

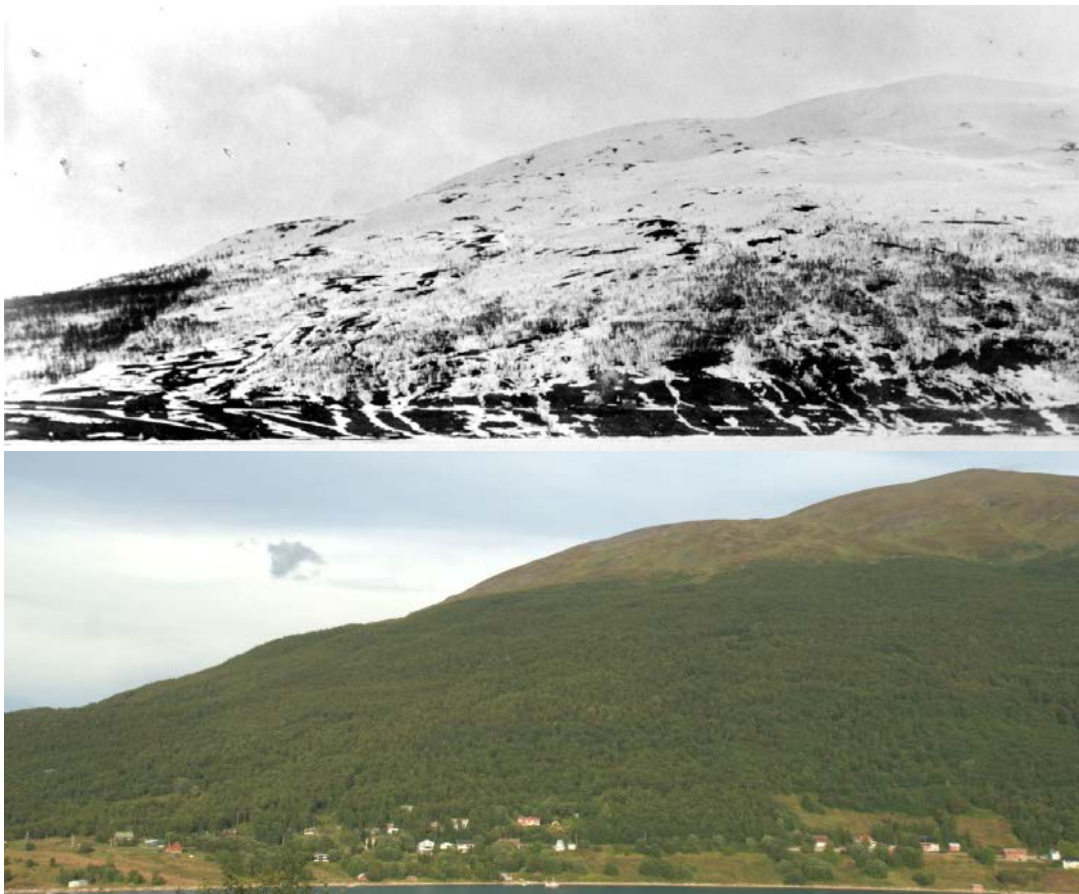


Examensarbete i ämnet biologi

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The shift in forest and tree limits in Troms County – with a main focus on temperature and herbivores

Kristoffer Normark





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*Förändringen av skog- och trädgränser i Troms fylke- med fokus på
temperatur och herbivorer*

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Keywords: forest limit, tree limit, temperature, herbivore

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Abstract

To better understand how various factors affect the establishment of forest and trees around the tree line-ecotone, this study was conducted in Troms County, Norway. The altitude of different forest and tree limits together with the surrounding vegetation type were collected during August 2011. Comparisons of the collected data were made with previously collected data from the same sites conducted 1914 and 1915. On average the forest limit has expanded with 26 meters in altitude, however, an expansion is not statistically significant for the whole area. The tree limit has significantly expanded in altitude. At all weather stations the temperature sum and length of the growing season have increased which is proposed to have positive effects on sapling establishment. There is no significant correlation between the change in sheep density in relation to the shift in forest and tree limit. The shift in reindeer density did not correspond to the shift of forest limit, but to the shift in tree limit. However the coefficient of determination was low which means that reindeer only accounts for a small part of the altitudinal shift. At many sites where the tree limit has expanded, reindeer density has declined which might have provided for new plants to establish and older to grow in size. The altitude of the forest and tree limits increases with increasing distance to the coast, most likely due to the degree of maritimity. It should also be noted that the magnitude of the shift in the limits, decrease with increasing distance to the coast. With reduced amount of reindeers and increased temperature vegetation changes have occurred. The amount of birch forest has increased, most likely, in expense of declined willow-thickets. Also abundance of alpine lichen/moss heath has increased, which might be a result of reduced grazing by reindeers.

Sammanfattning

För att bättre förstå hur olika faktorer påverkar etableringen av skog och träd i och kring trädgränsen, utfördes denna studie i Troms fylke, Norge. Altituden av olika skogs och trädgränser samt vegetationen 200 meter nedan och ovan respektive gräns, samlades in under augusti månad 2011. Jämförelser av det insamlade data gjordes med tidigare insamlat data från samma platser utfört 1914 och 1915. Skogsgränsen har i genomsnitt expanderat med 26 meter i altitud, men en expansion för hela området är inte statistiskt signifikant. Trädgränsen har expanderat vilket är statistiskt signifikant. På samtliga väderstationer har både temperatursumman och växtperiodens längd ökat vilket tros ha en positiv påverkan på plantornas etablering. Det finns ingen signifikant korrelation mellan förändringen av ren och förändringen av skog och trädgräns. Inget signifikant samband erhöles för förändring ren och förändring skogsgräns, men ett signifikant samband erhöles mellan rendensitet och förändringen av trädgränsen. Dock var förklaringsgraden låg vilket betyder att ren endast förklarar en liten del av förändringen av trädgränsen. Vid flertalet av de trädgränser som expanderat har rendensiteten minskat vilket kan betyda att en minskning i renantal möjliggjort för nya trädindivider att etablera sig samt gamla att tillväxa. Altituden för skogs- och trädgränser ökar med ökat avstånd från kusten mest troligt på grund av en maritim gradient. Vidare kan konstateras att storleken på gränsernas förändring minskar med ökat avstånd till kusten. Med minskat antal ren och ökad temperatur har vegetationen förändrats. Mängden björkskog har ökat, mest troligt, på bekostnad av videsnårklassen. Mängden lav- och mosshed har ökat, vilket kan bero på minskat bete av ren.

Introduction

In the Fennoscandian mountain range climate and grazing are two important factors influencing the altitudinal position of the uppermost forest- and tree-limit. The forest-limit represents a clearly defined limit between the sub-alpine birch forest (*Betula pubescens* spp. *czerepanovii*) and the alpine heath, while the tree limit in our study consists of the highest located tree (see figure 2). The tree limit represents the zone where alpine heath meets the subalpine birch forest. Studies have shown that climate change might have impacts on the environment (Allen et al. 2010), making

alpine heaths especially grateful to study since these represent a sensitive area for much of the vegetation (Went 1953; Oechel et al. 1993; Chapin et al. 1995; Starfield & Chapin 1996; Harsch et al. 2009). Particularly the zone around the tree-limit is profitable to study as many of the species found are living within the limit of their ecological niche (Kallio & Sonesson 1979; Kullman 2001).

The mountain birch (*Betula pubescens* spp. *czerepanovii*) is widely spread around the Scandinavian mountain chain and usually constitutes the tree limit. Factors limiting the distribution of tree growth are mainly the length of the growing season and temperature sum (Sykes et al 1996). Particularly milder winters, warmer summers, prolonged growing season and increased precipitation contributes to species richness (Michelsen et al. 2011) and tree limit advancement (Kullman 2002), sometimes as much as 100-165 m horizontal (Kullman 2001). This is probable due to reduced risk of drought and frost damage during the winter-time leading to an increased survival of saplings (Persson 1998). However there are still places where the plants would not be able to establish itself despite a more favorable climate. Examples of these are the often snow-free convex hills where erosion by wind exposes the sandy soils which reduce water retention and increases the risk of frost heaving of plants (Holtmeier et al. 2003). But also wind alone has proven to set the limits at which trees can grow (Daubenmire 1954). Tree line movement is not a new phenomenon. Ever since the last ice-age traces of a lower and higher located tree-limit has been found (Kullman 2002; Kjällgren & Kullman 2005). Some studies also claim that the tree limit is affected by the distance to the ocean (Wardle 1993; Kjällgren & Kullman 2002; Wöhl 2008). Some suggest that areas previously used for grazing by livestock (Odland et al. 1992) and anthropogenic activity such as collecting of wood account for a large part of the tree limit movement as they slowly return to being reforested again (Hester & Brooker 2007; Bryn 2008; Karlsson 2008). This seems to have a major part in the debate on the shift in tree limit, however, it does not mean that one rejects climate change as a contributing factor (Hofgaard 1997; Cairns & Moen 2004; Fasel et al. 2007; Hester & Brooker 2007; Tømmervik et al. 2009; Hofgaard et al. 2010; Boegart et al 2011).

In Norway farmers allow their goats, sheep and cows to graze in the forests and the upper mountain slopes and the Sami people have had the reindeers in the mountains during summertime (Austrheim & Eriksson 2001; Moen & Keskitalo 2010). Many suggest that this way of utilizing the forest and land affects the species composition and sets limits for tree growth (Hofgard 1997; Rössler et al. 2008; Tømmervik et al. 2009; Hofgard et al. 2010; Moen & Keskitalo 2010; Olofsson et al. 2010; Speed et al. 2010). A trial with different densities of sheep inside enclosures revealed that birch plants with a diameter <15mm and a height of 1-1.3m was sensitive to grazing by sheep (Speed et al. 2010). Intensive grazing has shown to have a large impact on species composition and vegetation biomass (Olofsson et al. 2010) and arctic ecosystem in certain are supposed to be sensitive to this kind of phenomenon (Van der Wal 2006). A study investigating browsing compared to climate change at four sites in central Norway showed that the temperature and moisture had increased within the area but that it mainly concerned the winter months (Rössler et al. 2008). Since tree-limit advancement due to climate change fundamentally is based on a prolonged growing season (Kullman 2002) it seemed unlikely that the advancement could be explained by climate change but of reduced browsing.

Besides sheep and goats, reindeer husbandry is a common activity which in centuries has fed families of the indigenous Sami people in Troms County. There have been several factors, mostly political, making reindeer herding difficult to practice (Lundmark 2002; Sverige. Regeringen 2005; Gauslaa 2007; Samer 2011) and at different times, pastures have been so strained that commissions have been send out to investigate the grazing conditions. It is the recorded data from one of these commissions "The 1913 Swedish and Norwegian reindeer herding delegation" (Norsk-Svenska renbetesdelegationen af 1913 års renbetestaxering) that mainly makes the basis for this thesis.

With the underlying background information of the introduction I would like this study to examine: whether (1) forest and tree limits have expanded in Troms County during the past 100 years; if (2) the temperature have increased during the same period and if it may have affected the forest and tree limits; if (3) there is a relationship between the altitude of the forest and tree limits and the distance to the coast: and (4) if the vegetation around the tree line-ecotone has changed.

