Cover Database (NMD), the area is dominated by pine forest (33%), young forest and clear-cut areas (19%), open mires (11%), Scots pine forest (6%), mixed coniferous forest (6%), deciduous forest (6%), exploited areas (2%), and water bodies (6%).

Betsarn has historically been a winter grazing land where the reindeer could graze all winter. The area is hilly, which reduces the risk of grazing becoming locked due to snow and ice conditions. Now, for the past 40-50 years, it has been used as a pre-winter grazing area where the reindeer move sometime between the latter part of October to mid-December, where they can then graze for a few months until snow conditions combined with reduced lichen height make the lichen difficult to access. After that, the reindeer graze eastward toward the best winter grazing areas around Övre Nyland. Reindeer can remain in the area until the end of February; the undulating terrain makes it difficult to gather the reindeer and get everyone along at the same time.

Reindeer and lichen

Reindeer are adapted to environments characterized by strong seasonal variation, with abundant forage during summer and limited food availability in winter (Skarin et al. 2022). For mountain herding communities in Sweden, migration from the mountain region to winter pastures typically occurs in autumn, during which reindeer shift toward greater lichen consumption. In winter, lichen can constitute more than 80% of their diet on good grazing grounds, making ground lichen a bottleneck resource (Heggberget et al. 2002).
At the same time, there has been a long-term decline in lichen availability. Data from the Swedish National Forest Inventory shows substantial reductions in lichen within the Swedish reindeer husbandry area: ground lichen-abundant forests declined by 71 % between 1955 and 2016 (Sandström et al. 2016) and the ground lichen cover declined by 57 % between 1996 and 2015 (Roos et al. 2025)

Methods

Sampling design

We conducted two inventories at different scales. For the entire Betsarn pre-winter grazing area, we built upon the lichen inventory already carried out by reindeer herders through the work with Reindeer Husbandry Plans (RHP) (Sandström et al., 2023), hereafter referred to as the RHP inventory. In addition, we selected eight sites, each 2–3 hectares in size, to monitor in more detail using the method described in Cronvall (2025), hereafter referred to as the detailed inventory.

For both inventories we used balanced sampling designs that uses auxiliary data to select a sample that is representative (Grafström and Schelin, 2014). By using auxiliary data that is correlated with the lichen abundance a lower variance of the lichen biomass estimate for a certain number of sample plots can be achieved and thereby making the survey more cost efficient.

For the **RHP inventory,** we used a balanced sampling design with the lichen indicator map (Adler et al. 2020; Horstkotte et al. 2023) as the balancing variable (Figure 2). First, we placed 1,000 potential tracts (500 m × 500 m) across the area and calculated the mean lichen cover for each tract based on the map. We then selected 20 of these tracts using the balanced sampling function lpm1 from the R package BalancedSampling (Grafström and Lisic 2018). This procedure ensures that the selected tracts reproduce the lichen distribution of the entire study area. In a second step, we again applied a balanced sampling approach within each tract to determine 8 sample plots with a radius of 5.64 m for field data collection, excluding all water bodies.

We used the **detailed inventory** to obtain more refined estimates, enabling us to monitor lichen abundance at specific forest stands and better understand the influence of different forest management practices on these areas. To do this, we manually selected eight sites of 2–3 hectares that we considered interesting to follow over time (Figure 3 & Appendix A). For these areas, we collected multispectral drone imagery from which NDVI and canopy height were derived. These data were used as auxiliary variables in the sampling process. For each site, we selected 30 sample plots using the balanced sampling function *lpm1* from the R package BalancedSampling (Grafström and Lisic 2018). In these plots, data on lichen cover and height were collected in the field.

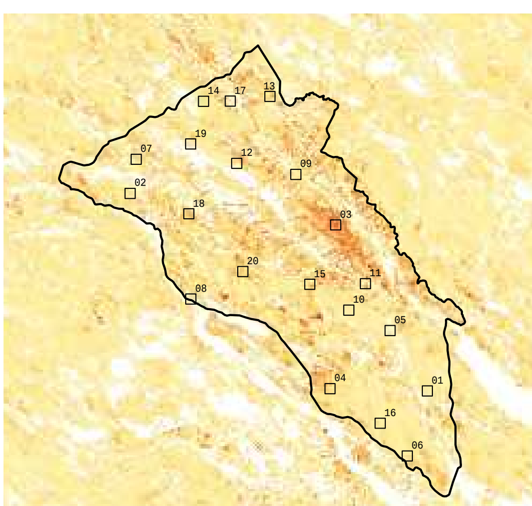

Figure 2. *The lichen map used for the sampling. The redder the color, the higher the lichen cover.*

Figure 3. *Location of the sites for the detailed inventory. Sites 1-6 within the Betsarn pre-winter grazing area and sites 7 and 8 in the Övre Nyland winter grazing area.*

Field data collection

All field work was conducted between October 12 and October 23, 2025, by two two-person teams. Each team worked independently, and within each team the two team members divided the different measurements and estimations between them during the RHP-method work.

For the detailed inventory, one person located the exact position of the sample plot while the other measured and estimated lichen cover and height and recorded the data. All data collection was done using the ESRI apps FieldMaps and Survey123 to reduce the risk of missing registrations or mistyping information. FieldMaps was used to locate the plots, and all data were then registered in. Survey123. All plots were photographed.

We slightly adjusted the original RHP methodology for lichen inventory by focus only on the ground lichen consumed by reindeer, and adding cover estimations for bare ground, bare rock, logging residues and dead wood (Table 1). By using the lichen map in the sampling design, we selected a sample that is representative of the lichen cover, but the distribution of the other data collected is not representative of the area in the same way and is not suitable for describing the site as a whole. It can however be used to understand how lichen abundance changes over time in each sample plot in relation to forest types, shrub cover, etc. Because of time constraints, only lichen cover and height were recorded for the sites included in the detailed inventory. This should be complemented with information about the forest stands. While some of this can be derived from the drone orthophotos and LiDAR data, it would be useful to collect field data such as stem density or basal area.

Emlid GNSS receivers were used to achieve centimetre-level precision for the sample plot locations. This level of accuracy was achieved for all detailed sample plots, where high positional precision is most important. In some areas, poor network connectivity prevented the receiver from obtaining location corrections, resulting in slightly lower positional accuracy for some of the RHP plots.

Estimations

When data on lichen cover and height was collected in the field, lichen biomass and reindeer grazing days was estimated in the same way for both inventories. For each sample plot, lichen volume was calculated as cover × height, and this

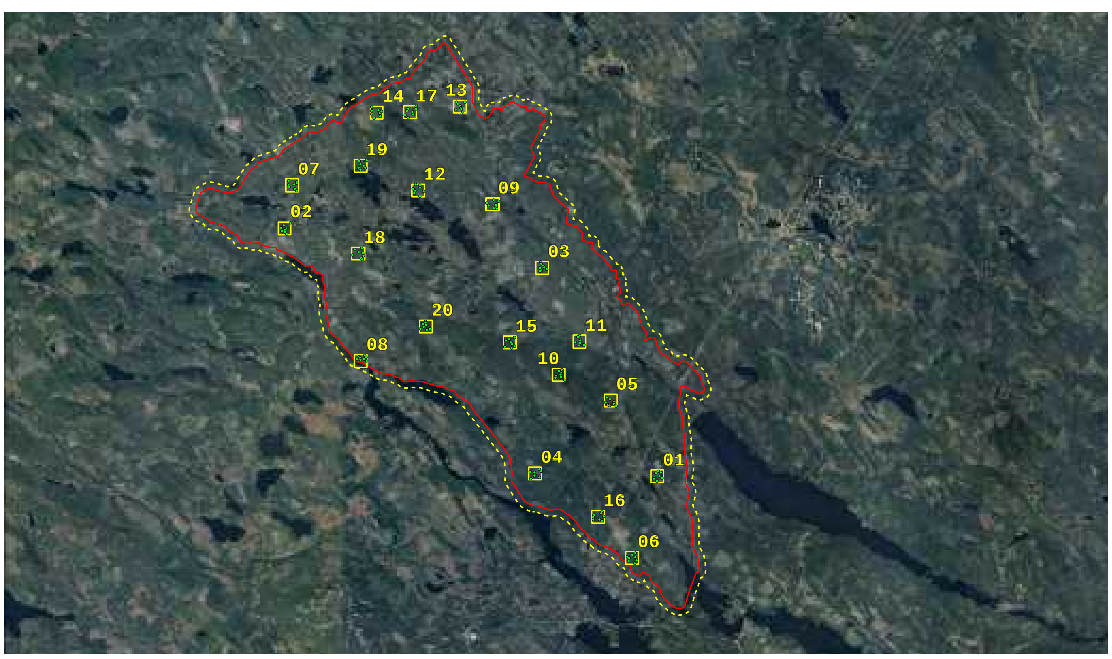

Figure 4. *The final sampling design for the Betsarn pre-winter grazing area. Tracts in yellow with 8 sample plots each. The dashed white line shows a 250 m buffer used for the sampling.*

volume was then converted to biomass using the coefficient 0.0148 kg/dm^3 derived from literature (Cronvall et al. 2025). Total cover and biomass for each areas was then estimated using the unbiased Horvitz–Thompson estimator.

We then combined the biomass estimate with data on lichen growth and reindeer daily lichen consumption to calculate the theoretical number of sustainable reindeer grazing days for each area, defined as the number of days for which reindeer grazing results in consumption of only the annual lichen growth each year. Following Cronvall et al. (2025) we used an annual lichen growth rate of 4 mm, and an average daily consumption of 2.25 kg of lichen per reindeer (including wastage) for the calculation.

