Seminar series nr 209

Increase of tree abundance between 1960 and 2009 in the treeline of Luongastunturi in the northern Swedish Scandes

Change detection based on aerial photographs

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2011

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Bachelor Degree thesis in Physical Geography and Ecosystem Analysis

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Abstract

Aerial photo interpretation shows a recent densification of trees has been occurring between 1960 and 2009 in the mountain birch (*Betula pubescens* ssp. *czerepanovii*) forest of the treeline ecotone in northern Swedish mountains. The correlation between treeline position and annual temperature is commonly accepted and advancing treelines are considered to be a useful indicator for monitoring climate changes. Previous research show that in the stressful environment that makes up the treeline ecotone, tree density often respond quicker to a temperature rise than an altitudinal advance of the treeline. The project is executed by counting trees and measuring the tree height within 50 systematically distributed sample plots. Mapping is done in black and white 1960 aerial photos and colour infrared aerial photos from 2009 in stereo view by using a digital photogrammetric station. Tree density changes from 1960 to 2009 within the sample plots are analyzed statistically. The results show that during the studied time period tree abundance have increased in the high elevation mountain birch forest of the study area. Mean trees per hectare has increased from 88 to 126. Tree height interpretation indicates a growth of previously existing trees. Densification is more significant on the northern sides of the mountains and with slightly higher rates. The increased growth is likely due to a warmer climate, but other factors like e.g. browsing by herbivores like reindeer has to be examined before securely attributing the densification to climate change.

Keywords: *Geography, physical geography, treeline dynamics, mountain birch, aerial photo interpretation*

Sammanfattning

Gränser mellan vegetationszoner fascinerar genom att på ett tydligt sätt påminna oss om sambanden som finns mellan det som lever och dess miljö. En av de mest påtagliga gränserna är den alpina trädgränsen, där fjällbjörkskogen gradvis övergår till kalfjäll. Den karga miljön som utgör kalfjället är starkt kopplat med temperatur och klimatförändringens ökade temperatur har medfört förändringar i trädgränszonen. På det viset kan trädgränsen fungera som klimatindikator. De senaste femtio åren är troligen de varmaste på 500 år. Tidigare forskning har visat hur trädlinjen avancerat uppåt under 1900-talet och prognoser för framtiden visar på fortsatta förändringar. Förändringarna kan förklaras med ett varmare klimat, men lokala variationer och faktorer som intensiteten av renbete spelar också in. Studien har gjorts i ett lågfjällsområde i Kiruna kommun. Genom att tolka gamla och nya flygbilder i 3D-modeller har träden räknats och höjdmätts för de båda åren. Statistiska analyser visar att en signifikant ökning av träd har skett sedan 1960, med en snitthöjning på 30-40 träd per hektar. Skillnaderna är som störst på nordsluttningar, där en ökad temperatur också kan förväntas påverka som mest. Resultaten visar också att tidigare existerande träd har vuxit i höjd. Svenska fjällens mosaikartade ekosystem är bland de av människan minst påverkade områdena i hela Europa. Ungefär en tredjedel av Sveriges alla arter växter, mossor och lavar lever här. En förändring skulle ha stor negativ påverkan, då temperaturkänsliga arter invadera de känsliga småskaliga ekosystemen. Undersökningen riktar sig i huvudsak på att upptäcka om det skett en förtätning av den typiskt glesa fjällbjörkskogen mellan 1960 och 2009.

Nyckelord: *Geografi, naturgeografi, trädgränsen, fjällbjörk, flygbildstolkning*

Contents

Introduction

Boundaries between vegetation zones fascinates because their abilities to effectively visualize the interaction between biologic life and their physical environment.