Materials and methods

Study site & back ground information

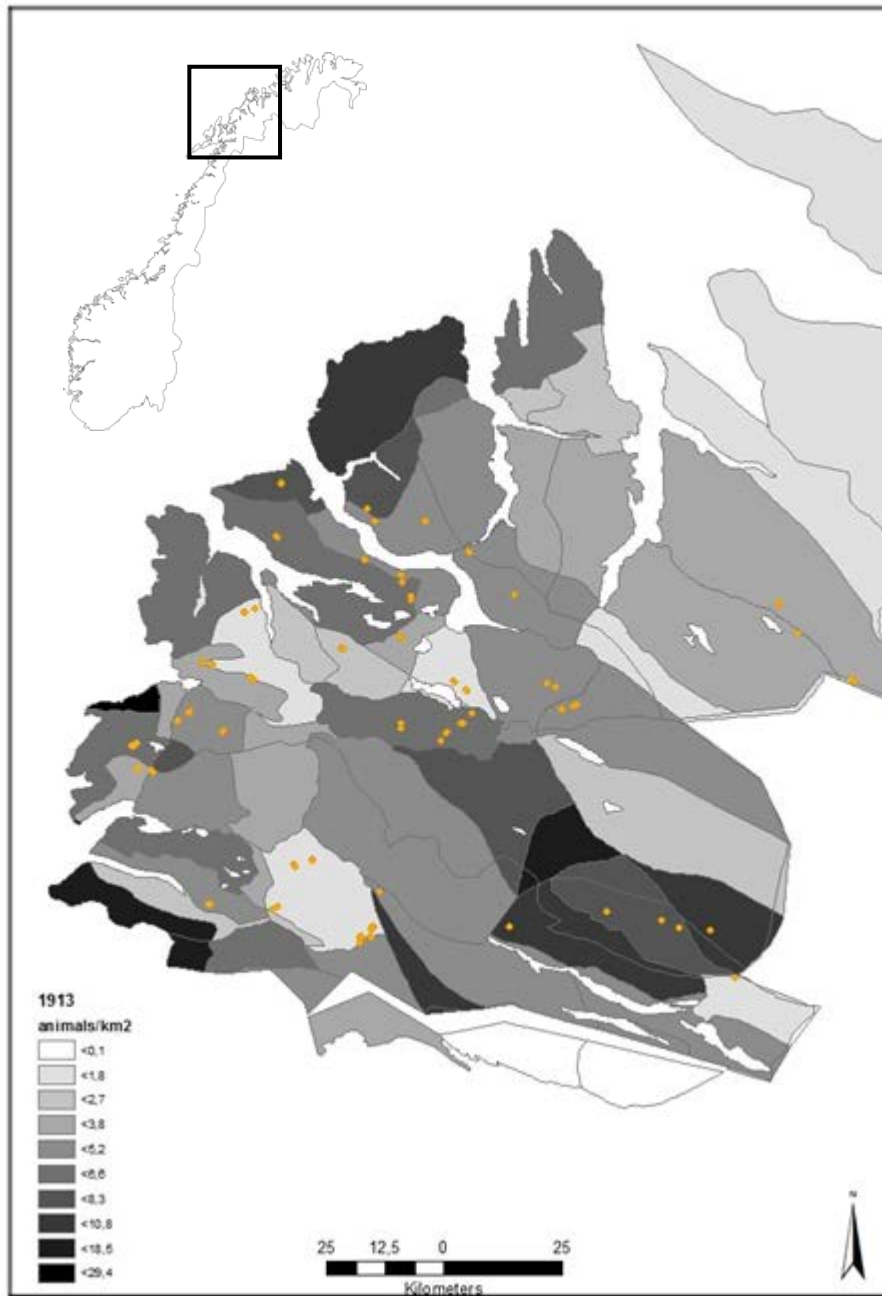


Figure 1 Map of Troms County (1913). Darker colors indicate higher density of sheep and reindeer. Orange dots are sites where forest and tree limits have been collected.

The study was carried out in Troms County, Norway. As a basis we had “The 1913 Swedish and Norwegian reindeer herding delegation” (renbeteskommissionen af 1913). The 1913 Swedish and Norwegian reindeer herding delegations main task was to investigate the vegetation, to get a better



Figure 2 Photo illustrating forest and tree limit. Photo: Åsa Lindgren.

view of the grazing potential in Troms County. Vegetation type transition along approximately 2000 km of line transects were therefore noted 1914 and 1915 and we have found at least 50 historical transects crossing the transition of subalpine birch forest into alpine heath. In the historical data, both the altitudinal and the geographical position were noted. Additionally, several of those forest and tree line locations were photographed 1914. By revisiting the historically documented sites, we have been able to document changes in the forest and tree line position both by GPS position, the altitude and visually by photographs. We have defined forest as trees with a height ≥ 2 metres and a canopy cover $\geq 30\%$, similar to the historical data set (see also, Boegart et al. 2011). The forest-limit represents a clearly defined limit between the sub alpine birch forest (*Betula pubescens spp. czerepanovii*) and the alpine heath, while the tree limit in our study consists of the highest located tree >2 meter height (see also, Wardle 1971; Kullman 2001)(see figure 2). Besides a description of each transect there was a map that showed the position of every single transect. As some changes in the landscape have occurred since the map was drawn we decided to transfer the transects to a digital topographic map. Where each transect crossed a forest/tree limit a waypoint were placed out and named with a number. I read the descriptions of each transect and the ones who obtained altitude when passing forest- or tree limit were sorted out. The data were transferred to two Garmin GPS units, a "Legend HCx" principally used and a "Colorado 300" who worked as an extra resource if facing problems. During fieldwork each waypoint was tracked with GPS and then the direction of the transect has been located using a map and compass.

Sheep and Reindeer data

To determine the grazing pressure from sheep and reindeer in Troms County 1913 and 2011, I had to locate a certain number of animals within a geographic area. As far back as 1918 the Central bureau of Statistics (ssb.no) in Norway had noted the number of sheep within each municipality in Troms. To make a comparison I also used statistics from 1999, which gets to represent the number of sheep 2011, as these were presented in the same way as statistics from 1918. During the 1913 Swedish and Norwegian reindeer herding delegation, the number of reindeer per reindeer district was noted. Thru reindrif (reindrif.no) and the four northernmost Sami villages in Sweden I collected the current number of reindeer per district.

Climate data

I collected climate and weather data from the Norwegian Climatic Institute (eklima.no), which possesses data from most of the active and former active weather stations in Norway and the Swedish Metrological Hydrological Institute (smhi.se) (table 1). The climate data that are documented from 1913 and earlier have proved to be extremely limited, especially temperature-based data. Because of this it has not been possible to match certain average temperatures to specific inventory sites. Thus an overall change in temperature for the entire area has been studied. Temperature data was collected as monthly mean values and divided into normal periods of 30 years when possible, sometimes there have been gaps in the time series so that normal periods have

been impossible to construct. The only weather station in Troms recording temperature before 1913 was situated in Tromsø at the altitude 20 m.a.s.l. and from that data it was possible to construct normal periods (table 1). In lack of temperature observations around Troms County, I had to include some weather stations outside Troms as well. Alta situated in west Finnmark shows a big variation when comparing temperatures from the end of 19th century with the beginning and end of 20th century and as Alta is a coastal town it was interesting to compare with Kautokeino situated in the inland of Finnmark at the altitude 319 m.a.s.l. I also included data from weather stations located in Karesuando, Kvikkjokk and Abisko. Since temperature sum and length of growing season is believed to affect plant growth, these categories have been investigated. These have been calculated by interpolate 30 year monthly averages receiving an average temperature (C°) for each day.

Table 1 Weather stations, location and altitude, from which temperature data has been collected and used for in this study. Normal periods and average temperature divided into 1st (1900) and 2nd (2000) period.

Location	Country	County	Altitude (m.a.s.l.)	1 st Period normal / average temperature	2 nd Period normal / average temperature
Alta	Norway	Finnmark	31	1871-1900	1981-2010
Torsvåg	Norway	Troms	21	1933-1962	1982-2011
Tromsø	Norway	Troms	20	1871-1900	1981-2010
Tromsø	Norway	Troms	100	1921-1950	1980-2011
Kautokeino	Norway	Finnmark	319	1889-1902	1981-1996
Karesuando	Sweden	Norrbottn	326	1890-1915	1980-2010
Abisko	Sweden	Norrbottn	408	1913-1932	1990-2010
Kvikkjokk	Sweden	Norrbottn	336	1890-1915	1980-2010

Forest and tree limit vs. distance to coast

The distance from each site to the nearest coast line were measured with measure tool in ArcGIS (ArcMap version 9.3.1. ESRI 2009) and a ruler on a map. During the analysis in minitab 16.0 (Minitab® 2010), I chose to logarithm the distance to the coast to receive a linear relationship. In order to compare the shift in forest and tree limit with the distance to the coast I used the logarithm of the distance to the coast.

GIS (Geographic Information System)

To be able to compare the historical densities of reindeer and sheep with the densities of today, I used grazing districts of reindeer and the municipalities of Troms County. The borders and also the areas of the different geographic regions have changed over time, therefore a comparison between years would not bring any relevant answers and that is why I have used ArcGIS 9.3.1. With this program I have digitalized old maps of municipalities and grazing districts. The reindriftno has a WMS service which allows people to take part of information concerning reindeer husbandry in Norway. I have used the district borders from the WMS service as a background layer which then could be depicted. I received the municipalities of Troms, 2011, as a shape file. The municipalities of Troms 1918, the grazing districts of 1913- and 2011 were digitalized as feature classes and were only made up by lines. I therefore changed all of the layers to polygons using “feature to polygon-tool”. I made a new column in the attribute table which was named “reindeer” or “sheep” so that each polygon could receive a number of animals. Many of the coastal municipalities contain a lot of ocean which affect the animal per square kilometre. Therefore it was important to exclude areas containing water and that concerned large lakes as well. I added a second column in the “attribute table” named “typ”. The “typ” could then be divided into “1” or “2” where “1” represented land and “2” represented water. I used a tool called “cut polygon” which divides polygons into minor polygons. Depending on whether the polygon was located on land or in water I categorized it as “1” or “2”. Still the different polygons contained animals, even those located in water. Therefore I added

a third column named “factor” which itself was categorized in “0” and “1”. I used “field calculator” to set an equation based on the amount of animals in each polygon, “typ” and “factor” resulting in the polygons on land containing animals which was not the case for those situated in water. I digitalized large lakes from the 1913 reindeer district map which I used to erase lakes from all maps. I exported tables of the polygons situated on land and the areas of polygons originated from the same municipalities was “summarized” and “joined” into the layer of which it was originated. I added new columns in the “attribute table” named “boskap/areal” and “boskap/km²”. These were calculated with “field calculator”. The last step in the process is to add the reindeer layer to the sheep layer which finally shows the total number of animals per square kilometre within each polygon.