For an area as large as the Betsarn pre-winter grazing land, there are extensive parts where lichen is so sparse that it is likely of less interest to reindeer, especially when snow cover is deep enough to make digging through the snow energetically demanding. Nevertheless, this sparse lichen cover can contribute notably to the total biomass. To assess the extent of this contribution, we also calculated grazing days using only sample plots with ground-lichen cover above 5 % and 10 %. Because the number of grazing days is difficult to interpret for a large area such as Betsarn, we additionally converted the results into sustainable grazing months per 1,000 reindeer.

Variance simulations

To investigate how the variance of the estimates is influenced by the number of tracts used, we used the collected field data and ran simulations with various numbers of tracts.

Variable	Description
Tract	Tract id
Sample plot	Sample plot id
Maturity class	Maturity classes:
	1. Unstocked forest (No seedlings)
	2. Thicket stage (Seedlings <1.3 m tall)
	3. Pre-commercial thinning stand (Trees >1.3 m tall, <10 cm DBH)
	4. Thinning stand (Trees ≥10 cm DBH)
	5. Forest mature for final felling (>80 years)
Tree height	Tree height (m)
Basal area	Basal area
Stems Total	Number of Stems Total
Stems Deciduous	Number of Stems Deciduous
Stems Pine	Number of Stems Pine
Stems Spruce	Number of Stems Spruce
Stems Contorta	Number of Stems Contorta
Stems Other Coniferous	Number of Stems Other Coniferous
Canopy Cover	Canopy Cover (%)
Shrubs present	Are Shrubs present?
Shrubs Cover	Shrubs Cover (%)
Shurbs Proportion Heather	Heather proportion of total shrub cover
Shurbs Proportion Crowberry	Crowberry proportion of total shrub cover
Shurbs Proportion Lingonberry	Lingonberry proportion of total shrub cover
Shurbs Proportion Blueberry	Blueberry proportion of total shrub cover
Ground lichen present	Are Ground lichen present?
Cover Reindeer Lichen	Cover Reindeer Lichen (in this case all pale lichens eaten by reindeer) (%)
Proportion *Cladonia stellaris*	*Cladonia stellaris* proportion of total reindeer lichen cover
Proportion *Cladonia rangiferina*	*Cladonia rangiferina* proportion of total reindeer lichen cover
Proportion *Cladonia arbuscula*	*Cladonia arbuscula* proportion of total reindeer lichen cover
Proportion *Cladonia uncialis*	*Cladonia uncialis* proportion of total reindeer lichen cover
Proportion *Stereocaulon sp.*	*Stereocaulon sp.* proportion of total reindeer lichen cover
Height Reindeer Lichen	Height Reindeer Lichen (Measured to the nearest 0.5 mm)
Cover Icelandic Lichen	Cover Icelandic Lichen (%)
Height Icelandic Lichen	Height Icelandic Lichen (Measured to the nearest 0.5 mm)
Cover Bare Ground	Cover Bare Ground (%)
Cover Bare Rock	Cover Bare Rock (%)
Cover Logging Residues	Cover Logging Residues (%)
Cover Dead Wood	Cover Dead Wood (%)
Arboreal lichen present	Are Arboreal lichen present?
Arboreal Total	Total amount of arboreal lichens:
	0. No lichen (< 0.5% of branches)
	1. Small proportion of branches (0.5 to <25%)
	2. Many branches (25-75%)
	3. Most branches (>75%)
Arboreal Alectoria Sarmentosa	Amount of *Alectoria Sarmentosa* (same classes as arboreal total)
Arboreal Bryoria sp.	Amount of *Bryoria sp.* (same classes as arboreal total)
Arboreal Usnea sp.	Amount of *Usnea sp.* (same classes as arboreal total)
Reindeer Grazing Class	Reindeer grazing vegetation classification

Table 1. Data collected from all sample plots within the RHP inventory.

Results

Lichen characteristics RHP inventory

Field data for 159 of the 160 sample plots in the RHP inventory was successfully collected. One plot was located under water in the river and therefore had to be excluded. Of the remaining plots, 118 contained ground lichens of at least one of the target species. *Cladonia rangiferina* and *Cladonia arbuscula* were clearly the most common species, accounting for 48% and 40% of the total lichen cover, respectively (Figure 5). Most other species never exceeded 10% cover in any of the plots (Figure 6). The mean cover of all lichen species combined was 14.9%, with a maximum cover of 78% in a single sample plot (Figure 7). The mean lichen height was 37.3 mm, with a maximum mean height of 60 mm in a single sample plot (Figure 8)..

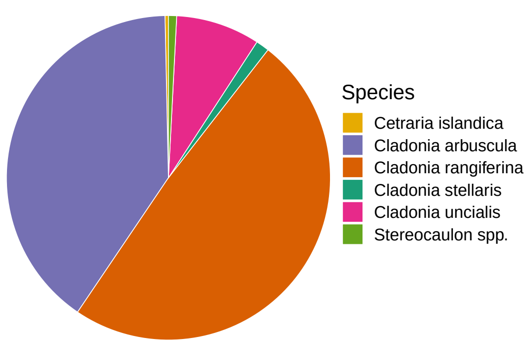

Figure 5. *The porportion for each species of the the total cover of ground lichen..*

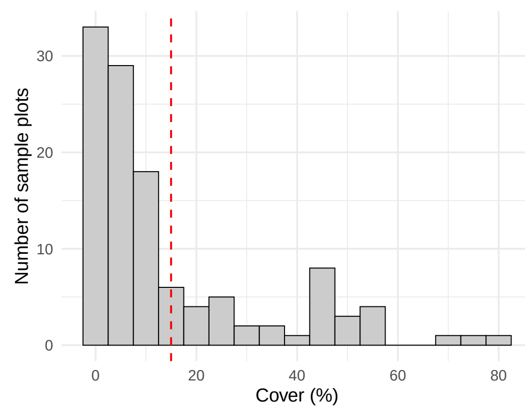

Figure 7. *Distribution of ground lichen cover for the RHP sample plots. The dotted red line shows the mean cover, 14.9%.*

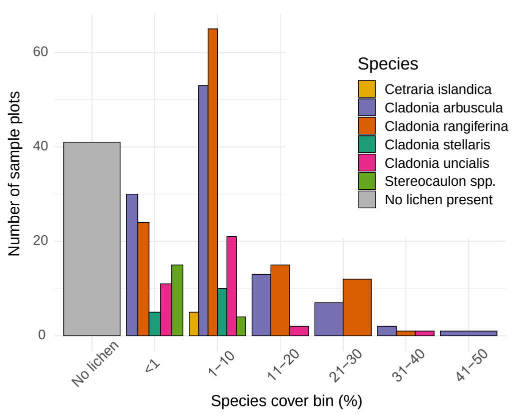

Figure 6. *Distribution of ground lichen species cover. Most species never exceed 10% cover in any sample plot and no species covers more than 50% of a sample plot.*

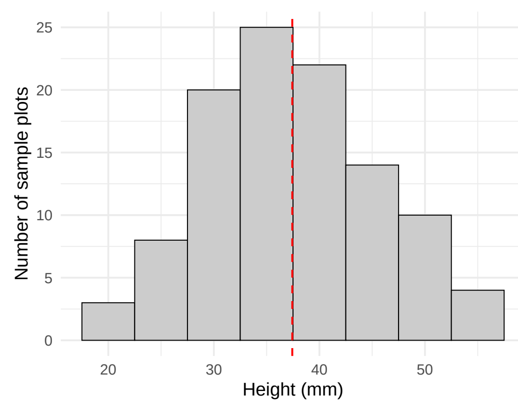

Figure 8. *Distribution of ground lichen height for the RHP sample plots. The dotted red line shows the mean height 37.6 mm.*

Lichen characteristics detailed inventory

Data from all 240 sample plots across the eight sites were collected in the field. The mean lichen cover was 28 % (Figure 9), with Sites 1 and 5 having a larger proportion of plots with low cover than the other sites (Figure 10). The mean lichen height was 28.3 mm (Figure 11). The distribution of lichen height was similar across most sites, except for Site 6, where no sample plot had a mean lichen height exceeding 30 mm (Figure 12).