One of the most striking features is the altitudinal treeline where the mountainous landscape abruptly shifts from arboreal forest to open alpine tundra. It has for centuries been the topic for researchers in a wide range of fields like biology, physical geography, ecophysiology and quarternary geology (Kullman & Öberg, 2009)

Treelines occur all over the world, and the exact principals for formation are complex and not yet fully understood (Cairns et al 2007). Nevertheless, the dynamics of the treeline are commonly accepted to be strongly related with temperature, why many studies focus on surveying responses from treeline changes on a fluctuating climate (Kullman & Öberg 2009, Holtmeier 2009).

The last 50 year period is very likely to have been the warmest in five hundred years (IPCC 2007, Callaghan et al 2010). Climate change of the 20th century is unequivocal and very likely to continue with a faster rate in the 21th century. The temperature rise is significantly greater in northern latitudes (IPCC 2007). This raises the interest for the alpine treeline which is considered to be a good indicator for climate change, and can be readily monitored due to its strict definition which enables repetitive and comparable field studies (Kullman 1998).

The Fennoscandian mountains constitutes an area less affected by anthropogenic disturbances than most other places in Europe, and major part of the native flora and fauna is relatively unaltered. The zone from high elevation mountain birch forest up to the tree-less alpine tundra holds almost one third of the total species numbers of plants, mosses and lichens in Sweden. A few dozens of these are considered rare and a handful species are endemic (Bernes 2001). Shifts in vegetation zones can have serious impacts on the high biodiversity of the vulnerable small-scale ecosystems (Moen et al 2004).

Advancing tree limits are recorded from various places in the world. In Sweden, upward migration and structural changes of the treeline are observed in both the southern Swedish Scandes (Kullman 1993, 1998, 2001, 2002) and in the northern (Hållmarker 2002, Troung et al 2006, Van Bogaert 2011).

Observations of larger geographical distribution would improve the understandings of treeline dynamics on a large-scale and overcome distortions from regional variations. A methodology study by Heiskanen et al (2008) speaks for remote sensing with aerial photos as an effective method for detecting treeline changes over extensive areas.

Aims

The main aim of this study is to detect:

1. If there has been a significant increase of trees between 1960 and 2009 in the mountain birch forest of the treeline ecotone in northern Swedish mountains.
2. The magnitude of the possible changes
3. If existing trees have grown
4. If changes in tree density have occurred in different rates on north- and south-facing slopes

Theoretical background

Treeline terminology

The terminology used to describe the ecological borders from the upper-boreal forest to subalpine belt and tree-less alpine tundra varies greatly with the author. Most definitions of the forestline and treeline are based on different minimum levels of tree height or forest cover.

The alpine treeline, sometimes also called timberline or tree limit, refers to the highest elevation where a tree individual is found assumed that the tree qualifies as a tree, typically either by having an arboreal shape or meet a threshold size value (Heiskanen et al 2008, Holtmeier 2009). In Sweden the commonly used definition is that the treeline marker must be taller than two meters. This definition is used in research done from the early 20th century and it indicates that the tree is not entirely snow-covered during winter (Kullman 2001, Kullman & Öberg 2009).

In Sweden the treeline is generally marked by Mountain birch (*Betula pubescens ssp. czerepanovii*) which reaches the overall highest elevations, Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) reaches around 50 m respectively 100 m lower (Kullman 1998). All three species can be found up to 500-700 m above the treeline in the form of seedlings or individuals shorter than two meters. The highest elevation a tree species individual is found on, no matter what tree height, is called the tree species line (Kullman & Öberg 2009).

The treeline ecotone is the transitional zone, with descending tree height and density with altitude, between the upper margins of coniferous forest up to the mountain birch treeline and is characterized by sparse mountain birch forest with dispersed spruces (Kullman 2001). Sometimes the word treeline is used for the whole ecotone (Holtmeier 2009).

Distinction is done between treeline and forest-line, where the forestline is the diffuse border between closed forest and the subalpine belt with sparse birch forest, and is often defined with a threshold value of forest cover around 10-30 % (Heiskanen et al 2008). Since the definitions of the forestline are subjective and highly dependent on regional variation it is therefore not as readily used for monitoring (Kullman & Öberg 2009).