Data analyses and Statistics

When the statistical analysis has been implemented, I have been using ArcGis 9.3.1 , Microsoft Excel and Minitab 16.0. Raw data, which contained the amount of reindeer- and sheep per square kilometer- and also total amount of grazing animals per square kilometer within a polygon, I received from ArcGIS. The amount of municipalities at 1913 tended to be larger and therefore smaller in surface compared to the municipalities of today. I considered this to complicate the analysis when comparing areas at various times as for example three polygons in 1913 could represent one polygon at 2011. The resolution of data in 1913 would thus be higher than in 2011, which would not give a true picture. I therefore matched municipalities and reindeer districts 1913 together roughly fitting municipalities and reindeer districts of today. Then I calculated a mean value of the different parameters, such as total number of grazing animals, sheep- and reindeer density, to better fit the 2011 parameters. The waypoints from the forest and tree limit inventory has also been added linking each point to a specific animal density. In Excel, I made graphs based on the changes in forest and tree limits with the change in total number of animals, change in reindeer density and the change of sheep density. They gave a first indication of any correlation between different parameters. Furthermore, I exported the data in Excel into Minitab 16.0 to investigate correlation, covariance, and perform linear regressions, one and two-tailed t-test analysis. The level of significance was set at $P = 0.05$. Performing t-tests the following hypothesis was used.

One tailed t-test:

$$H_0: \mu_1 > \mu_2$$

$$H_1: \mu_1 = \mu_2$$

Two tailed t-test:

$$H_0: \mu_1 = \mu_2$$

$$H_1: \mu_1 \neq \mu_2$$

Vegetation classes

To describe the properties of soil and vegetation, a classification system was developed by the 1913 Swedish and Norwegian reindeer herding delegation (renbeteskommissionen af 1913). This classification system was applied when conducting the recent mapping 2011 (table 2). The different layers are divided into a "forest-layer", such as birch forest, a "thicket-layer" which includes species like sallow and dwarf birch (*Betula nana*) "Grass- and herbal plant-layer" deals with everything from grasses *Deschampsia flexuosa* to herbs such as *Geranium sp.* "Shrub-layer" deals with shrubs like *Vaccinium myrtillus*, *Empetrum sp.* and *Vaccinium uliginosum*. Finally there is the "Lichen-layer" where the inventories of lichens are handled. As two classes “lichen heath” (Ea) and “moss heath” (Eb) was very similar to each other, I thought that the risk of over or underestimating any of them was imminent. Therefore, I summarized them into one class “lichen/moss heath” (Ea/Eb). During field work 2011, I collected the distance each vegetation class occurs, starting 200 m below the forest limit up to 200m above. I made the same procedure for the tree limit. If the distance

between the forest and tree limit proved to be less than 400m, I mapped the entire route, if longer distance, only 400m was mapped i.e. 200m above the forest limit and 200m below the tree limit and also distance between forest limit and tree limit was recorded. When the inventory was executed in 1914 and 1915 the motive was to objectively collect data, observe the surroundings and converse with the native people to get an overall picture (renbeteskommissionen af 1913).

Table 2 Vegetation classes based on soil properties and vegetation (renbeteskommissionen af 1913).

Code	Type	Summary
Bb1	Empetrum-rich moss-birch-forest	Sparse "forest-layer", often wind affected birches. "Thicket-layer" is often missing-sometimes willow and <i>Juniperus</i> -shrubs. "Grass- and herb-layer"- usually very sparse. <i>L. pilosa</i> , <i>S. virgaurea</i> , occurs. "Shrub-layer"- abundant, <i>Empetrum</i> and <i>Calluna</i> occur in abundance. <i>V. myrtillus</i> may occur. Lichens- often lacking.
Bb2	Blueberry-rich moss-birch-forest	"Forest-layer"- often dense, lush birch trees. "Thicket-layer"- as <i>Salix</i> . "Grass- and herb-layer"- usually sparse. <i>D. flexuosa</i> , -sparingly but evenly spread. <i>S. Virgaurea</i> , <i>T. Europaea</i> and others. "Shrub-layer" usually <i>V. myrtillus</i> and <i>Vuliginosum</i> . "Lichen-layer" - often missing.
Bc1	Fern-rich meadow-birch-forest	"Forest-layer"- dense. Birch is common, <i>Alnus incana</i> , <i>P. Padus</i> , <i>S. aucuparia</i> , <i>Salix spp</i> and <i>P. tremula</i> occur. <i>R. idaeus</i> and <i>R. rubbum</i> may occur as "Thicket-layer". "Grass- and herb-layer" Ferns dominate completely. Grasses and other herbs- <i>Valerian sambucifolia</i> , <i>Stellaria nemorum</i> , etc. "Lichen-layer"- missing.
Bc2	Grass- and herb-rich meadow-birch-forest	"Forest-layer" is dense and commonly birch. <i>S. aucuparia</i> , <i>A. incana</i> , <i>P. Padus</i> , <i>S. caprea</i> and <i>P. tremula</i> . "Thicket-layer"- <i>Salix</i> -shrubs "Grass- and herb-layer"- abundant. <i>S. virgaurea</i> , <i>Geranium</i> etc. "Shrub-layer" sparse - <i>V. myrtillus</i> can occur. "Lichen-layer"- missing.
Bd	Deciduous swamp	Forest and thicket- often one layer. Birch, <i>A. incana</i> , <i>Salix spp. are</i> common. "Grass- and herb-layer"- well developed- <i>Geranium</i> , <i>Comarum</i> , <i>Trollius</i> , <i>Ulmaria</i> , <i>Caltha</i> , <i>Menyantes</i> , <i>C. purpurea</i> . Shrub-" and "Lichen-layer" missing
C	Meadow-willow-thickets	Thicket layer- abundant. Grey willows just as green willow. The height of thickets- 3dm - 2m. "Grass- and herb-layer" abundant. Common species, <i>Geranium</i> , <i>Trollius</i> , <i>Stellaria alpestris</i> , etc. "Shrub-" and "Lichen-layer"- missing.
Da	Bog	Forest Layers- sparse, birches, sometimes crooked pines. "Thicket layer" <i>B. nana</i> and <i>S. glauca</i> . "Grass- and herb-layer"- sparse. Characteristic species- <i>R. chamaemorus</i> and <i>E. vaginatum</i> . "Shrub-layer"- usually dense, <i>Empetrum</i> , <i>V. myrtillus</i> , <i>V. uliginosum</i> , etc.. "Lichen-layer"- fairly sparse, but <i>C. rangiferina</i> occur.
Db	Grass-mire	"Forest- and thicket-layer" in willow-swamps. There <i>S. lapponium</i> , <i>S. glauca</i> , etc. "Grass- and herb-layer"- fairly developed. <i>E. vaginatum</i> , <i>S. caespitosus</i> and <i>Carex spp.</i> "Shrub-" and "Lichen-layer"- missing.
Ea/Eb	Lichen/Moss-heath	"Forest-layer"- missing, "thicket-layer"- <i>S. glauca</i> and <i>B. nana</i> . "Grass- and herb-layer"- well developed. Characteristic species- <i>Carex spp.</i> , <i>Elyne Bellardi</i> , <i>C. rigid</i> , etc. Commonly found- <i>Phaca frigid</i> , <i>Campanula uniflora</i> and <i>Pedicularis flammea</i> . "Shrub-layer"- strongly developed -"rich" depending on most common species i.e. <i>Empetrum</i> . Other shrubs are <i>Vaccinium myrtillus</i> , <i>Vaccinium vitis-idaea</i> , and <i>Arctostaphylos alpina</i> "Lichen-layer"- missing mostly in <i>Dryas</i> - and <i>V. myrtillus</i> -rich moss heaths. However, <i>C. rangiferina</i> , <i>Cetraria nivalis</i> and <i>Lecanora tartrea</i> occur.
Ec	Grass-heath	"Forest. and thicket-layer"- missing. "Grass- and herb-layer"- fairly sparse. <i>C. rigid</i> (<i>C. rigid</i> -heath), <i>C. ligo torment</i> , <i>C. vitilis</i> , etc. Common features include <i>Viola biflora</i> , <i>R. nivalis</i> , <i>R. acer</i> , and <i>S. polaris</i> . "Shrub-layer"- missing. "Lichen-layer"- weak, but exists. <i>Stereocaulon</i> and crustose-lichens- dominant.
Fa	Low-grown meadow	"Grass- and herb-layer" range from sparse to fairly dense. Common species- <i>R. acer</i> , <i>P. viviparium</i> , etc. Within low-grown areas dominated mainly <i>R. acer</i> -meadow and meadow- <i>P. viviparium</i> . Because of early or late snowmelt meadows tend to be classified as more or less tall. The late melting areas tend to result as <i>C. rigid</i> -meadow. "Shrub-" and "Lichen-layer"- missing.
Fb	Highly-grown meadow	"Grass- and herb-layer" highly grown and dense. Common species include <i>Geranium</i> , <i>Trollius</i> , <i>Rumex</i> , <i>Cirsium</i> , etc. "Shrub-" and "Lichen-layer"- missing.
G	Snow-patched areas	Conditioned by extremely long indwelling snow resulting in sparse vegetation. "Grass- and herb-layer" consists of <i>R. glacialis</i> , <i>R. nivalis</i> , etc. Common snow patches: <i>S. herbacea</i> -, <i>S. herbacea</i> , <i>Gnaphalium supinum</i> , <i>R. glacialis</i> -, <i>R. nivalis</i> - and <i>Saxifraga</i> -snow patches. "Shrub-" and "Lichen-layer" ususually missing.
H	Impediment	Areas where no grazing may be conducted since vegetation is lacking. Rock surfaces, stones, boulders, water, sand and gravel.

When I made the analysis of the vegetation classes I wanted to see if the vegetation had changed. I summarized the total length of each vegetation class for both 1913 and 2011 as a percentage of the total mapped vegetation. Then I put the 1913 vegetation classes on the y-axis and the 2011 vegetation classes on the x-axis as a 1:1 linear relationship should appear if no changes have occurred.

Results

Forest and tree limits

My study of 48 forest limits shows that 32 have expanded, 1 remains unchanged and 15 have retreated. On average, the forest limit was located at the altitude of 453 m.a.s.l. 1913, as for 2011 it was located at 479 m.a.s.l. This means that the forest limit on average have expanded by 26 meters in altitude. However, it is not statistically significant that there have been an expansion between 1913 and 2011 ($T=-1.37$, $P=0.087$) (figure 3a). The study of 27 tree limits show that 25 have expanded and 2 have retreated. At 1913 the average tree limit was located at the altitude of 436 m.a.s.l. as for 2011 it was located at 510 m.a.s.l. Thus on average the tree limit has expanded by 74 meters in altitude. The expansion between 1913 and 2011 is statistically significant ($T=-2.34$, $P=0.012$) (figure 3b).