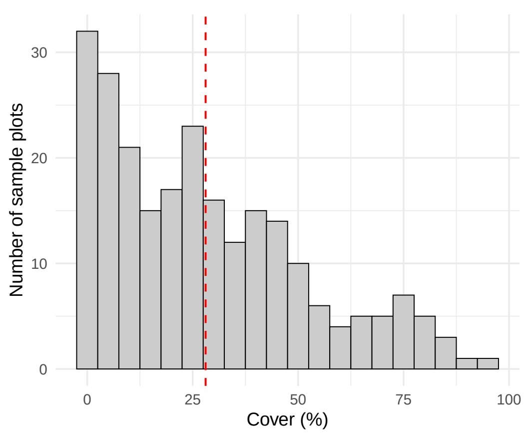

Figure 9. *Distribution of ground lichen cover for all detailed sample plots. The dotted red line shows the mean cover, 28%.*

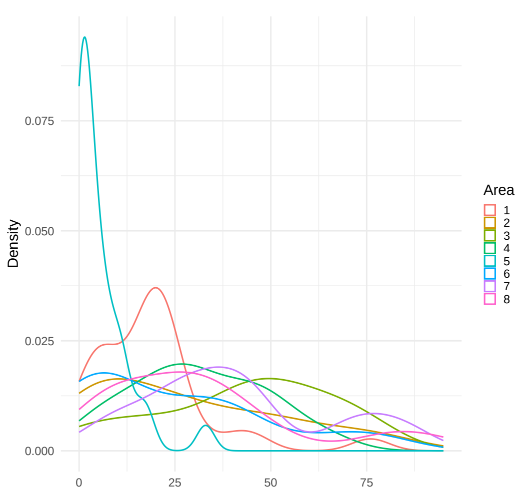

Figure 10. *Distribution of ground lichen cover for the different detailed inventory sites.*

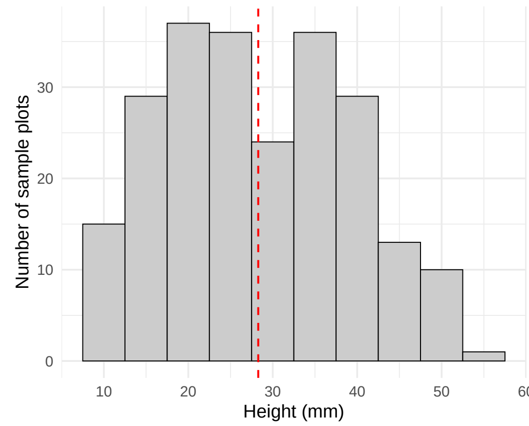

Figure 11. *Distribution of ground lichen height for all detailed sample plots. The dotted red line shows the mean height 28.3 mm.*

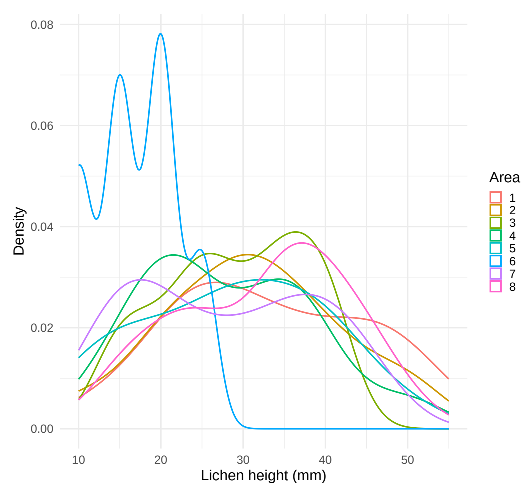

Figure 12. *Distribution of ground lichen height for the different detailed inventory sites.*

Time consumption

We calculated the time needed at each sample plot using time stamps from when data registering started and ended for each sample plot. the sample plots themselves took on average only 12 minutes for the RHP inventory (Figure 13) and about 2 minutes on average for the detailed inventory (Figure 14). This is, however, only a small part of the total time needed for the field work, which also includes transportation, locating the sample plots, etc. In general, each team was able to finish 2 RHP tracts—with a total of 16 sample plots—per day 10-hour working day, and at most 2.5 tracts

(20 sample plots). For the detailed inventory, they managed to complete 3 sites (90 sample plots) per day.

Estimations

The total ground lichen biomass for the full Betsarn area was estimated at 9,534 tonnes, equivalent to 494,784 grazing days or 16.49 grazing months per 1,000 reindeer, with a relative standard error (RSE) of 17% (Table 2). Excluding areas with less than 5% or 10% lichen cover reduced the number of grazing days by 6.3% and 12.8%, respectively. Based on these estimates, 1,000 reindeer can sustainably graze the area for 15.45 or 14.38 months, respectively.

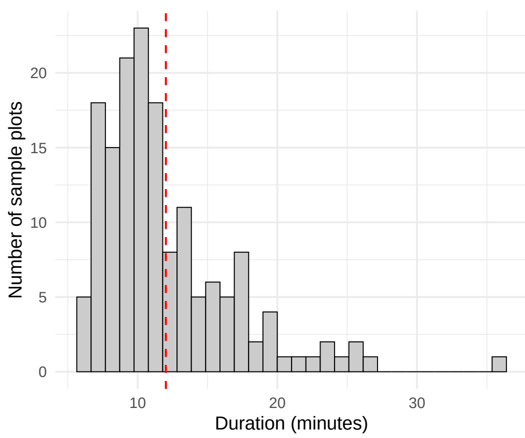

Figure 13. Distribution of durations for collecting data at the RHP sample plots..

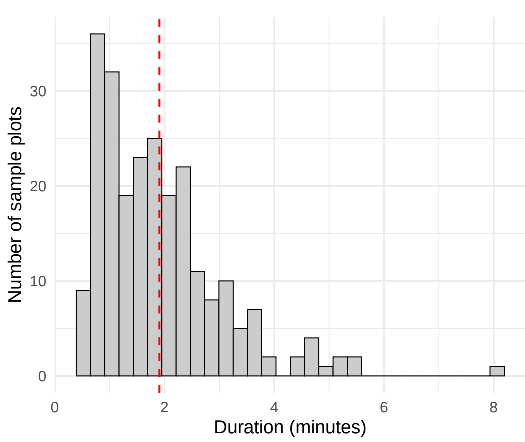

Figure 14. Distribution of durations for collecting data at the detailed sample plots.

The ground lichen biomass at the sites where the detailed inventory method was used ranged from 191 to 1,707 kg/ha, equivalent to approximately 15 to 113 sustainable grazing days (Table 3). The relative standard error (RSE) was relatively high at Site 5 (18.2%) and Site 6 (24.6%), but ranged from 8.8% to 13.4% at the remaining sites.

Variance simulations

Simulations with different numbers of tracts clearly showed that increasing the number of tracts used in the sampling design improved the precision of the estimates (Figure 15).

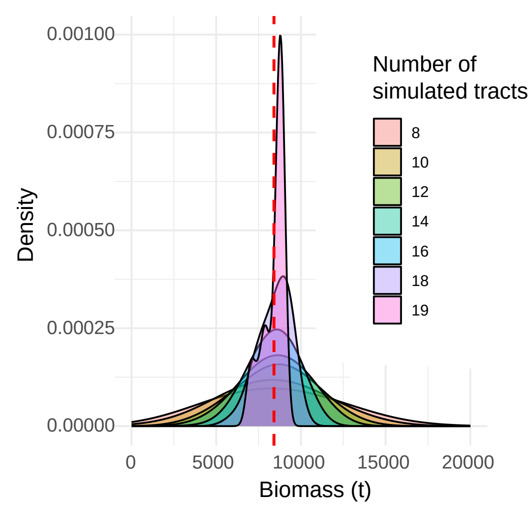

Figure 15. Simulated relationship between variance and the number of tracts used. The dotted red line indicates the estimated biomass.

Lichen cover	Area (ha)	Cover (ha)	Cover (%)	Biomass (tonne)	RSE (%)	Grazing days	Grazing months/ 1,000 reindeer
All data	18861	2083±367	11±1.9	9797±1620	17	494784±162214	16.49±2.76
lichen cover >5%	18861	1951±377	10±2.3	9098±1674	18	463441±166851	15.45±2.84
lichen cover > 10%	18861	1815±391	9.6±2.1	8410±1749	21	431258±174170	14.38±2.96

Table 2. Estimates for the RHP inventory. Lichen cover and biomass with standard error (SE). Reindeer grazing days, with uncertainties derived from the differences between years using the lower and upper bounds of the 95% confidence intervals for the estimates.

Site	Area (ha)	Cover (m^2)	Cover (%)	Mean height (cm)	Biomass/ha (kg)	RSE (%) Biomass	Grazing days
1	2.2	1880 ± 225	18.8 ± 2.2	3.1 ± 0.3	794 ± 78	8.8	49.5 ± 8.5
2	2.4	2853 ± 411	28.5 ± 4.1	3.0 ± 0.2	1150 ± 154	13.0	75.1 ± 18.4
3	3.2	4287 ± 341	42.9 ± 3.4	2.9 ± 0.2	1707 ± 150	13.4	112.8 ± 12.7
4	2.8	3107 ± 342	31.1 ± 3.4	2.8 ± 0.2	1200 ± 156	9.9	81.7 ± 12.7
5	2.9	550 ± 85	5.5 ± 0.8	2.3 ± 0.2	191 ± 35	18.2	14.5 ± 1.9
6	2.8	2473 ± 465	24.7 ± 4.7	1.5 ± 0.1	652 ± 160	24.6	65.1 ± 21.6
7	3.6	4090 ± 432	40.9 ± 4.3	2.8 ± 0.2	1498 ± 144	9.59	107.6 ± 16
8	2.7	3213 ± 366	32.1 ± 3.7	3.2 ± 0.2	1427 ± 161	11.3	84.5 ± 15.2

Table 3. Estimates for the detailed inventory. Lichen cover, height and biomass with standard error (SE). Reindeer grazing days, with uncertainties derived from the differences between years using the lower and upper bounds of the 95% confidence intervals for the estimates.

Conclusions and recommendations

Estimations

The estimates for the Betsarn area had an RSE of around 20%, which we consider acceptable. The simulations clearly show that increasing the number of tracts reduces variance. Ultimately, the choice of sampling effort depends on how small a change in lichen biomass one aims to detect, weighed against the time and cost of collecting field data. Combined with the data on time requirements, these simulations provide a robust basis for predicting the cost needed to achieve a desired level of precision.