Ecological characteristics

Ecosystems are composed as the results of prevailing stress agents and disturbances that encourage species with the best strategies for survival and most cost-effective reproduction.

Treelines occur worldwide, however the complexity of the mechanisms behind treeline formations make no single explanation commonly accepted. Different hypothesis have in common that removal of biomass pushes the environment to the edge of survival (Cairns et al 2007).

Freezing and desiccation are stress factors while hard winds and snow blasting (Kullman 2005) are recurring disturbances suggested to have key roles in forming the treeline ecotone (Cairns et al, 2007). Winds may lead to stem breakage and accumulation and removal of snow (Kullman 2005). Freezing can damage plants during extremely low temperatures or frost during growing season. Poor cuticule developing during summer can cause desiccation stress during winter (Cairns et al, 2007).

On a large regional scale, the treeline in Sweden declines gradually in altitude westwards with a shorter distance to the sea and a maritime climate, characterised by cooler summers, stronger winds and higher precipitation compared with a continental climate. It also has an inverse relation with latitude because of decreasing temperatures further north (Kjällgren & Kullman 1998). The highest tree limits in Sweden are found in the provinces of Dalarna and Härjedalen in the southeast part of the Scandes, where the climate is relatively continental. The treeline elevations there reach above 1000 m.a.s.l., compared with approximately 600 m.a.s.l. in the northern Swedish Scandes (Kullman 2005). Warm temperatures affect growth more than cold temperatures. Warm summers extend the growth season and are also thought to encourage physical growing processes in trees (Kjällgren & Kullman 1998).

On a smaller scale, the treeline is related to the aspect of the slope. Due to differences in insolation, snowmelt etc. the treeline reaches significantly higher elevations on the southern slopes compared with northern slopes for all three species. Large local variations are imposed by the topography. Lee sides of ridges, depressions in the landscape and shrubs can entrap windblown snow and increase availability of ground moisture. Snow accumulations can protect the ground from extremely cold temperatures causing desiccation (Sturm et al 2001, Holtmeier 2009)

Kullman (2001) categorized changes in the treeline ecotone as phenotypic and genotypic changes. Phenotypic changes affect the appearance of a tree individual, as when favourable conditions like a period of warm and dry summers cause rapid radial and vertical growth, or when harsher conditions lead to damage or deterioration. Genotypic change is sexual reproduction and growth of established new genetic individuals during favourable environmental conditions and death under opposite circumstances (Kullman 2001).

Vegetative (clonal) reproduction e.g. through basal sprouts is far less energy consuming than sexual reproduction with seeds and may still occur under climatic circumstances that stun seed development. The altitudinal advance of trees is therefore highly depending on the species ability to reproduce and regenerate vegetatively (Holtmeier 2009). Conversely, the abilities for clonal reproduction are enhanced by occasional stem breakage from physical stress (Kullman 2005). Closer to the treeline the reproduction gets mainly vegetative (Kullman 2001). Both mountain birch and spruce possess high potentials of vegetative reproduction while pine is less prone for this and completely dependent on its sexual reproduction, which is the main explanation why birch and spruce dominate the treeline ecotone. Spruce and birch may live in the form of a krummholz tree, i.e. a dwarf phase, to extreme age with alternating periods of growth, stability or down wear (Kullman 2005).

Migration of the treeline up and down the mountain slopes is often a result of already established individuals undergoing phenotypic change driven by the physical environment, rather than genotypic change through seed establishment (Kullman 2001).

Impacts of climate change

Tree growth on high elevations and dynamics of the treeline are commonly believed to be strongly correlated with temperature, and changes within the ecotone continue until it reaches equilibrium with current macroclimate. (Kullman & Öberg 2009, Holtmeier 2009).