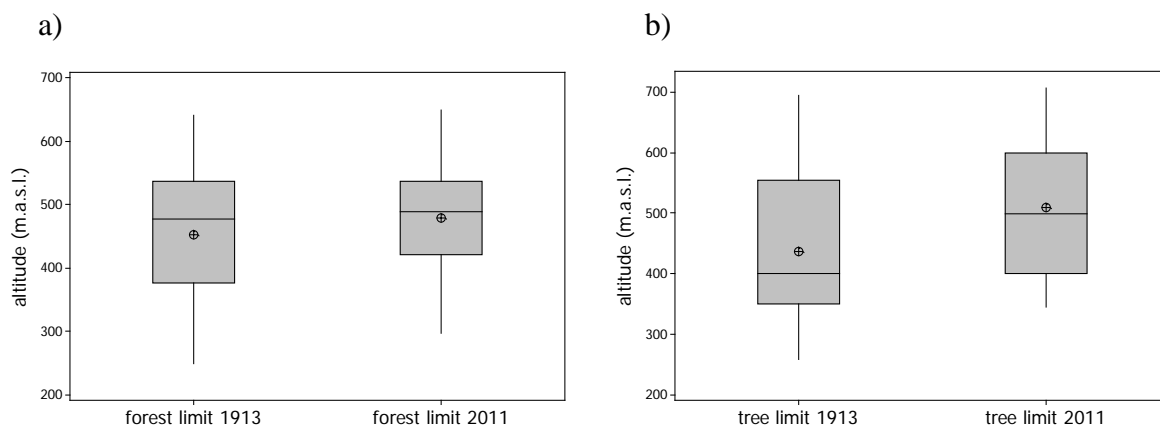


Figure 3 Box plot illustrating a t-test between a) forest limit 1913 and 2011 and b) tree limit 1913 and 2011.

Climate

Comparing temperature sum at all sites it is evident that it has increased ($T= -2.52$, $P= 0.014$). At 1913 average temperature sum was 473.0 dd and at 2011 it was 591.4 dd. Also the length of the growing season has increased at all sites from being on average 119.3 days at 1913 to 132.8 at 2011 (see figure 4). However it is not statistically significant ($T= -1.66$, $P= 0.061$).

Comparing the normal in Tromsø from the beginning of 21st and the end of 19th century, spring arrive earlier (figure 5) which in this case results in 12%, or 15 days, increased growing season and 24%, or 118 degree days (dd), increased temperature sum. The same trend is being revealed at two other weather stations located in Troms. One of them is placed in Tromsø at the altitude 100 m.a.s.l. which has been active since 1921. It shows that temperature sum has increased with 2%, or 11 dd, and the growing season with 6% or 8 days. According to the data, summer arrives 7 days earlier for period 1980-2011. The other weather station is located in Torsvåg, Karlsøy municipality, and has recorded temperature since 1933. It shows that the temperature sum has increased with 4%, or 20 dd (figure 6) and increased growth period with 4% or 6 days (figure 7). Although the weather stations in Tromsø altitude 100 m.a.s.l. and Torsvåg was not active until 1921 and 1933 they still show the same trend as Tromsø 20 m.a.s.l.

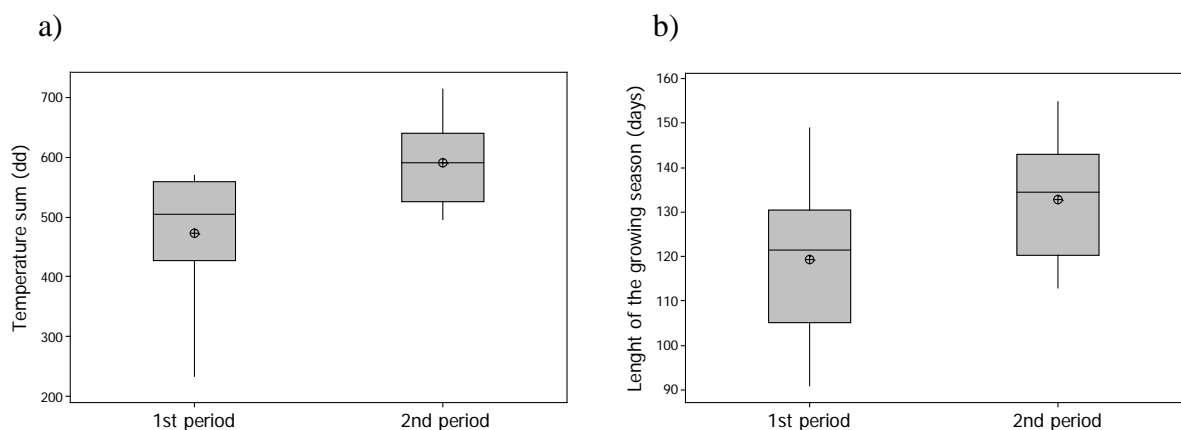


Figure 4 Box plot illustrating a) temperature sum (dd) between 1st period symbolizing (1900) and 2nd period symbolizing (2000) and b) the length of the growing season (days) between 1st period symbolizing (1900) and 2nd period symbolizing (2000).

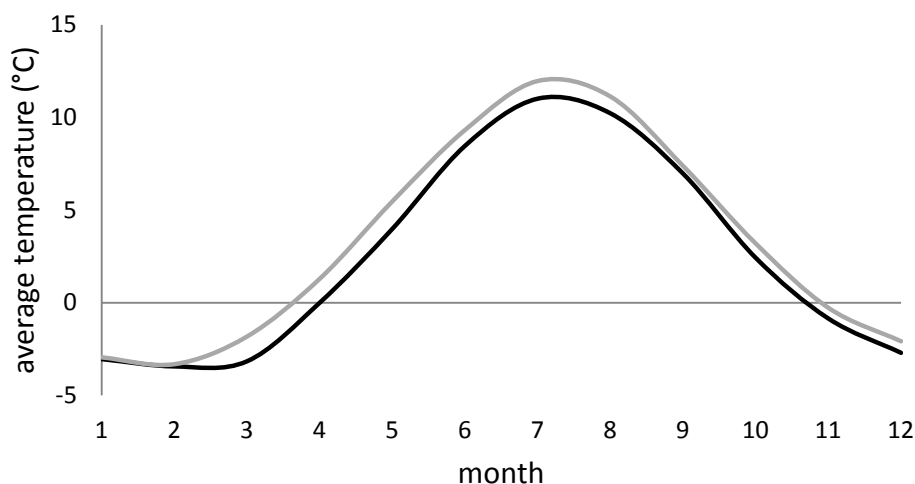


Figure 5 Average temperature (°C) for the normal period 1871-1900 (black) and 1981-2010 (grey) in Tromsø meteorological station.

In Alta temperature sum has increased with 36%, or 187 dd, comparing the 1st and the 2nd normal period (figure 6). The length of the growing season has also increased with 13% or 16 days during the same period (figure 7). In Kautokeino, temperature sum has increased with 17% or 71 dd and the length of the growing season has increased with 7% or 7 days, mainly during spring. But lacking weather recordings between 1902-1921 and after 1996 makes comparisons complicated. We know that temperatures generally have been warmer during the 21st century (SMHI 2006) and hence it is probable that the average temperature for the period 1980-1996 would show a higher temperature sum and length of the growing season than it currently does. Karesuando and Kvikkjokk shows the same trend as previous weather stations. In Karesuando the temperature sum has increased with 38%, or 165 dd, and in Kvikkjokk by 18%, or 99 dd. The length of the growing season has increased in Karesuando with 15 days, mainly during spring and in Kvikkjokk by 10 days. Abisko shows an increased temperature sum of 273 dd and increased length of the growing season by 30 days (figure 7).

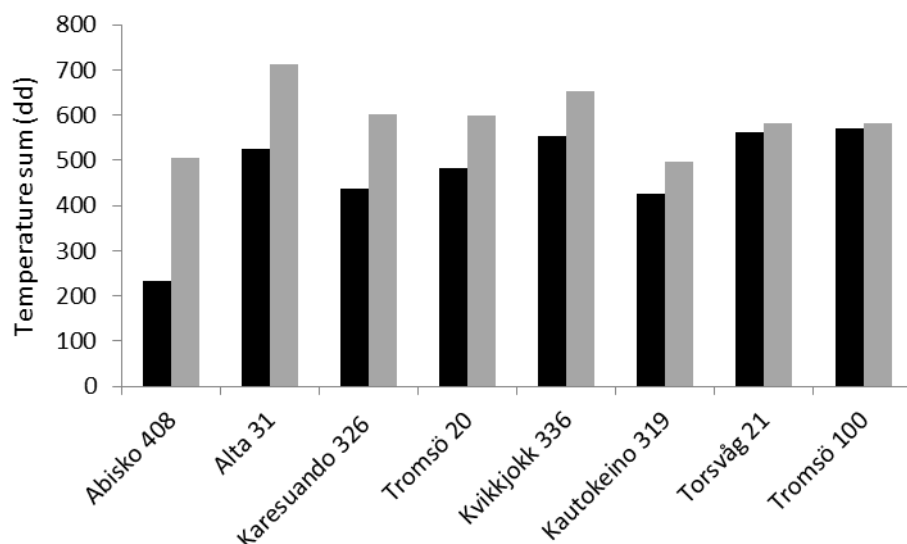


Figure 6 The temperature sum (the sum of average temperature >5°C) at 8 different weather stations where 1st period represents 1900 (black columns) and 2nd period, 2000 (grey columns). Number after the name shows at which altitude the weather station is situated. Declining shift from left to right.

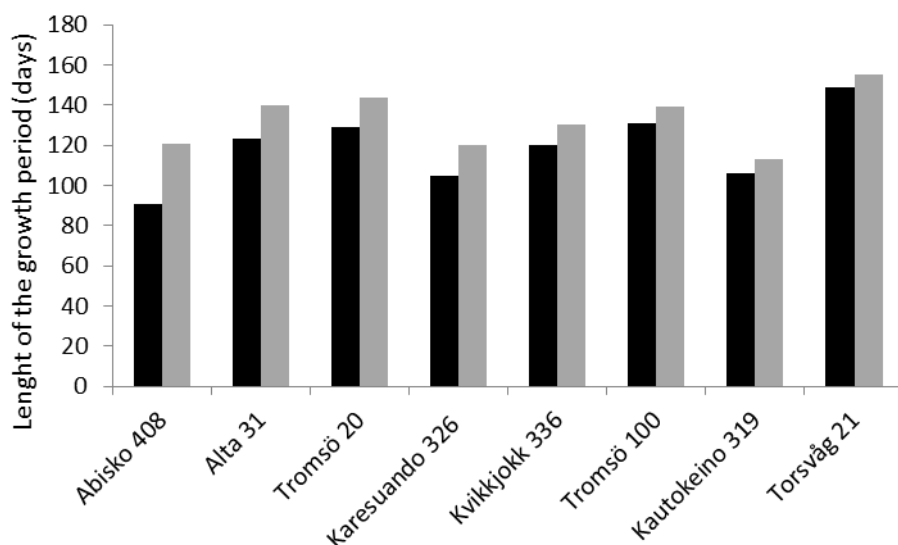


Figure 7 The length of the vegetation period (total number of days with average temperature >5°C) at 8 different weather stations where 1st period represents 1900 (black columns) and 2nd period, 2000 (grey columns). Number after the name shows at which altitude the weather station is situated. Declining shift from left to right.

Sheep and reindeer

There have been both changes and no changes of reindeer and sheep density in Troms County between 1913 and 2011 (figure 8). The average density of reindeer 1913 was 2.7 animals/km² as for 2011 the density was 2.8 animals/km². However this is a bit misleading since from a total of 76 sites, 59 forest and tree limits show a decline of reindeer as 17 shows an increase. This means that a few sites 2011 severely affect the results (see figure 8a). Although it seems like the number of reindeer has declined at a lot of sites it finds no statistical support ($T = -0.18$, $P = 0.857$). Thus the null hypothesis cannot be rejected.