When developing the detailed method, we originally used 40 sample plots per area, compared with 30 in this pilot study. For most of the detailed areas, the RSE (9.8–13.4%) was, despite this, lower than that of the areas in the original study (Cronvall et al. 2025). The two sites with high RSE in this pilot contained substantial amounts of bare ground, and the site with the highest RSE was a clear-cut area with only small tree seedlings. In such cases, the auxiliary data used for sampling—NDVI and tree height—are not very useful: bare ground has low NDVI values similar to those of lichen, and thus does not help reduce variance. It should be investigated whether other data might be more suitable to use for the sampling for these types of sites; for example, the NIR band from the multispectral orthophotos may be better correlated with lichen presence. In addition, more sample plots should be if the sites contain more variability in vegetation and ground cover, but in general, 30 sample plots should be sufficient.

To follow changes over time, we recommend that the plots are revisited every 5 years. This is the interval used in the Swedish National Forest Inventory and the National Inventory of Landscapes (NILS), and experience from these programs indicates that changes become observable over this period.

The actual use of an area will also depend strongly on winter weather and snow conditions, which influence the accessibility of lichen. Incorporating herders' knowledge of how the grazing area is used, together with improved documentation of the actual number of grazing days, would make it possible to better assess lichen availability and could support further development of these methods.

Reindeer grazing days

Using annual lichen growth to calculate the number of theoretical sustainable reindeer grazing days for an area provides a straightforward estimate of grazing capacity. However, this approach represents a theoretical maximum rather than a realistic expectation. In practice, reindeer do not consume only the annual lichen growth evenly across the landscape. Instead, they graze opportunistically where lichen is accessible through snow cover, concentrating their foraging in areas where cratering through snow is feasible. The calculated grazing days assume complete utilization of the entire lichen resource over time—an assumption that rarely holds in real-world conditions. Lichen distribution, landscape accessibility, snow and ice–related constraints on lichen access, and disturbances from human activities, infrastructure, predators, among other factors, means that not all lichen resources can be effectively exploited. Therefore, the estimated number of theoretical sustainable grazing days should be interpreted as an upper bound on grazing capacity rather than an achievable target, with actual sustainable use likely being substantially lower depending on local conditions.

To further refine these estimates, and to better understand their practical implications it is essential to integrate them with local knowledge from reindeer herders about how the area is used. This can be further supported by spatial information derived from GPS-collared reindeer and using drones to observe reindeer behavior. In addition, more knowledge is needed to better understand the factors influencing lichen availability. Forest structure and topography of the area can provide information on which areas are more or less likely to be available for feeding or become inaccessible for grazing due to snow and ice conditions. While studies demonstrate that reindeer select digging sites with lower snow depth and hardness than the average conditions within a feeding area, the snow conditions they are willing to dig through depend on available alternatives. Both the decision to initiate cratering at a specific location and the decision to remain in or abandon an area likely involve simultaneous assessment of multiple factors, including cues indicating the probability of finding forage beneath the snow cover (Heggberget et al. 2002).

To improve understanding and prediction of the effects of reindeer grazing, it would be valuable to study areas where lichen abundance has been quantified prior to grazing and where the number of reindeer and duration of grazing are known. This would allow assessment of changes in lichen abundance following grazing and, in turn, provide partial validation of the consumption values used in the calculations. To evaluate this approach, Sites 7 and 8 from the detailed inventory would be well suited for follow-up surveys after winter grazing.

This study included only ground lichens; however, arboreal lichens can provide an important dietary supplement, especially during periods of demanding snow and ice conditions. Incorporating arboreal lichen abundance estimates would therefore improve grazing day estimates.

Improved lichen map and model assisted estimates

Data from the RHP inventory can be used to refine the lichen map. To make the map even more useful—for example, when estimating lichen biomass for a subarea—model-assisted estimation can be applied. This approach combines values from a predicted map with an adjustment term derived from the difference between field measurements and model predictions. It is particularly useful when the number of available field plots is too low or not representative of the area.

As an illustrative example, we consider a hypothetical scenario in which a subarea of the Betsarn area is exploited and thus becomes unavailable for grazing (Figure 16). The subarea covers 867 ha, and according to the lichen map, ground lichen

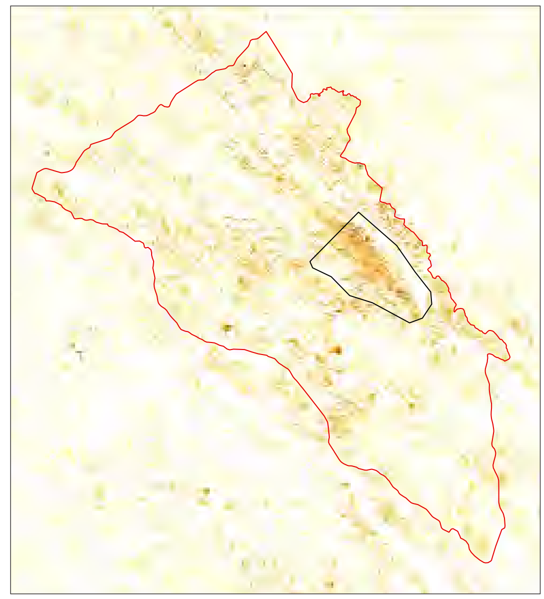

Figure 16. *The lichen map with the Betsarn area (red) and the subarea used for the example of a model assisted estimate (black).*

covers 108 ha (12.4 %). Field data indicate that the map generally underestimates lichen cover by 8.5 %; however, for this particular subarea the underestimation is substantially larger, at 21 %. Applying this correction yields an estimated lichen cover of 32 % (Model assisted estimate). Using the mean lichen height for the subarea (27.7 mm), we can estimate lichen biomass and the corresponding number of reindeer grazing days. This indicates that 68,907 grazing days would be lost if the subarea were excluded from grazing. That represents approximately 14 % of the total grazing capacity of the Betsarn area, despite the subarea accounting for only 6 % of the total area, reflecting its comparatively high lichen abundance.

Effects of adaptive forest management practices

Being able to estimate lichen cover for subareas also makes it possible to predict how different forest management strategies may affect lichen cover over time. Forestry plays a key role in mitigating and potentially reversing the long-term decline of lichen within the reindeer husbandry area. Although our detailed inventory of stands subjected to different forest management practices over time will provide further insight into the local effects of reindeer-adapted forestry, much is already known at a general level about measures that can promote lichen abundance. Such measures include increasing thinning intensity in young stands to create more open forests with greater light penetration, as well as removing logging residues (Skogforsk, SLU & Umeå universitet 2025). Using simulations with the forest decision support system Heureka, Eggers et al. (2024) showed that adapted forest management increased ground lichen habitat area by 22% within 15 years, while maintaining current forest management practices would result in an additional reduction in ground lichen cover

In addition to the lichen map used in this study, which reflects recent lichen conditions, we have also developed a historical lichen map representing the situation in the 1980s. This map can serve as a useful tool for identifying areas suitable for lichen restoration. Forests that had high lichen cover in the 1980s but no longer do so are likely to be particularly suitable candidates for restoration efforts.

Making the method more effective and accessible

To make the detailed inventory method easier to use and more widely applicable, further development is needed. In its current form, the use of drone imagery to derive auxiliary data for sampling—such as NDVI and tree cover—requires multiple site visits, and drone surveys are also highly weather dependent. Although such data provide up-to-date data with high spatial detail, they do not necessarily offer the most practical solution for repeated or large-scale applications. Instead, publicly available datasets—such as airborne LiDAR data and orthophotos (both RGB and infrared imagery) from Lantmäteriet, as well as high-resolution satellite imagery—could serve as alternative sources of auxiliary data, even if they are not fully up to date. Integrating these data with a web-based tool that supports sampling design would allow the number and spatial distribution of field sample plots to be determined prior to site visits. This would enable a relatively efficient estimation of lichen cover at the forest-stand scale before forest management actions are implemented.

The current approach also places high demands on centimetre-level precision in location accuracy to correctly match the 50 × 50 cm field-inventoried sample plot with a pixel in the auxiliary data. Determining the exact plot position is therefore time-consuming. Using a larger sample plot would, at least to some extent, mitigate the effects of slightly less precise positioning.

Both the efficiency of field work and the consistency of the field data can be improved by using automated methods. For this pilot study we relied on visual estimates to determine lichen cover. However, the photos from the small plots in the detailed inventory can be used to automatically estimate lichen cover with a neural-network model trained to identify lichen (see Appendix C for examples). We are currently developing this method, and if the sites are revisited, we recommend applying it to the photos from both sampling occasions to obtain more consistent and objective measurements of lichen cover. However, compared with other methods such as visual cover estimates or point-intercept methods, detailed image segmentation appears to yield lower lichen cover estimates (Lovitt et al. 2022; Cronvall et al. 2025), as is also evident from our examples (Appendix C). Therefore, it may be necessary to adjust the conversion factor between lichen volume and biomass.

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Appendix A
Descriptions of detailed sites

Site 1
Forest management adapted to promote ground lichens. Thinning with removal of logging residues (Swedish: GROT)

Estimated lichen cover: **18.8%**
Mean lichen height: **3.1 cm**
Estimated lichen biomass: **794 kg/ha**
Estimated reindeer grazing days: **49.5**

Site 2
Control for Site 1, Conventional forest management.

Estimated lichen cover: **28.5%**
Mean lichen height: **3.0 cm**
Estimated lichen biomass: **1150 kg/ha**
Estimated reindeer grazing days: **75.1**

Site 3
Forest management adapted to promote ground lichens.