The temperature variations in Sweden correspond to the global trend of increasing temperatures as an effect of anthropogenic climate change (Swedish Meteorological and Hydrological Institute 2011). The largest temperature rise is expected in high latitudes(IPCC 2007), especially in northern Scandinavia (Truong et al 2006).

During the early Holocene, about 11 200 years ago, the treeline reached its peak elevation when the climate was considerably dryer and the growing season 2.5 ^{o}C warmer. Since then it has dropped almost linearly with 30 meters per millennium. The treeline position was around 500 meters higher on its peak than its minimum a century ago (Kjällgren & Kullman 2006).

During the 20th century the treeline has advanced with 100-165 meters in the southern Scandes in Sweden as a response to climate warming, mostly before the 1950s coinciding with a warm period in the 1930s. Then came a period of stability before a continuing advance in the 1990s as a response to several years of warm summers and mild winters (Kullman 2001). Tree ring studies by Kullman (1993) conclude that a temperature rise has a positive effect on both radial growth and vegetative reproduction. Research by Troung et al (2006) indicates that temperature increase has a positive effect on growth of birch seedlings and that an observed treeline rise in Abisko in the northern Sweden could be a response to climate warming.

The growth season, which is suggested by Sykes et al (1996) to be a more important factor than temperature distributional changes of vegetation zones, has increased in the northern half of Sweden with a mean of two weeks during the last forty years based on temperature data from 16 different meteorological stations (Swedish Meteorological and Hydrological Institute, 2011).

Changes of vegetation are not restricted only to the movement of the upper-limit treeline, but affect the whole biomass production in the treeline ecotone. Phenotypic changes can be detected as changes in individual trees as well as tree spreading with basal sprouts (Kullman, 2001). Sturm et al (2001) showed that the abundance and density of shrubs in Alaska has increased the last fifty years as a response to temperature rise, in some cases dramatically. Same tendencies are confirmed for Dwarf birch (*Betula nana*) in the northern Fennoscandian mountains by Olofsson et al (2009).

Even if the treeline migration is proposed as an effective indicator of responses to climate change, positive changes in tree density and cover is shown to respond even quicker to temperature rise (Lescop-Sinclair & Payette 1995, Holtmeier 2009).

Other factors of changes

Besides ultimate determination from climate and topography, the position and structure of the treeline is influenced by disturbances like herbivory, moth outbreaks and sudden events like avalanches, landslides and fire (Holtmeier 2009). The stressful ecosystem, with its low productivity and slow-growing plants living on the margins, underscore that even minor disturbances can have long-term effects (Cairns & Moen 2004). Changes in the treeline ecotone may locally be entirely controlled by disturbance. Therefore, the use of the treeline for monitoring climate changes should be done with caution (Bogaert 2011).

Livestock or naturally abundant herbivores can alter the advance and structure of the treeline directly or indirectly (Cairns et al 2007). The expansion of shrubs and trees is more pronounced in areas preserved from mammalian herbivores, including reindeers and microtine rodents, and that the positive relation between vegetation and temperature can be counter-balanced by herbivore control (Olofsson et al 2009). In northern Fennoscandia where the treelines are formed by Mountain birch it is suggested that browsing by semi domesticated reindeers (*Rangifer tarandus*) may, when grazing pressure is high enough, slow down or halt the establishment of new seedlings in the treeline (Cairns & Moen 2004). Bogaert et al (2011) concluded observed advances of the treeline were significantly correlated with periods of low reindeer populations. Bark stripping by moose (*Alces alces*) affects mainly aspen (*Populus tremula*) and may reduce the population by half (Van Bogaert 2009).

An abrupt treeline with a shift from relatively large trees directly to open heath can be a result of herbivores eliminating small seedlings (Cairns & Moen 2004). Indirect effects of herbivory can be opening up of the landscape and increased wind stress or when browsing imposes a loss in shrub cover and following snow accumulation (Cairns et al 2007). Trampling by reindeers can locally trigger erosion (Kullman 2005) and seed establishment can be suppressed by a ground cover reduction of lichens, mosses and dwarf shrubs (Olofsson et al 2009).