Average density of sheep was 1.8 animals/km² at 1913 and 2011 it was 4.3 animals/km², resulting in an average increase of 2.5 animals/km². At 53 sites out of 76, the density of sheep has increased and

at 23 sites it has declined. Sheep density can be said to have changed between 1913 and 2011 which also are statistically significant ($T = -4.97$, $P < 0$). Therefore the null hypothesis can be rejected.

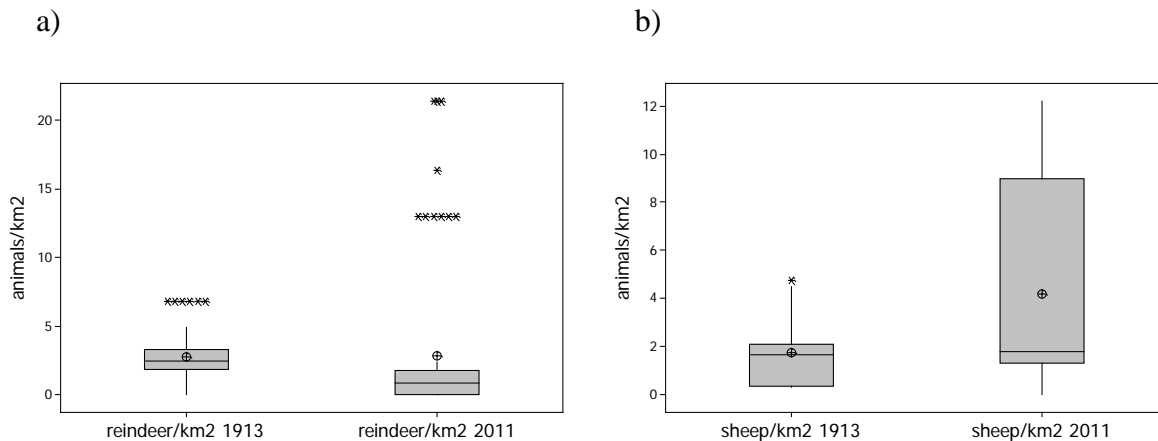


Figure 8 Boxplot comparing a) reindeer density 1913 and 2011 ($P = 0.857$, $T = -0.18$) and b) sheep density 1913 and 2011 ($P < 0$, $T = -4.97$).

Animals vs. forest & tree limits

Reindeer have no impact on the forest limit since changes in forest limit occurs independently of changes in reindeer density. Linear regression strengthens this assumption since it is not statistically significant (see table 3, figure 9a). It can be assumed that reindeer can have an impact on the tree limit, but there are also other factors involved (figure 9b). This is also shown by linear regression when a statistically significant relationship is obtained. However the coefficient of determination is low, strengthen the assumption that other factors also influencing the tree limit (table 3).

Sheep seems to have little impact on the forest limit as the changes in the forest limit occurs independently of changes in sheep density. There are forest limits expanding although increased density of sheep and the other way around (figure 10a). The linear regression also strengthens this assumption indicating that there are other factors which are more relevant to forest limit expansion and retardation (table 3). Most likely sheep does not affect the tree limit as changes of tree limits occurs regardless of increase or decrease in sheep density (figure 10b). As in the previous regression, statistic reveals that there is no clear relationship between changes in sheep density and shift in tree limit (table 3).

Table 3 Results from linear regression with shift in forest and tree limits (altitude) as response variables and shift in reindeer and sheep density (animals/km²) as predictors.

Response	Predictor	R ²	P
Shift forest limit	Shift reindeer density	2.2%	0.311
Shift tree limit	Shift reindeer density	17.8%	0.028
Shift forest limit	Shift sheep density	5.3%	0.115
Shift tree limit	Shift sheep density	11.3%	0.086

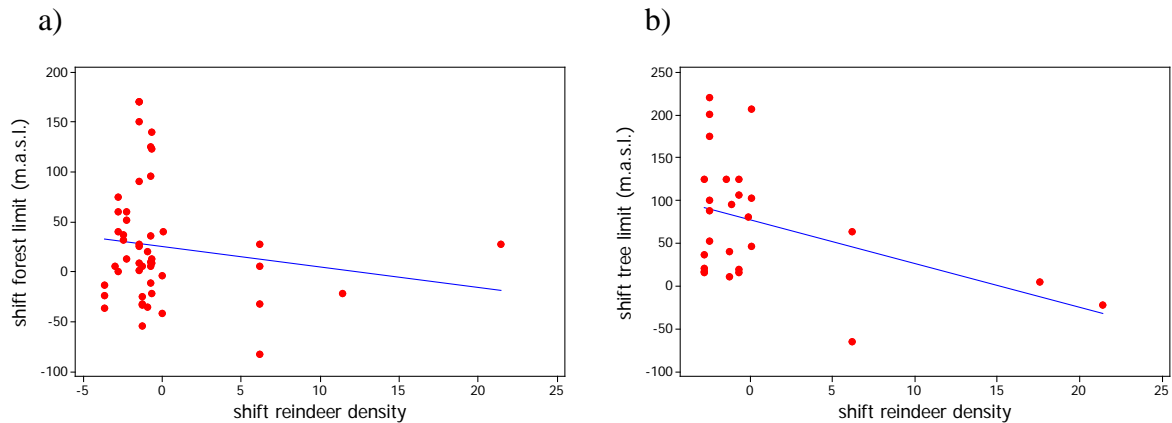


Figure 9 Plot illustrating reindeer density compared to shift in a) forest limit ($P= 0.311$, $R^2= 2.2\%$, $S= 58.9$) and b) tree limit ($P= 0.028$, $R^2= 17.8\%$, $S= 66.2$) (animals/km²).

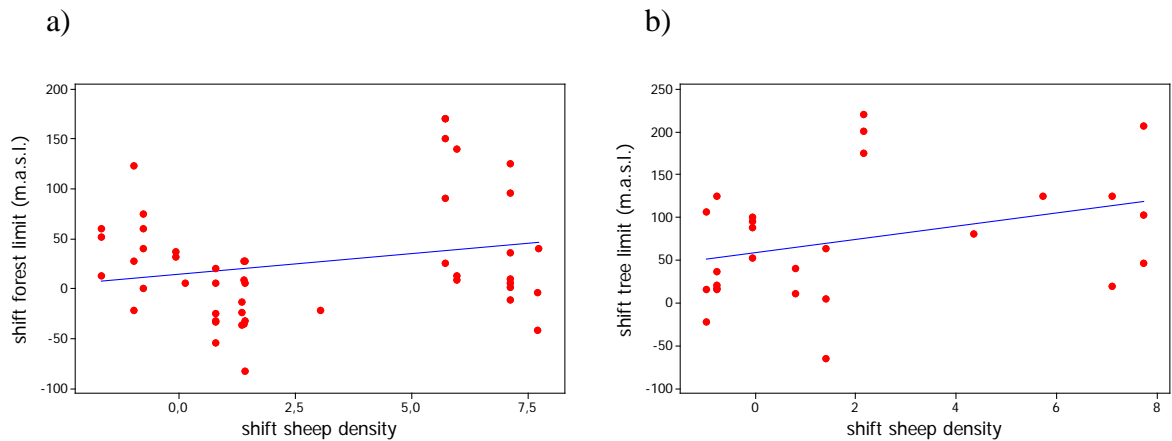


Figure 10 Plot illustrating sheep density compared to shift in a) forest limit ($P= 0.115$, $R^2= 5.3\%$, $S= 57.97$) and b) tree limit ($P= 0.086$, $R^2=11.3\%$, $S= 68.7$) (animals/km²).

Forest and tree limit vs. distance to coast

The altitude of the forest limit increases with increasing distance to the coast, this means that there is a positive relationship between the forest limit and the distance to the coast (figure 11a). This is statistically significant with a fairly high coefficient of determination. There is also a strong relationship between the tree limit and the distance to the coast. This is also statistically significant with a high coefficient of determination (figure 11b). The same results have been shown in previous studies (Kjällgren & Kullman 1998; Kjällgren & Kullman 2003; Wöll 2008). However it should be noted that the distance to the coast is not the main reason for the change in altitude, but factors related to the distance to the coast.

The shift of the forest limit compared with the distance to the coast shows a strong negative relationship. Although not as strong as the altitude of the forest and tree limit compared with the distance to the coast. But it is however statistically significant with a coefficient of determination of 28.5% (figure 12a). The shift of the tree limit compared with the distance to the coast shows a weak relationship with a declining shift of the tree limit altitude as the distance to the coast increases. Linear regression does not reveal a statistical significance, moreover the coefficient of determination may be considered low and the standard error large (figure 12b).

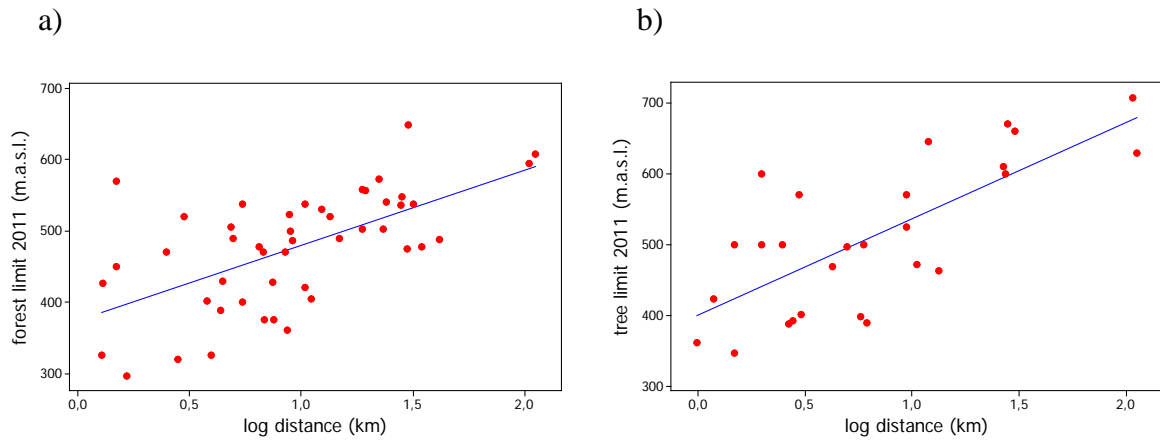


Figure 11 Plot illustrating logarithmic distance to coast (km) compared to a) the forest limit 2011 ($P < 0$, $R^2 = 37.5\%$, $S = 64.4$) and b) the tree limit ($P < 0$, $R^2 = 72.8$, $S = 51.8$).