Estimated lichen cover: **42.9%**
Mean lichen height: **2.9 cm**
Estimated lichen biomass: **1707 kg/ha**
Estimated reindeer grazing days: **112.8**

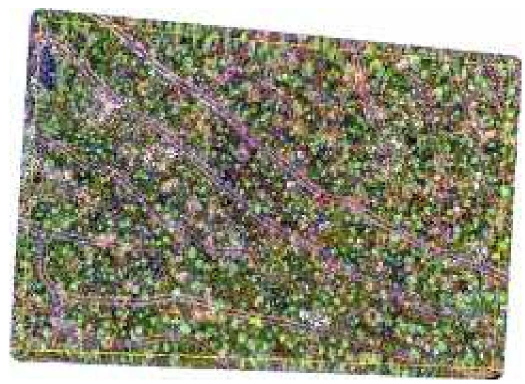
Site 4
Control for Site 3. Conventional forest management.

Estimated lichen cover: **31.1%**
Mean lichen height: **2.8 cm**
Estimated lichen biomass: **1200 kg/ha**
Estimated reindeer grazing days: **81.7**

Site 5

Forest management adapted to promote ground lichens.

Estimated lichen cover: **5.5%**
Mean lichen height: **2.3 cm**
Estimated lichen biomass: **191 kg/ha**
Estimated reindeer grazing days: **14.5**



Site 6

Forest management adapted to promote ground lichens.

Estimated lichen cover: **24.7%**
Mean lichen height: **1.5 cm**
Estimated lichen biomass: **652 kg/ha**
Estimated reindeer grazing days: **65.1**

Site 7
Very good winter grazing area in Övre Nyland

Estimated lichen cover: **40.9%**
Mean lichen height: **2.8 cm**
Estimated lichen biomass: **1498 kg/ha**
Estimated reindeer grazing days: **107.6**


Site 8
Very good winter grazing area in Övre Nyland

Estimated lichen cover: **32.1%**
Mean lichen height: **3.2 cm**
Estimated lichen biomass: **1427 kg/ha**
Estimated reindeer grazing days: **84.5**


Appendix B - Field data
RHP sample plots, Tract 1-10

Tract	Sample plot	Coordinates SWEREF 99	Maturity class	Tree height	Basal area	Stems Total	Stems Deciduous	Stems Pine	Stems Spruce	Stems Contorta	Stems Other Coniferous	Canopy Cover (%)	Shrubs Cover (%)	Shurbs Proportion Heather	Shurbs Proportion Crowberry	Shurbs Proportion Lingonberry	Shurbs Proportion Blueberry	Cover Reindeer Lichen (%)	Proportion *Cladonia stellaris*	Proportion *Cladonia rangiferina*	Proportion *Cladonia arbuscula*	Proportion *Cladonia uncialis*	Proportion *Stereocaulon sp.*	Height Reindeer Lichen (mm)	Cover Icelandic Lichen (%)	Height Icelandic Lichen (mm)	Cover Bare Ground (%)	Cover Bare Rock (%)	Cover Logging Residues (%)	Cover Dead Wood (%)	Arboreal Total	Arboreal *Alectoria Sarmentosa*	Arboreal *Bryoria sp.*	Arboreal *Usnea sp.*	Reindeer Grazing Class
1	1	N 7116105, E 662435	2			1	1	0	0	0	0	13	27	0	0	60	40										16	2	3	0	0	0	0	0	103
1	2	N 7116055, E 662535	5	20	28		3	3	22	0	0	63	76	0	0	60	40										0	0	0	0	3	1	3	3	107
1	3	N 7116035, E 662335	2			1	1	0	0	0	0	4	43	0	0	55	45	3	0	100	0	0	0	35	0		18	7	6	0	0	0	0	0	103
1	4	N 7115915, E 662495	5	19	33		9	6	18	0	0	91	26	0	0	75	25										0	0	0	2	3	2	3	1	107
1	5	N 7115865, E 662275	5	20	21		3	1	17	0	0	62	77	0	0	35	65										0	0	0	5	3	1	3	1	107
1	6	N 7115835, E 662595	3	10		83	80	0	3	0	0	89	1	0	0	100	0										0	0	0	0	0	0	0	0	208
1	7	N 7115805, E 662275	5	16	15		2	0	13	0	0	64	54	0	15	40	45										0	0	0	0	3	1	3	1	107
1	8	N 7115725, E 662405	4	8	13		1	12	0	0	0	34	27	70	30	0	0	1	0	100	0	0	0	45	0		0	0	0	0	1	0	1	0	506
2	1	N 7125895, E 647945	2			1	0	0	1	0	0	0	64	56	0	0	44										6	4	2	1	0	0	0	0	302
2	2	N 7125795, E 647665	3	3		12	0	12	0	0	0	15	81	0	1	34	65	0	0	20	80	0	0	45	0		0	1	8	0	1	0	1	0	103
2	3	N 7125705, E 647575	3	2		4	2	1	1	0	0	24	72	0	4	46	50	3	0	88	12	0	0	30	0		0	2	1	0	1	0	1	0	106
2	4	N 7125675, E 647775	4	16	12		4	4	4	0	0	39	86	0	1	50	49	0	0	91	9	0	0	55	0		0	0	1	0	2	0	2	0	106
2	5	N 7125625, E 647735	1										37	0	0	45	55										3	0	33	1	1	0	1	0	other
2	6	N 7125565, E 647605	4	18	19		1	12	6	0	0	63	91	10	20	35	35	0	0	82	18	0	0	40	0		0	2	0	1	3	0	3	1	103
2	7	N 7125535, E 647715	4	16	21		4	13	4	0	0	65	89	0	11	60	29	0	0	70	30	0	0	40	0		0	0	0	0	2	0	2	0	103
2	8	N 7125455, E 647805	4	11	10		0	10	0	0	0	58	37	0	6	47	47	0	0	10	90	0	0	20	0		0	0	0	1	1	0	1	0	103
3	1	N 7124345, E 657805	4	10	10		0	10	0	0	0	34	64	20	25	35	20	44	10	40	35	15	0	35	0		0	21	0	7	1	0	1	0	114
3	2	N 7124285, E 657825	4	12	11		0	11	0	0	0	29	32	50	15	15	20	52	1	34	45	20	0	35	0		1	24	0	5	1	0	1	0	113
3	3	N 7124205, E 657905	4	11	16		0	16	0	0	0	38	52	60	5	15	20	52	5	50	35	10	0	30	1	30	0	16	0	2	1	0	0	0	113
3	4	N 7124125, E 657945	4	11	10		1	9	0	0	0	17	44	25	40	20	15	27	5	65	25	5	0	35	0		0	23	0	5	2	0	2	0	114
3	5	N 7124115, E 657785	4	11	19		0	19	0	0	0	56	84	30	10	20	40	56	2	45	43	10	0	25	0		0	9	0	3	1	0	1	0	113
3	6	N 7124055, E 658055	4	13	14		1	13	0	0	0	26	72	40	30	20	10	22	5	45	40	10	0	35	0		0	3	0	1	1	0	1	0	115
3	7	N 7124025, E 657825	4	10	18		0	18	0	0	0	34	74	40	10	20	30	47	5	50	30	15	0	35	0		0	27	0	1	1	0	1	1	114
3	8	N 7123985, E 657785	4	11	18		0	18	0	0	0	51	36	40	5	40	15	51	5	45	45	5	0	30	0		0	19	0	6	1	0	1	0	113
4	1	N 7116175, E 657765	2			0	0	0	0	0	0	17	56	0	0	70	30										2	3	2	0	0	0	0	0	103
4	2	N 7116115, E 657835	4	18	21		7	5	9	0	0	43	95	0	0	53	47										0	0	0	0	3	0	3	1	103
4	3	N 7116085, E 657385	4	17	25		0	22	3	0	0	68	97	0	15	50	35	1	0	75	25	0	0	40	0		0	11	0	1	2	0	2	0	103
4	4	N 7116055, E 657565	2			5	4	0	1	0	0	23	72	0	20	35	45	2	0	60	20	20	0	30	0		2	29	0	0	1	0	1	0	103
4	5	N 7115965, E 657595	4	18	23		8	14	1	0	0	54	96	0	0	46	54										0	1	1	0	1	0	0	1	103