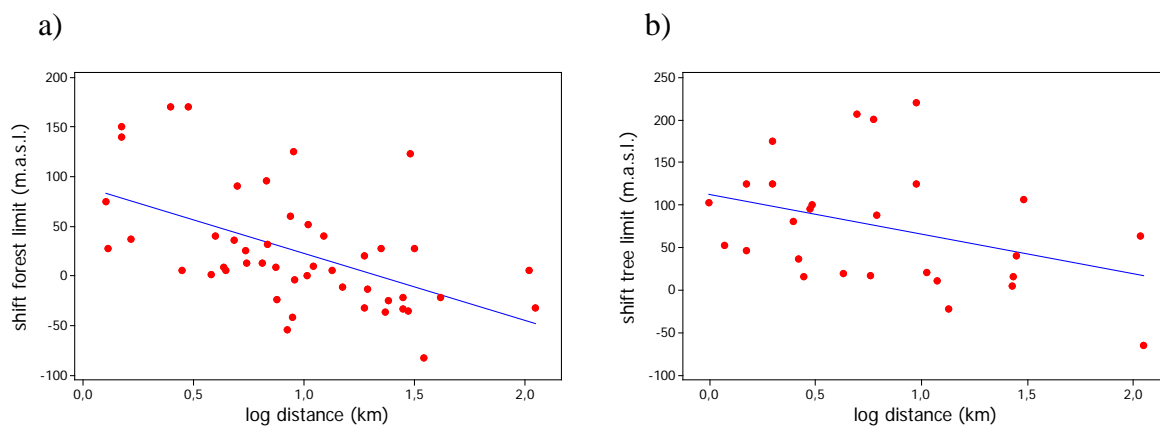


Figure 12 Plot illustrating logarithmic distance to coast (km) compared to a) the shift of forest limit 2011 ($P < 0$, $R^2 = 28.5\%$, $S = 50.75$) and b) the shift of tree limit ($P = 0.06$, $R^2 = 13.3\%$, $S = 68.0$).

Vegetation classes

The 1:1 linear relationship is not perfect which indicates that there have been changes. The “blueberry-rich birch forest” (Bb2) and “fern-rich meadow birch forest” (Bc1) have increased (figure 14a). The willow meadow thicket class (C) shows the largest decline as the total distance has decreased by 38%. The lichen/moss heath (Ea/Eb) has increased with 27% or 1130 meter and the grass-heath (Ec) has declined with 87% or 750 meter. Though, when making a rough classification (9 classes) of the different vegetation classes in a plot, for example the sum of all moss-birch forest (Bb1 and Bb2) or the sum of all alpine heaths (Ea, Eb and Ec), it seems as they make up a linear relationship (figure 13b). That indicates that some of the changes have occurred within a group of classes, for example that grass-heath (Ec) have changed to become a lichen/moss-heath (Ea) (figure 14b).

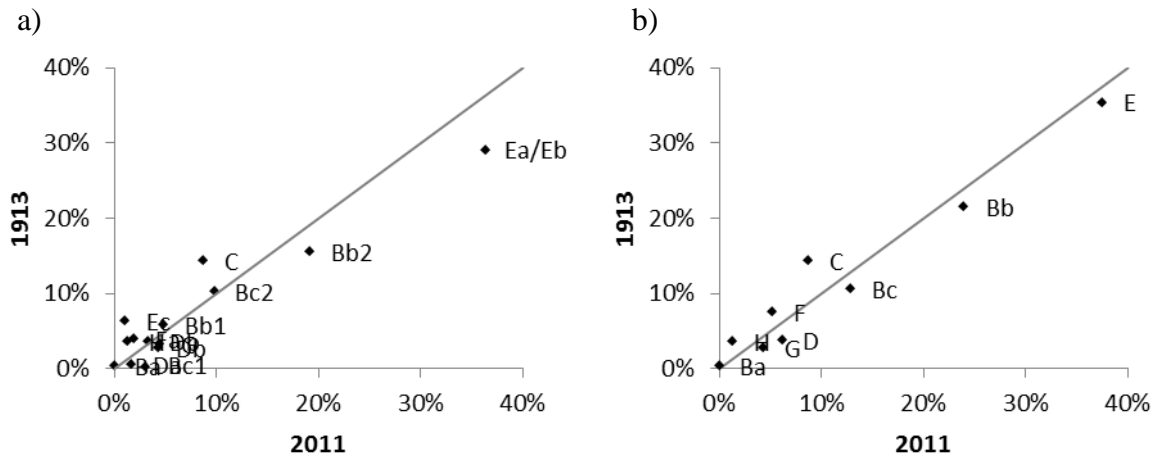


Figure 13 a) A plot of the vegetation classes (n=14) in percent of total distance 1913 and 2011. b) A more rough classification of the vegetation classes (n=9) in percentage of total distance 1913 and 2011. Grey line reveals a 1:1 relationship.

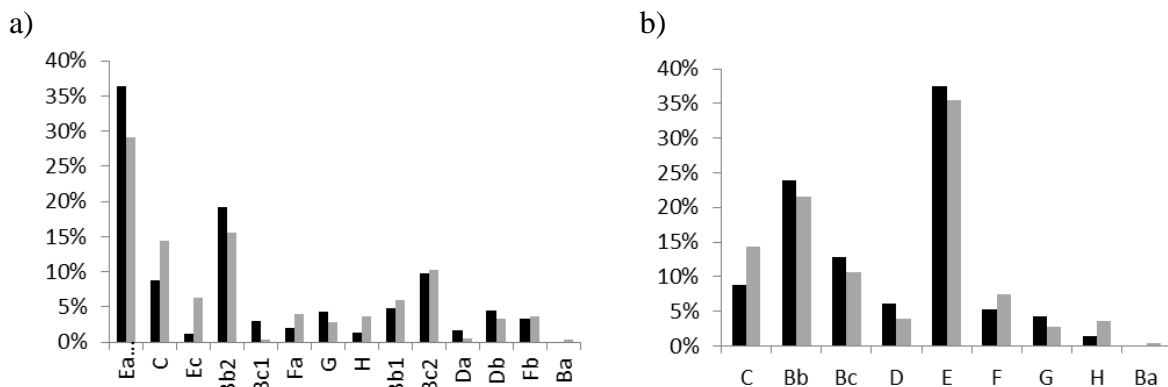


Figure 14 a) Chart illustrating the occurrence of each vegetation class (n=14) in percent of total distance 1913 (grey) and 2011 (black). b) A more rough classification of the vegetation classes (n=9) 1913 (grey) and 2011 (black). Declining shift from left to right.

Discussion

The study shows that the climate and altitude of forest and tree limits compared with the distance to the coast were of greatest interest. The density of sheep and reindeer showed no clear relationship with either the forest or tree limit. However at many sites where reindeer density has decreased, the tree limit has expanded and vice versa. Vegetation classes generally have not changed much except that the proportion of gray- and green willow-dominated areas has decreased by 38% between 1913 and 2011. The altitude of forest and tree limits increase with increased distance to coast where the largest expansions seems to have occurred near the coast. It has also been minor changes within the group alpine heaths (Ea/Eb and Ec) and at the same time as the willow-thicket class (C) has decreased with 800 meters, birch forest (Bb and Bc) has increased with approximately the same distance.

Forest and tree limit

Overall the forest limit has expanded by 26 meters in altitude. The expansion cannot be said to be statistically significant, but there is a clear trend showing that most forest boundaries follow an expansion pattern. The tree limit has on average expanded by 74 meters in altitude and thus shows a clear expanding trend. This is also statistically significant.

It is evident that the tree limit has expanded in a greater extent than the forest limit. Of the surveyed sites, forest limits have expanded, retreated and not changed at all. It is possible that the tree limit because in many ways representing a sensitive area where certain vegetation can live and thrive (Kallio & Sonesson 1979) faster will indicate a change. Thus it is likely that already established plants of trees when exposed to a more favorable environment responds with rapid growth. Moreover the possibility of the spreading and establishment of seeds increases as climate becomes more favorable. My study shows the same results as previously published material (Kullman 2001; Kullman 2002; Kjällgren & Kullman 2005; Rundqvist et al. 2011). It also seems likely that individual trees show faster response than an entire forest belt which may explain why a significant correlation was not obtained when an increase of the forest limit was tested. During the inventory I was able to recreate some photos that were taken 1913. Even if the photos are taken at different seasons it is possible to detect changes. At Fagerfjellet located at the coast, a great shift can be seen (figure 15). But it is not only at the coast that changes have occurred, in Skjold 70 km from the coast one can see the same tendencies (figure 16). It has also happened that one no longer passes the tree limits when walking along the transect (figure 17).

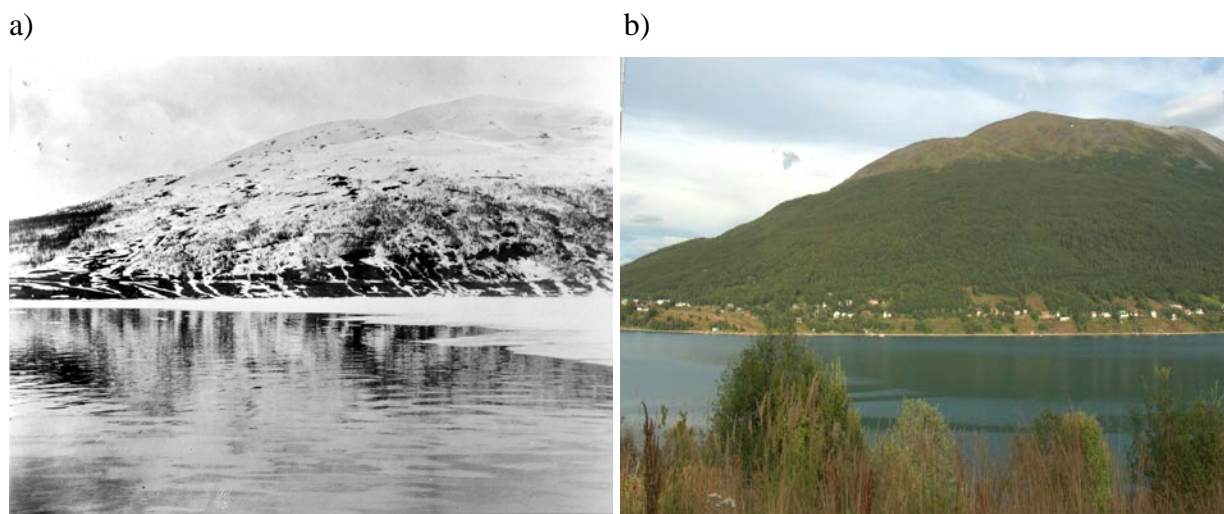


Figure 15 Fagerfjellet taken from Hans Larsa-neset, Ramfjorden, a) 1913 and b) 2011. The forest belt reveals a large expansion between 1913 and 2011. Photo: 15a) The 1913 Swedish and Norwegian reindeer herding delegation, b) Kristoffer Normark.

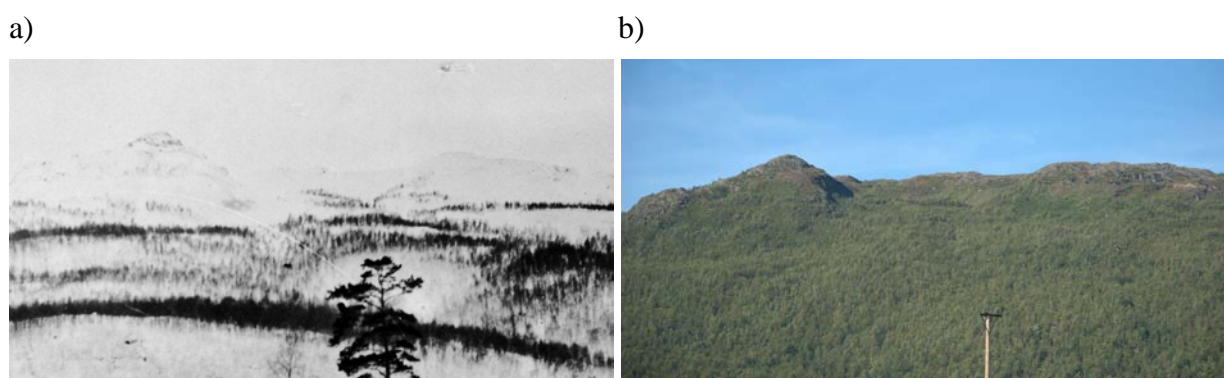


Figure 16 Kalvhauet taken from Skjold a) 1913 and b) 2011. Almost the entire summit are afforested 2011 compared to 1913. Photo: 16a) The 1913 Swedish and Norwegian reindeer herding delegation, b) Kristoffer Normark.



Figure 17 The transects around Vakkerhumpen, Sörresia. There are notes that indicate that they passed the tree limit at 1913. Today it is only a tiny strip at the uppermost summit (in the back of the picture) that is treeless. Photo: Kristoffer Normark.

With increased growth periods and temperature sum other problems might emerge. Publications have shown that mortality of birch seedlings more often was due to soil drought on sites where the growth period was longer. On sites where the growth period was shorter, seedlings primarily died during winter (Kullman 1986). This should be an important aspect if the plants will be able to benefit from more favorable temperature. Since the majority of the days which the growing season has increased by tend to have occurred in the spring it might lead to an induced risk of frost (Rigby & Porporato 2008).

Also when in contact with older people, many attest that the forest has become denser and that the stem has increased in diameter. The opinions differ as some people believe that a diminished grazing regime is the primary cause, while others suggest climate change is the main reason behind this phenomenon.

My study is very much dependent on that the approximate transects are placed in the right place and that it really goes in the right direction. There were many people who carried out the inventory in 1914, this may be a weakness when instruction can be interpreted differently by different people. But I believe that the collected data is so large that overall, errors will be small in context.

Climate

At all stations temperature sum have increased by 20-273 dd (degree days), with an average increase of 119dd. This can be compared with the average temperature sum for 2011 on 593 dd. Thus, the temperature sum on average has increased by 26% which also could be strengthened by statistics. In terms of length of the growing season, a compilation of data shows that it has increased at all weather stations with 7-30 days, which means an average value of 14 days. However it was not statistically significant that the length of the growing season has increased. Rössler et al. (2008) concluded that temperature and precipitation mainly had increased during the winter months. In this study, however, the results show that the increase mainly concerns february-august which should result in spring arriving earlier. Although it is not statistically significant, data show that the growth period has increased at every weather station. Both growth period and temperature sum should logically affect plants growth conditions, with increased temperature and growing season (Persson 1998). The temperature sum has proven to be really important in, for example, the bud pricking of white birch (Heinonen & Rousi 2007). Moreover spreading and establishment of seeds is favored by warmer temperatures (Wahlberg 2009). Consequently increased temperature ought to be of great importance when discussing expansion of forest-and tree limits which is consistent with previous studies (Daubenmire 1954; Kullman 2001; Kullman 2002). A factor worth being taken into consideration is that if climate gets more favorable at high altitudes, plants need to be more wind resistant as wind tends to increase with altitude (Odland & Birks 1999).

Few weather stations in Troms registered temperature before or at 1913. This made me include temperature data from weather stations outside Troms and in Sweden. Most of these have been available within a reasonable distance from Troms and thus represent the same climate zone. It would have been favorable to link a specific temperature to each site so that by regression analyses are able to strengthen the importance of temperature which unfortunately was not possible. However, all weather stations show the same trend which cannot be considered a coincidence.

Sheep- and reindeer

The results show a significant change in sheep density while reindeer density cannot be said to have changed. Even though sheep density has increased it does not seem to have any relationship with either the forest or the tree limit. It is likely that sheep are able to affect tree limits in such way that they cannot expand, but that the sheep alone would force the forest and tree limits to retreat seems unlikely (Speed et al. 2010), especially the forest limit. However grazing combined with other disturbances such as avalanches or landslides that primarily remove trees (Gehrig-Fasel et al. 2007) might control tree limits at a lower altitude.

The results reveal that shift of reindeer density do not have any relation with the shift in forest limit but a significant correlation is found between the shift of reindeer density and the shift in tree limit. However the correlation is primarily based on 3 sites which make these important for the result, also the coefficient of determination is low which means that the reindeers only explain about 18% of the shift in tree limit. Besides reindeers in relationship to tree limit, these results stands in contrast to what other studies have revealed (Hofgaard 1997; Gehrig-Fasel et al. 2007; Hester & Brooker 2007; Tømmervik et al. 2009; Hofgaard et al. 2010; Speed et al. 2010; Boegart et al. 2011). At 22 of 27 sites, the shift in reindeer density coincide with the shift in tree limit which means that at 20 sites where the density of reindeers has declined, the tree limit has expanded and on 2 sites where the tree limit has retreated, the density of reindeers has increased. Reindeers may act very opportunistic when in constant movement can graze the most desirable fodder that is both more digestible and nutritious (Thun 2005). As reindeers during some parts of the summer, prefer pristine leaves and shoots of birch (Staaland et al. 1993) this could be a reason for the retreated tree limits as the density of reindeers on these sites have increased (Holtmeier et al. 2003; Hester & Brooker 2007; Wehn et al. 2011). As some of the forest and tree limits have expanded and others have retreated it might perhaps be that the grazing of sheep and reindeers are more important on a local level while the climate, regionally, is of greater importance (Austrheim & Eriksson 2001).



Figure 18 Reindeers above the tree limit in Troms County. Photo: Åsa Lindgren.

In this study, I modeled grazing pressure by finding out the number of animals that can be connected to a specific area (sheep-municipality, reindeer-herding district). One should also remember that this is just a theoretical picture of the reality and may cause problems when making analyzes. If there is an area of 1000km^2 where the number of animals are 10,000 we have a density

of 10 animals/km². In reality, however, it is possible that the majority are present on a surface of 500 km², and thus gives a real density of 20 animals/km² in that particular area. Many of the animals, especially reindeer, are in constant motion and thus it is difficult to isolate a specific number to a certain area. This may lead to an excessively low resolution, making it difficult to see any correlation.

I have chosen to focus on reindeer and sheep as they make up the largest groups of free-range grazing animals. This means that I have not included other animals such as cattle or elk. But since these represent only a small proportion of free-range animals, it should not change the results significantly. However, there are studies that show that outbreaks of moths can affect the tree limit (Van Bogert et al. 2011) but these areas have been few, if not nonexistent in the areas I have passed. Slides from snow and soil with broken tree trunks as a result were more common.

Forest and tree limits vs. distance to coast

According to previous studies, there is a correlation between the distance to the ocean and the tree limit altitude (Wardle 1993; Kjällgren & Kullman 1998; Kjällgren & Kullman 2002; Wöll 2008). The results of my study show that this also applies to both forest and tree limits in Troms. The increase of the altitude should however stagnate the further inland you come to finally cease, i.e. reach a maximum altitude. Anything else would be unlikely. Also important to note is that the distance to the coast is not the main cause for the change of forest and tree limits in altitude, but factors that change with distance. Theories of salt particles which are brought with the winds severely affecting forest and tree limits near the coast have been suggested as possible causes for this phenomenon (Wöll 2008). However a more likely cause should be the degree of maritimity which has been suggested by Kjällgren & Kullman (1998) as this factor changes with the distance to the coast. Wardle (1993) noticed that tree lines were located at higher altitudes when inland compared to tree lines near the coast. Higher summer temperatures compared to coastal tree lines are thought to be the main cause which is consistent with the degree of maritimity.

Something that might be seen as a weakness is the lack of observations between 40 and 100 km from the coast. Also standard deviation must be seen as pretty large indicating that there are obvious variations in the altitude of forest and tree limits. Despite this I believe we have a clear relationship between altitude of forest and tree limits with the distance to the coast which must be considered reliable.

The shift of the forest limit shows a stronger relationship with distance from the coast than the shift of the tree limit, which also indicates a relationship, although not as strong. This means that the largest expansions of the forest limit have occurred near the coast. One reason for this could be the declined density of reindeer near the coast. However we also have evidence that shows the opposite which weakens the argument. Standard deviation must be seen as fairly high, showing a large variety of shifts in the altitude of forest and tree limits independent of the distance to the coast. Further research is needed to gain a more nuanced picture of the underlying causes of this phenomenon.

Vegetation classes

The vegetation classes have not changed much. However there are changes in the willow thicket class (C) which has decreased by 38% between 1913 and 2011. There have also been changes in the birch forest. The “blueberry-rich birch forest” (Bb2) and the “fern-rich meadow birch forest” (Bc1) have increased by 24% respective 1025% between 1913 and 2011. Most likely the birch forest has increased due to climate change and at expense of the willow thicket class (Odland et al. 1970). Also the lichen-moss heath (Ea/Eb) has increased at the same time as the grass heath (Ec) has declined. As many studies have revealed, increased temperature have caused shrubs and bushes to

increase in both abundance and size, my study shows the opposite (Olofsson et al. 2009; Forbes et al. 2010; Elmendorf et al. 2012; Walker et al. 2012). However, generally, reindeers have decreased which might have resulted in increase of lichen and moss heath as well as a decline in grass heath (Olofsson et al. 2004). No detailed analyze was made on vegetation changes due to time constrains. This means that the topic is open for development.



Figure 19 Rowan (*Sorbus aukuparia*) growing on high altitude. Photo: Åsa Lindgren.

Conclusions

The forest limit has on average expanded by 25m in altitude showing an expanding trend. The tree limit has expanded by 74 m in altitude which also statistically significant. This is also likely as expansion of individual trees occurs at a faster rate than expansion of a forest limit. According to temperature data being available, it can be shown that both temperature sum and the growth period have increased. These factors matter a lot to both disperse and establishment of seeds as the growth of trees. Based on the results, sheep does not seem to affect either forest or tree limit as for reindeer it cannot be said to affect the forest limit. However at several tree limits the density of reindeers has declined as the tree limit has expanded and according to linear regression there is a statistical significance. But as this is mainly based on 3 tree limits, the coefficient of determination is low which indicate a weak relationship. Most likely, sheep and reindeer do not have the ability to degrade the forest limit but in association with a major disruption i.e. an avalanche or landslide that primarily remove trees, sheep and especially reindeer are most likely to prevent the establishment of new individuals by grazing small plants. The altitude of forest and tree limits can be attributed to the distance to the coast, which is strengthened by linear regression. This ought to be due to the grade of maritimity. It also seems like the magnitude of the shifts in forest and tree limits increase with reduced distance to the coast. Possible explanations might be a general decrease of reindeers near the coast. However, other results are shown in the study, which is opposed to this argument. Therefore more research is needed to be able to shed some light on this question. Some vegetation changes have occurred, mainly within the birch forest and at the willow thicket class. The “blueberry-rich moss birch forest” and “fern-rich meadow birch forest” have increased as the “meadow willow-thickets” have declined. This is most likely due to increased temperature. The “grass heath” has declined as “lichen/moss heath” have increased, this might be due to a general decline of reindeers. Many questions have been answered by the study. Many go hand in hand with previous studies, but the change in forest and tree limits relative to the change in the sheep and reindeer densities show a slight opposite effect. Maybe it is because of the method used, or that the climate might have a much larger impact on the fluctuation of the forest and tree limits with sheep and particularly reindeer as suppressor. What causes changes in the environment within and around the forest and tree limit is a complex question to answer. However one thing is sure, several factors are involved and they all affect the environment in different ways.