4	6	N 7115925, E 657555	4	19	23		5	18	0	0	0	62	79	0	0	65	35	3	0	49	49	0	2	45	0		0	27	0	1	2	0	2	0	103
4	7	N 7115855, E 657765	4	16	22		1	5	0	16	0	83	85	0	0	40	60										0	10	0	0	1	0	1	0	108
4	8	N 7115805, E 657425	4	18	36		5	24	7	0	0	82	73	0	0	40	60										0	0	0	0	1	0	1	0	109
5	1	N 7119015, E 660415	5	17	29		2	1	26	0	0	54	14	0	0	60	40										0	0	0	2	3	0	3	1	106
5	2	N 7118945, E 660535	3	7		213	199	0	14	0	0	97	27	0	0	100	0										0	0	0	0	0	0	0	0	208
5	3	N 7118835, E 660685	4	10	11		4	1	6	0	0	84	76	0	0	60	40										0	1	0	0	1	0	1	0	109
5	4	N 7118805, E 660375	3	10		13	1	0	12	0	0	26	87	0	40	40	20	5	0	49	50	1	0	40	0		0	1	1	0	3	0	3	0	106
5	5	N 7118765, E 660695	4	8	8		4	0	4	0	0	56	53	0	30	50	20										0	0	0	0	1	0	1	0	106
5	6	N 7118725, E 660465	4	21	29		0	29	0	0	0	29	91	0	10	50	40										1	0	0	6	1	0	1	0	103
5	7	N 7118685, E 660515	4	20	38		0	36	2	0	0	56	68	0	5	55	40	1	0	40	60	0	0	35	0		0	0	1	0	2	0	2	1	103
5	8	N 7118675, E 660775	4	12	21		9	5	7	0	0	82	86	0	0	60	40										0	0	1	2	2	0	2	0	109
6	1	N 7112875, E 661545	3	5		17	0	13	4	0	0	18	79	0	6	51	43	3	0	100	0	0	0	40	0		0	8	31	0	0	0	0	0	103
6	2	N 7112805, E 661425	3	6		24	0	15	9	0	0	26	64	2	4	58	36	23	0	98	1	0	1	45	0		1	4	28	0	0	0	0	0	103
6	3	N 7112745, E 661225	3	7		34	0	1	33	0	0	67	82	0	0	52	48										0	0	24	0	1	0	1	0	106
6	4	N 7112705, E 661535	3	6		17	0	11	6	0	0	36	83	0	2	46	52	2	0	99	1	0	0	40	0		0	13	21	0	0	0	0	0	103
6	5	N 7112695, E 661285	4	18	15		1	0	14	0	0	62	24	0	1	76	23										0	0	2	0	3	1	3	1	106
6	6	N 7112595, E 661595	5	21	19		2	13	4	0	0	48	95	0	0	65	35	1	0	20	75	0	5	35	0		0	4	1	6	3	0	3	0	104
6	7	N 7112565, E 661265	5	19	21		1	4	16	0	0	74	76	0	0	61	39										0	0	0	0	2	1	2	2	107
6	8	N 7112475, E 661525	5	19	6		2	2	2	0	0	44	96	0	0	45	55										0	0	2	1	2	0	2	0	103
7	1	N 7127555, E 647875	4	9	3		0	3	0	0	0	48	58	7	40	27	26	9	0	45	54	1	0	25	0		0	7	0	0	1	0	1	0	115
7	2	N 7127515, E 648185	4	12	9		0	8	1	0	0	67	70	11	15	40	34	3	0	60	40	0	0	45	0		0	3	0	0	1	0	1	0	103
7	3	N 7127465, E 648195	4	15	15		1	13	1	0	0	62	34	0	0	95	5	12	0	49	50	1	0	30	0		0	2	0	2	1	0	1	0	115
7	4	N 7127415, E 648095	4	13	10		0	9	1	0	0	42	50	0	11	42	47	7	0	55	43	1	1	35	0		0	7	1	0	1	0	1	0	115
7	5	N 7127375, E 647865	4	14	11		4	7	0	0	0	21	85	2	35	35	25	1	0	91	9	0	0	30	0		0	1	0	0	1	0	1	1	103
7	6	N 7127315, E 647905	3	12		6	0	6	0	0	0	16	36	4	56	20	15	12	0	35	64	0	1	20	0		0	14	1	4	1	0	1	0	115
7	7	N 7127245, E 648105	4	13	9		3	6	0	0	0	32	66	0	20	40	40	4	22	38	38	0	2	35	0		0	3	0	0	1	0	1	0	103
7	8	N 7127175, E 648185	4	12	6		4	2	0	0	0	32	85	1	15	45	39	0	0	100	0	0	0	25	0		0	1	0	0	1	0	1	0	208
8	1	N 7120675, E 650885	4	17	17		0	17	0	0	0	26	49	30	5	35	30	29	0	70	30	0	0	45	0		0	0	1	0	2	0	2	0	112
8	2	N 7120615, E 650645	4	11	5		0	5	0	0	0	26	78	40	10	40	10	19	0	70	30	0	0	50	0		0	0	0	0	1	0	1	0	115
8	3	N 7120605, E 650935	4	19	19		0	19	0	0	0	18	91	10	10	40	40	27	0	45	55	0	0	40	1	55	0	0	0	0	3	0	3	1	112
8	4	N 7120565, E 650675	4	7	10		0	10	0	0	0	21	76	55	10	20	15	6	0	100	0	0	0	55	0		0	0	0	0	1	0	1	0	506
8	5	N 7120525, E 650565	5	7	10		2	0	8	0	0	34	64	0	40	45	15	1	0	50	50	0	0	45	0		0	2	0	0	3	1	3	0	506
8	6	N 7120515, E 650855	4	14	25		0	25	0	0	0	53	83	25	0	50	25	46	0	40	55	5	0	30	0		0	6	0	3	1	0	1	0	114
8	7	N 7120505, E 650695	4	9	18		10	8	0	0	0	58	88	10	30	40	20	3	0	80	20	0	0	55	0		0	0	0	0	2	0	2	0	103
8	8	N 7120455, E 650945	3	2		5	0	5	0	0	0	13	46	10	15	55	20	72	0	35	45	20	0	20	0		8	14	5	0	0	0	0	0	113
9	1	N 7126795, E 655945	4	15	33		0	33	0	0	0	59	84	0	40	50	10	18	0	49	50	1	0	50	0		0	8	0	0	3	0	3	0	115
9	2	N 7126755, E 656145	Sample plot in river																																
9	3	N 7126685, E 655685	4	13	12		3	8	1	0	0	28	82	5	40	45	10	5	0	75	25	0	0	45	0		0	0	0	0	2	0	1	1	109
9	4	N 7126595, E 656025	4	13	14		2	10	2	0	0	49	68	1	39	35	25	14	0	65	30	5	0	45	1	80	0	0	0	0	3	0	3	0	109
9	5	N 7126585, E 655755	4	13	24		14	7	3	0	0	34	89	0	30	45	25	3	0	60	40	0	0	50	0		0	6	0	0	2	0	2	1	109
9	6	N 7126505, E 656045	4	16	10		0	10	0	0	0	6	77	50	15	25	10	78	0	34	25	40	1	40	1	5	0	0	0	0	2	0	2	0	111
9	7	N 7126475, E 655975	2			0	0	0	0	0	0	4	52	25	15	50	10	16	0	60	30	10	0	40	0		28	8	4	2	2	0	2	0	115
9	8	N 7126445, E 656065	5	17	24		7	12	5	0	0	64	89	0	20	45	35	2	0	100	0	0	0	50	0		0	1	0	0	3	0	2	0	104
10	1	N 7120105, E 658635	4	14	25		6	15	4	0	0	62	21	0	10	60	30										0	0	0	0	1	0	1	0	506
10	2	N 7120065, E 658545	3	5		34	23	0	11	0	0	34	87	0	40	20	40	3	0	50	50	0	0	20	0		0	5	0	0	0	0	0	0	106
10	3	N 7119965, E 658615	5	20	26		4	0	22	0	0	64	64	0	0	70	30										0	0	0	21	2	1	2	2	107
10	4	N 7119915, E 658595	5	20	29		14	0	15	0	0	71	84	0	0	45	55										0	0	0	12	1	1	1	1	109
10	5	N 7119865, E 658425	5	18	35		17	0	18	0	0	92	23	0	0	55	45										0	1	0	2	2	0	2	1	109
10	6	N 7119805, E 658605	4	14	30		9	3	18	0	0	77	88	0	0	40	60										0	0	0	0	2	0	2	1	109
10	7	N 7119795, E 658385	4	11	11		5	3	3	0	0	53	74	0	10	30	60										0	1	0	0	1	0	1	0	109
10	8	N 7119685, E 658755	5	14	34		2	0	32	0	0	82	13	0	0	55	45										0	0	0	2	2	0	2	0	105

Appendix B - Field data
RHP sample plots, Tract 11-20

Tract	Sample plot	Coordinates SWEREF 99	Maturity class	Tree height	Basal area	Stems Total	Stems Deciduous	Stems Pine	Stems Spruce	Stems Contorta	Stems Other Coniferous	Canopy Cover (%)	Shrubs Cover (%)	Shurbs Proportion Heather	Shurbs Proportion Crowberry	Shurbs Proportion Lingonberry	Shurbs Proportion Blueberry	Cover Reindeer Lichen (%)	Proportion *Cladonia stellaris*	Proportion *Cladonia rangiferina*	Proportion *Cladonia arbuscula*	Proportion *Cladonia uncialis*	Proportion *Stereocaulon sp.*	Height Reindeer Lichen (mm)	Cover Icelandic Lichen (%)	Height Icelandic Lichen (mm)	Cover Bare Ground (%)	Cover Bare Rock (%)	Cover Logging Residues (%)	Cover Dead Wood (%)	Arboreal Total	Arboreal *Alectoria Sarmentosa*	Arboreal *Bryoria sp.*	Arboreal *Usnea sp.*	Reindeer Grazing Class
11	1	N 7121455, E 659345	4	14	25		0	25	0	0	0	53	73	0	20	75	5	26	0	35	50	15	0	25	0		0	19	0	2	2	0	2	0	114
11	2	N 7121405, E 659275	4	12	18		8	5	5	0	0	69	12	0	10	75	15										0	13	0	0	1	0	1	0	109
11	3	N 7121245, E 659375	3	6		29	27	0	2	0	0	27	67	0	0	75	25	11	0	60	40	0	0	35	0		4	11	0	0	1	0	1	0	115
11	4	N 7121195, E 659365	3	3		16	7	7	2	0	0	43	27	0	20	50	30	34	1	74	25	0	0	40	0		11	9	0	0	0	0	0	0	114
11	5	N 7121175, E 659185	4	11	17		0	17	0	0	0	37	73	5	15	50	30	23	0	34	60	5	1	30	0		0	9	2	1	1	0	1	0	115
11	6	N 7121155, E 659375	3	3		21	17	3	1	0	0	64	26	0	25	40	35										0	3	0	0	0	0	0	0	103
11	7	N 7121075, E 659515	4	16	15		1	14	0	0	0	32	76	0	35	40	25	12	0	70	20	5	5	40	0		0	4	1	1	2	0	2	1	115
11	8	N 7121065, E 659315	4	10	8		0	8	0	0	0	26	54	10	25	40	25	74	0	25	60	10	5	25	2	25	0	5	1	0	1	0	1	0	113
12	1	N 7127415, E 652865	4	15	11		0	11	0	0	0	39	83	15	15	30	40	46	5	45	40	10	0	45	0		7	6	4	4	2	0	2	0	112
12	2	N 7127375, E 653055	4	16	11		0	11	0	0	0	27	84	25	40	25	10	34	1	55	44	0	0	40	0		6	5	5	3	3	0	3	0	112
12	3	N 7127285, E 653055	4	13	17		0	15	2	0	0	32	91	10	25	25	40	12	0	75	25	0	0	35	0		0	0	0	0	1	0	1	0	115
12	4	N 7127235, E 652775	4	11	13		0	12	1	0	0	32	54	40	15	40	5	47	0	40	35	20	5	45	0		1	1	0	3	1	0	1	1	114
12	5	N 7127165, E 652845	4	13	17		5	9	3	0	0	62	84	10	20	30	40	5	0	90	10	0	0	40	0		0	0	0	1	2	0	2	0	103
12	6	N 7127135, E 653185	4	13	13		0	12	1	0	0	48	76	20	40	30	10	12	0	40	60	0	0	35	0		1	7	0	1	1	0	1	1	115
12	7	N 7127075, E 652835	4	10	6		0	5	1	0	0	18	46	30	40	20	10	44	5	70	20	5	0	40	0		0	0	0	0	2	0	2	0	506
12	8	N 7126945, E 653035	1										82	49	40	10	1	6	0	90	10	0	0	45	0		0	0	0	0	2	0	2	0	502
13	1	N 7130655, E 654485	2			0	0	0	0	0	0	1	49	30	10	30	30	12	0	65	35	0	0	25	0		6	5	1	0	0	0	0	0	302
13	2	N 7130645, E 654825	2			0	0	0	0	0	0	0	58	15	10	45	30	2	0	40	60	0	0	35	0		4	3	6	0	0	0	0	0	302
13	3	N 7130575, E 654545	2			2	0	0	0	2	0	2	51	35	11	35	19	10	0	65	35	0	0	30	0		4	1	3	0	0	0	0	0	302
13	4	N 7130505, E 654635	3	8		13	1	4	8	0	0	36	59	45	7	25	23	6	0	19	80	1	0	35	0		0	2	0	0	1	0	1	0	106
13	5	N 7130425, E 654655	2			5	0	5	0	0	0	8	46	40	20	20	20	12	0	52	48	0	0	25	0		10	5	1	0	1	0	1	0	other
13	6	N 7130385, E 654685	2			0	0	0	0	0	0	0	53	45	2	35	18	6	0	60	40	0	0	35	0		8	7	5	1	0	0	0	0	301
13	7	N 7130365, E 654465	4	14	8		0	8	0	0	0	47	67	40	15	30	15	5	0	30	70	0	0	30	0		0	2	0	1	1	0	1	0	103
13	8	N 7130255, E 654725	2			6	4	2	0	0	0	3	27	5	38	38	19	3	0	50	50	0	0	25	0		2	42	2	0	0	0	0	0	301
14	1	N 7130455, E 651155	4	14	10		2	2	6	0	0	56	48	0	15	78	6										0	0	0	0	3	0	3	1	106
14	2	N 7130345, E 651415	3	5		9	2	2	1	4	0	22	54	1	45	30	24	3	0	82	18	0	0	40	0		0	2	6	0	0	0	0	0	103
14	3	N 7130315, E 651135	2			3	2	0	1	0	0	12	47	30	35	25	10	11	0	57	43	0	0	30	0		2	1	2	0	1	0	1	0	302
14	4	N 7130285, E 651525	3	9		13	5	0	2	6	0	26	42	0	0	40	60	0	0	100	0	0	0	25	0		0	1	21	0	0	0	0	0	103
14	5	N 7130215, E 651455	3	6		12	1	0	3	8	0	19	53	1	40	40	19	2	0	70	30	0	0	35	0		0	1	11	0	1	0	1	0	103
14	6	N 7130185, E 651145	3	2		4	3	1	0	0	0	7	34	65	5	15	15	14	0	47	53	0	0	30	0		0	1	1	4	1	0	1	0	302
14	7	N 7130095, E 651475	3	8		10	1	0	2	7	0	18	37	0	6	50	44	1	0	68	32	0	0	30	0		0	1	6	0	0	0	0	0	103
14	8	N 7130015, E 651245	2			1	1	0	0	0	0	3	68	42	37	18	3	1	0	52	48	0	0	30	0		3	2	1	1	1	0	1	0	302
15	1	N 7121385, E 656785	4	11	12		1	9	2	0	0	32	62	35	35	25	5	22	5	55	34	5	1	35	0		0	1	0	0	1	0	1	0	115
15	2	N 7121295, E 656565	4	14	20		14	2	4	0	0	69	91	0	0	40	60										0	1	2	0	1	0	0	1	109
15	3	N 7121255, E 656445	4	9	14		5	3	6	0	0	52	73	0	40	20	40	2	0	90	9	1	0	40	0		0	0	0	2	1	0	1	0	109
15	4	N 7121195, E 656645	4	10	11		0	9	2	0	0	59	82	10	30	45	15	23	0	40	50	10	0	35	0		0	9	0	0	1	0	1	0	115
15	5	N 7121115, E 656695	4	10	17		0	17	0	0	0	68	78	30	30	30	10	8	0	50	45	5	0	40	0		0	1	0	0	1	0	1	0	103
15	6	N 7121045, E 656785	4	8	10		3	4	3	0	0	23	24	0	10	40	50	1	0	50	50	0	0	35	0		0	0	0	0	1	0	1	0	503
15	7	N 7121005, E 656395	4	14	24		9	0	15	0	0	89	27	0	0	90	10										0	0	0	3	1	0	1	0	105
15	8	N 7120955, E 656655	4	9	11		0	11	0	0	0	41	97	25	50	20	5	12	0	74	25	0	1	50	0		0	2	0	0	1	0	0	0	115
16	1	N 7114525, E 660225	5	19	11		2	0	9	0	0	43	96	0	0	40	60										0	0	0	5	3	2	3	1	107
16	2	N 7114435, E 660205	3	4		8	0	0	8	0	0	14	56	0	0	55	45										0	6	21	0	1	0	1	1	105
16	3	N 7114365, E 659905	4	12	20		1	7	12	0	0	48	72	10	15	25	50	4	0	100	0	0	0	45	0		0	0	0	0	3	0	3	1	106
16	4	N 7114335, E 660305	3	4		18	3	1	14	0	0	21	44	0	15	60	25										0	13	16	0	0	0	0	0	105
16	5	N 7114295, E 659875	4	19	25		0	25	0	0	0	63	87	0	0	38	62										0	0	0	0	1	0	1	1	103
16	6	N 7114205, E 660125	4	10	15		3	2	10	0	0	64	91	10	20	40	30	4	0	45	55	0	0	50	0		0	1	0	0	3	0	3	1	106
16	7	N 7114195, E 659885	4	20	27		0	27	0	0	0	58	94	20	20	25	35	1	0	100	0	0	0	30	0		0	0	0	0	2	0	2	0	103
16	8	N 7114165, E 660225	4	10	21		0	4	17	0	0	67	84	0	10	25	65	2	0	85	15	0	0	50	0		0	1	0	0	2	0	2	1	106
17	1	N 7130485, E 652905	4	21	16		1	15	0	0	0	53	71	0	0	72	28	0	0	100	0	0	0	40	0		0	0	0	0	1	0	1	1	103
17	2	N 7130385, E 652575	3	9		11	0	7	4	0	0	43	39	40	40	18	2	0	0	100	0	0	0	50	0		0	0	0	1	1	0	1	0	103
17	3	N 7130375, E 652905	4	21	21		2	17	2	0	0	65	78	35	2	35	28										0	0	0	3	1	0	1	1	103
17	4	N 7130305, E 652545	4	14	8		1	2	5	0	0	68	66	10	35	50	3	0	0	85	15	0	0	50	0		0	0	0	0	3	0	3	1	106
17	5	N 7130265, E 652755	4	12	16		9	5	2	0	0	41	83	35	30	27	8										0	0	0	1	1	0	1	0	103
17	6	N 7130165, E 652775	4	11	8		3	4	1	0	0	37	72	35	35	25	0	0	0	0	100	0	0	10	0		0	0	0	1	0	0	0	0	103
17	7	N 7130145, E 652465	4	14	10		0	10	0	0	0	22	75	40	5	40	15	9	0	80	20	0	0	35	0		0	2	0	0	1	0	1	0	103
17	8	N 7130035, E 652585	4	11	11		2	9	0	0	0	22	54	60	9	25	6	6	0	34	65	0	1	40	0		0	3	0	0	1	0	1	0	103
18	1	N 7124885, E 650745	3	2		13	0	11	2	0	0	19	86	30	35	20	15	5	0	80	20	0	0	40	0		1	0	0	0	1	0	1	0	103
18	2	N 7124855, E 650475	3	3		22	0	22	0	0	0	42	64	50	25	20	5	54	0	35	50	10	5	30	0		1	1	1	0	0	0	0	0	113
18	3	N 7124755, E 650635	3	2		18	0	18	0	0	0	28	68	35	45	15	5	43	0	45	50	0	5	45	0		3	2	0	5	0	0	0	0	114
18	4	N 7124695, E 650795	3	3		23	0	21	2	0	0	29	86	30	40	25	5	43	0	54	45	0	1	30	0		1	6	0	1	0	0	0	0	114
18	5	N 7124615, E 650395	4	18	24		0	24	0	0	0	48	89	0	30	40	30	17	0	75	25	0	0	40	0		0	0	1	0	3	0	3	0	115
18	6	N 7124595, E 650815	3	3		17	0	17	0	0	0	33	73	40	30	20	10	42	1	38	50	10	1	35	0		1	11	0	0	0	0	0	0	114
18	7	N 7124505, E 650735	3	3		21	0	20	1	0	0	32	78	40	30	20	10	52	0	55	30	15	0	35	0		1	2	0	0	1	0	1	0	113
18	8	N 7124445, E 650785	3	3		10	0	10	0	0	0	28	53	35	35	20	10	57	0	30	60	10	0	30	0		2	8	1	1	1	0	1	0	113
19	1	N 7128365, E 650945	4	13	14		0	14	0	0	0	56	54	60	7	30	3	9	0	17	83	0	0	30	0		0	0	1	0	1	0	1	0	103
19	2	N 7128325, E 650665	1										64	35	9	45	11	6	0	31	69	0	0	30	0		2	1	17	0	0	0	0	0	other
19	3	N 7128225, E 650705	1										61	50	5	44	1	4	0	47	53	0	0	40	0		1	1	12	0	0	0	0	0	other
19	4	N 7128145, E 650845	3	5		20	4	0	16	0	0	36	58	2	47	43	2	0	0	100	0	0	0	60	0		0	0	0	0	1	0	1	1	106
19	5	N 7128125, E 650605	5	20	16		2	11	3	0	0	38	59	0	5	49	46	1	0	51	49	0	0	40	0		15	0	0	0	2	0	2	1	103
19	6	N 7128075, E 650635	4	15	15		0	15	0	0	0	23	12	0	0	85	15	1	0	91	9	0	0	35	0		46	0	11	0	1	0	1	0	103
19	7	N 7128055, E 650895	4	15	11		0	10	1	0	0	51	15	0	2	50	48	4	0	50	49	0	1	25	0		1	4	5	0	0	0	0	0	103
19	8	N 7127995, E 650705	4	17	13		0	11	2	0	0	39	59	0	9	52	39	1	0	95	5	0	0	35	0		3	0	8	0	1	0	1	0	103
20	1	N 7122025, E 653255	4	8	8		0	8	0	0	0	19	87	25	50	10	15	13	0	60	40	0	0	40	0		0	2	0	0	1	0	1	0	115
20	2	N 7121965, E 653255	4	10	17		0	17	0	0	0	61	77	30	20	25	25	5	0	75	25	0	0	50	0		0	1	0	0	0	0	0	0	103
20	3	N 7121905, E 653175	4	8	5		0	5	0	0	0	18	89	10	55	15	20	9	0	55	45	0	0	40	0		0	1	0	1	1	0	1	0	103
20	4	N 7121865, E 653285	4	9	10		0	10	0	0	0	28	76	25	45	20	10	9	0	80	20	0	0	45	0		1	2	0	0	1	0	1	0	103
20	5	N 7121805, E 653205	4	8	8		1	7	0	0	0	38	86	40	25	25	10	9	0	75	25	0	0	55	0		0	4	0	2	1	0	0	0	103
20	6	N 7121725, E 653445	4	9	15		0	15	0	0	0	41	58	35	30	25	10	16	0	50	50	0	0	50	0		3	9	0	0	1	0	1	0	115
20	7	N 7121715, E 653075	5	17	18		0	13	5	0	0	42	81	10	20	35	35	1	0	50	50	0	0	55	0		0	0	0	7	3	3	3	1	104
20	8	N 7121665, E 653305	4	9	14		0	14	0	0	0	44	73	35	25	30	10	4	0	70	30	0	0	50	0		0	4	0	3	1	0	1	0	103