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References

- Allen, S., Stocker, T., Dahe, Q., Platter, G-K., Tignor, M., Midgley, P., IPCC. 2010. IPCC Workshop on Sea Level Rise and Ice Sheet Instabilities. Kualalumpur: ISBN 978-92-9169-130-2.
- Austrheim, G. & Eriksson, O. 2001. Plant species diversity and grazing in the Scandinavian mountains – patterns and processes at different spatial scales. *Ecography*. **24**:683-695.
- Bogaert, R.V., Haneca, K., Hoogesteger, J., Jonasson, C., Dapper, M.D. & Callaghan, T.V. 2011. A century of tree line changes in sub- Arctic Sweden shows local and regional variability and only a minor influence of 20th century climate warming. *Journal of Biogeography (J. Biogeogr.)*. **38**: 907–921.
- Bryn, A. 2008. Recent forest limit changes in south-east Norway: Effects of climate change or regrowth after abandoned utilisation? *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*. **62**: 251- 270.
- Cairns, D.M. & Moen, J. 2004. Herbivory influences tree lines. *Journal of Ecology*. **92**: 1019–1024.
- Daubenmire R. 1954. Alpine Timberlines in the Americas and Their Interpretation. *Butler University Botanical Studies*. **11**:119-136.
- ESRI 2009. ArcGIS Desktop: Release 9.3.1. Redlands, CA. Environmental Systems Institute.
- Elmendorf et al. 2012. Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. *Ecology Letters*. **15**: 164-175.
- Forbes, B.C., Fauria, M.M. & Zetterberg, P. 2010. Russian Arctic warming and ‘greening’ are closely tracked by tundra shrub willows. *Global Change Biology*. **16**:1542-1554.
- Gauslaa, J. 2007. Samisk naturbruk og rettssituasjon fra Hedmark til Troms. Oslo: Lobo Media AS. (Norges offentlige utredninger 2007:14)
- Geirig-Fasel, J., Guisan, A. & Zimmermann, N.E. 2007. Tree line shifts in the Swiss Alps: Climate change or land abandonment? *Journal of Vegetation Science*. **18**: 571-582.
- Harsch, M.A., Hulme, P.E., McGlone, M.S. & Duncan, R.P. 2009. Are tree lines advancing? A global meta-analysis of tree line response to climate warming. *Ecology Letters*. **12**: 1040–1049.
- Heinonen, J. & Rousi, M. 2007. Temperature sum accumulation on within-population variation and long-term in date of bud burst of European white birch (*Betula pendula*). *Tree physiology*. **27**: 1019-1025.
- Hester, A. J. & Brooker, R. 2007. Threatened habitats: marginal vegetation in upland areas. *Biodiversity under threat*. ISBN: 978-1-84755-765-0.
- Holtmeier, F-K., Broll, G., Mütterthies, A. & Anschlag, K. 2003. Regeneration of trees in the treeline ecotone: northern Finnish Lapland. *Fennia*. **181**: 103–128.
- Hoofgard, A. 1997. Inter-relationships between treeline position, species diversity, land use and climate change in the central Scandes Mountains of Norway. *Global Ecology and Biogeography Letters*. **6**: 419-429.

- Hofgaard, A., Løkken, J.O., Dalen, L. & Hytteborn, H. 2010. Comparing warming and grazing effects on birch growth in an alpine environment – a 10-year experiment. *Plant Ecology & Diversity*. **3**: 19-27.
- Kallio, P., & Sonesson, M. 1979. Fennoscandian Tree-line Conference: Introduction. *Holarctic Ecology*. **2**: 205-207.
- Karlsson, H. 2008. *Vegetation changes and forest-line positions in the Swedish Scandes during late Holocene*. Doctoral thesis, Swedish university of agricultural science, 901 83 Umeå.
- Kjällgren, L. & Kullman, L. 1998. Spatial patterns and structure of the mountain birch tree-limit in the southern Swedish scandes – A regional perspective. *Geografiska Annaler*. **80**: 1-16.
- Kjällgren, L. & Kullman, L. 2002. Geographical patterns of tree-limits of Norway spruce and Scots pine in the southern Swedish Scandes. *Norwegian Journal of Geography*. **56**: 237-245.
- Kjällgren, L. & Kullman, L. 2005. Holocene pine tree-line evolution in the Swedish Scandes: Recent tree-line rise and climate change in a long-term perspective. *Boreas*. **35**: 159-168.
- Kullman, L. 1986. Demography of *Betula pubescens* ssp. *tortuosa* sown in contrasting habitats close to the birch tree-limit in Central Sweden. *Vegetation*. **65**: 13-20.
- Kullman, L. 2001. 20th Century Climate Warming and Tree-Limit Rise in the Southern Scandes of Sweden. *Ambio*. **30**: 72-80.
- Kullman, L. 2002. Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. *Journal of Ecology*. **90**: 68-77.
- Kullman, L. 2003. Förändringar i fjällens växtvärld – effekter av ett varmare klimat. *Svensk botanisk tidskrift*. **97**: 210-221.
- Michelsen, O., Syverhuset, A. O., Pedersen, B. & Holten, J. I. 2011. The Impact of Climate Change on Recent Vegetation Changes on Dovrefjell, Norway. *Diversity*. **3**: 91-111.
- Minitab INC. 2010. Minitab® statistical software 16.0.
- Moen, J. & Keskitalo, E. C. H. 2010. Interlocking panarchies in multi-use boreal forests in Sweden. *Ecology and Society*. **15** [online] URL: <http://www.ecologyandsociety.org/vol15/iss3/art17/>
- Odland, A. & Birks, H. J. B. 1999. The altitudinal gradient of vascular plant richness in Aurland, western Norway. *Ecography*. **22**: 548-566.
- Odland, A., Bevanger, K., Fremstad, E., Hanssen, O., Reitan, O. & Aargard, K. 1992. Fjellskog i Sør-Norge:biologi og forvaltning. *NINA Oppdragsmelding*. **123**: 1-90.
- Oechel, W. C., Hastings, S. J., Vourlitis, G., Jenkins, M., Riechers, G. & Grulke, N. 1993. Recent change of Arctic tundra ecosystems from a net carbon dioxide sink to a source. *Nature*. **361**: 520-523.
- Olofsson, J., Moen, J. & Östlund, L. 2010. Effects of reindeer on boreal forest floor vegetation: Does grazing cause vegetation state transitions? *Basic and Applied Ecology*. **11**: 550-557.
- Olofsson, J., Oksanen, L., Callaghan, T., Humle, P. E., Oksanen, T. & Suominen, O. 2009. Herbivores inhibit climate-driven shrub expansion on the thundra. *Global Change Biology*. **15**: 2681-2693.
- Olofsson, J., Stark, S. & Oksanen, L. 2004. Reindeer influence on ecosystem processes in the tundra. *Oikos*. **105**: 386-396.
- Porporato, A. & Rigby, J. R. 2008. Spring frost risk in a changing climate. *Geophysical Research Letters*. **35**: 1-5.
- Persson, B. 1998. Will Climate Change affect the Optimal Choice of *Pinus sylvestris* Provenances? *Silva Fennica*. **32**: 121-128.
- Renbeteskonventionen af 1913 handlingar. 1913.
- Rundqvist, S., Hedenås, H., Sandström, A., Emanuelsson, U., Eriksson, H., Jonasson, C. & Callaghan, TV. 2011. Tree and shrub expansion over the past 34 years at the tree-line near Abisko, Sweden. *Ambio. A Journal of the Human Environment*. **40**: 683-692.
- Rössler, O., Bräuning, A. & Löffler, J. 2008. Dynamics and driving forces of treeline fluctuation and regeneration in central Norway during the past decades. *Erkunde*. **62**: 117-128.
- Sápmi. Hemsida. [online](2005-04-15) Available from: <http://www.samer.se/1601> [2011-11-14]

- Sápmi. Hemsida. [online](2009-03-25) Available from: <http://www.samer.se/1217> [2011-11-14]
- SMHI (2009). 250 Years of Weather Observations at the Stockholm observatory [online]. Available from: http://www.smhi.se/polopoly_fs/1.17736!webbNr27_eng_ver.pdf [2012-02-15]
- Sonesson, M. & Callaghan, T. V. 1991. Strategies of Survival in Plants of the Fennoscandian Tundra. *Arctic*. **2**: 95-105.
- Speed, J., Austrheima, G., Hesterb, A. & Mysterud, A. 2010. Growth limitation of mountain birch caused by sheep browsing at the altitudinal treeline. *Forest Ecology and Management*. **261**: 1344–1352.
- Starfield, A. M. & Chapin, F. S. 1996. Model of Transient Changes in Arctic and Boreal Vegetation in Response to Climate and Land Use Change. *Ecological Applications*. **6**: 842–864.
- Sverige. Regeringen 2005. Regeringens skrivelse 2004/05:79: Upphörande av 1972 års svensk-norska renbeteskonvention. Stockholm: Regeringen.
- Sykes, M. T., Prentice, I. C. & Cramer, W. 1996. A Bioclimatic Model for the Potential Distributions of North European Tree Species Under Present and Future Climates. *Journal of Biogeography*. **23**: 203-233.
- Thun, A-K. 2005. Classification of reindeer forage by using site index vegetation classification. Examensarbete. Institutionen för skogsskötsel, Sveriges Lantbruksuniversitet (SLU), 901 83Umeå.
- Tømmervik, H., Johansen, B., Riseth, J.A., Karlsen, S.R., Solberg, B. & Høgda, K.A. 2009. Above ground biomass changes in the mountain birch forests and mountain heaths of Finnmarksvidda, northern Norway, in the period 1957–2006. *Forest Ecology and Management*. **257**: 244–257.
- Van der Wal, R. 2006. Do herbivores cause habitat degradation or vegetation state transition? Evidence from the tundra. *Oikos*. **114**: 177–186.
- Walker et al. 2005. Plant community responses to experimental warming across the tundra biome. *PNAS*. **103**: 1342-1346.
- Wardle, P. 1971. An Explanation for Alpine Timberline. *New Zealand Journal of Botany*. **9**: 371-402.
- Wardle, P. 1993. Causes of alpine timberline: a review of the hypotheses. *Life Sciences*. **244**: 89-103.
- Wehn, S., Pedersen, B. & Hanssen, S.K. 2011. A comparison of influences of cattle, goat, sheep and reindeer on vegetation changes in mountain cultural landscapes in Norway. *Landscape and Urban Planning*. **102**: 177-187.
- Went, F.W. 1953. The effect of temperature on plant growth. *Annual Review of Plant Physiology*. **4**: 347-362.
- Wöll, V.C. 2008. Treeline of mountain birch (*Betula pubescens Ehrh.*) in Iceland and its relationship to temperature. Diploma thesis in Forest Botany. Department of Forestry, Technical University, Helmholtzstraße 10, 01062 Dresden.

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