Appendix B - Field data
Detailed sample plots

Site	Sample plot	Coordinates SWEREF 99	Lichen cover (%)	Lichen height (mm)
1	1	N 7124270.75, E 657637.25	15	35
1	2	N 7124267.25, E 657700.25	19	35
1	3	N 7124266.75, E 657661.25	20	30
1	4	N 7124265.75, E 657588.75	8	25
1	5	N 7124257.25, E 657698.75	24	30
1	6	N 7124232.25, E 657633.25	18	25
1	7	N 7124228.75, E 657657.25	21	25
1	8	N 7124228.25, E 657632.25	46	25
1	9	N 7124224.75, E 657673.75	40	20
1	10	N 7124204.75, E 657704.75	19	30
1	11	N 7124203.75, E 657604.75	22	25
1	12	N 7124202.75, E 657654.75	21	25
1	13	N 7124195.25, E 657591.75	0	10
1	14	N 7124192.75, E 657651.25	76	10
1	15	N 7124191.75, E 657705.25	18	15
1	16	N 7124182.75, E 657608.25	21	20
1	17	N 7124180.25, E 657658.75	26	35
1	18	N 7124176.25, E 657699.75	5	45
1	19	N 7124170.25, E 657648.25	23	40
1	20	N 7124161.25, E 657649.25	24	50
1	21	N 7124158.75, E 657596.25	3	45
1	22	N 7124142.25, E 657716.75	17	45
1	23	N 7124135.75, E 657703.25	30	35
1	24	N 7124133.25, E 657614.25	6	40
1	25	N 7124133.25, E 657623.75	14	50
1	26	N 7124128.75, E 657600.75	9	50
1	27	N 7124119.75, E 657669.75	4	55
1	28	N 7124115.25, E 657636.25	5	20
1	29	N 7124110.25, E 657691.75	10	45
1	30	N 7124108.25, E 657619.25	0	0
2	1	N 7123624.25, E 658255.75	10	20
2	2	N 7123617.75, E 658292.25	76	10
2	3	N 7123598.75, E 658337.75	2	25
2	4	N 7123592.75, E 658314.75	7	20
2	5	N 7123590.25, E 658259.25	53	25
2	6	N 7123581.75, E 658303.75	70	20
2	7	N 7123581.25, E 658268.25	41	20
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2	11	N 7123566.25, E 658289.25	67	30
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3	10	N 7121885.75, E 659267.75	67	30
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3	15	N 7121846.25, E 659256.75	19	25
3	16	N 7121829.25, E 659207.25	33	15
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4	9	N 7121582.25, E 659839.75	52	10
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4	14	N 7121547.25, E 659836.75	26	20
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5	9	N 7124109.25, E 651955.75	33	10
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5	15	N 7124077.25, E 652017.75	5	35
5	16	N 7124072.75, E 651944.25	5	40
5	17	N 7124071.25, E 652057.25	9	45
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6	4	N 7123890.25, E 651239.75	8	15
6	5	N 7123876.25, E 651298.25	78	25
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6	20	N 7123795.25, E 651252.25	31	25
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6	27	N 7123753.25, E 651263.75	45	20
6	28	N 7123742.75, E 651228.25	17	15
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6	30	N 7123729.25, E 651213.25	2	25
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7	3	N 7124125.75, E 651892.75	44	20
7	4	N 7124125.25, E 651874.75	85	10
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7	7	N 7124116.25, E 651950.75	29	15
7	8	N 7124113.25, E 652071.25	26	25
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7	15	N 7124077.25, E 652017.75	16	35
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7	21	N 7124046.75, E 651970.75	36	40
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7	24	N 7124025.25, E 652010.75	48	40
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8	6	N 7123857.75, E 651237.75	87	35
8	7	N 7123845.75, E 651193.25	43	25
8	8	N 7123843.75, E 651224.25	53	30
8	9	N 7123842.25, E 651283.25	4	20
8	10	N 7123839.25, E 651150.75	10	25
8	11	N 7123838.75, E 651333.25	95	15
8	12	N 7123837.25, E 651201.75	27	40
8	13	N 7123829.25, E 651236.75	25	25
8	14	N 7123817.75, E 651275.75	11	15
8	15	N 7123815.75, E 651146.25	7	20
8	16	N 7123807.75, E 651193.75	8	35
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8	22	N 7123788.75, E 651256.75	7	45
8	23	N 7123788.25, E 651221.75	27	50
8	24	N 7123780.75, E 651274.75	36	45
8	25	N 7123769.75, E 651187.75	17	35
8	26	N 7123765.25, E 651148.75	31	45
8	27	N 7123753.25, E 651263.75	36	40
8	28	N 7123742.75, E 651228.25	27	40
8	29	N 7123736.25, E 651211.25	7	35
8	30	N 7123729.25, E 651213.25	42	40

Appendix C - Image segmentation examples

Site 1, Sample plot 1
Cover: Visual estimate: 15%, Image segmentation: 3%

Site 2, Sample plot 1
Cover: Visual estimate: 10%, Image segmentation: 2%

Site 3, Sample plot 1
Cover: Visual estimate: 70%, Image segmentation: 13%

Site 4, Sample plot 1
Cover: Visual estimate: 52%, Image segmentation: 21%

Site 5, Sample plot 1
Cover: Visual estimate: 0%, Image segmentation: 0%

Site 6, Sample plot 1
Cover: Visual estimate: 1%, Image segmentation: 0%

Site 7, Sample plot 1
Cover: Visual estimate: 45%, Image segmentation: 28%

Site 8, Sample plot 1
Cover: Visual estimate: 19%, Image segmentation: 9%