Outbreaks of the autumnal moth (Epirrita autumnata) and winter moth (Operophtera brumata) happen roughly every ten years. An exploded population of moth caterpillars may cause severe damage and stem die-back on mountain birch stands from intense defoliation (Tenow et al 2004). Moths may become a more frequent problem in the future with a warmer climate. The caterpillar eggs are killed by temperatures below -35^{o}C, and a lack of cold winters may increase survival and enhance outbreaks (Callaghan et al 2010)

Remote sensing

Monitoring the treeline by the use of remote sensing, in combination with understanding gained from field studies, has several advantages. Complications in field due to local variations may be diminished by studying a larger sample i.e. a larger area. Satellite images and aerial photos are available in a wide range of different scales and historical photos enables surveying changes over time (Heiskanen et al 2008). Many studies on treeline changes are done by using ordinary photographs (Kullman 2001, Sturm et al 2001, Luckman & Kavanagh 2000).

Mapping vegetation with highest possible accuracy is done in aerial photos with high resolution from 1:30 000 to 1:10 000. Colour infrared camera film is optimal since reflection differences between vegetation types are largest in the near-infrared spectrum (Ihse et al, 1993). Change detection mapping is preferably done with historical and modern photos in the approximately same scale (Heiskanen et al 2008).

By using digital photogrammetric workstations the mapping can be done with three-dimensional view directly in digital stereo-models and enables interpreting object heights. Tree heights can be measured, but is subjective and gives systematic underestimations depending on the image quality and the shape of the object (Axelson & Nilsson 1993, Næsset 2002, Allard et al 2005).

A methodical study on using digitally scanned aerial photos from the 1970s and the 2000s to detect changes in the treeline ecotone was performed by Heiskanen et al (2008). Three different methods were evaluated. The first method was a large scale complete cover mapping where visual borders in the landscape were mapped as polygons. The second was a small scale sample plot method, where individual trees were mapped as vector points within small size (20 m radius) test plots that were systematically distributed over the target area. In the third method eventual changes of the tree-line position was mapped in transect polygons on mountain slopes. The best results were achieved with the sample plot method partly due to its cost-effectiveness, the ability to compare results in standard statistical tests and readiness to carry out in the photo scale 1:30000 and 1:60000. Also, larger differences were observed when comparing changes in numbers of individuals instead of changes in percentage forest cover. Shrubs and small trees cannot be mapped reliably. Heiskanen et al (2008) assumed that mapping changes in distribution of trees in the treeline ecotone were of ecologically greater relevance than mapping changes in altitudinal movement of the tree-limit.

Another study on stem density changes using aerial photos was performed by Hållmarker (2002) where trees were counted for seven small sites in Abisko. This was done before the common use of digital photogrammetric stations, hence the mapping was done by drawing on plastic film in analogous instruments and digitalizing afterwards with a bit lower accuracy as a consequence.

Materials

Study site

The location of the study site is chosen mainly for the availability of aerial photographs. It is a low alpine area called Luongastunturi consisting of two mountain tops, Ylinenlaki to the north and Keskinenlaki to the south. The area is about 18 km^2 and lies about 9 kilometers SE of the village of Svappavaara (fi. Vaskivuori) in the municipality of Kiruna in Sweden. The coordinate for the northeast corner of the site is N 67° 36.818', E 21° 15.560' and for the southwest corner N 67° 34.439', E 21° 12.275'.

The annual mean temperature for the county of Norrbotten has been rising since 1961, essentially since the late 1980s. A continuing temperature increase is projected (Swedish Meteorological and Hydrological Institute 2010). The maximum elevation above mean sea level is 642 meters for Ylinenlaki and 590 meters for Keskinenlaki. The area used for this project lies within the range of 515-626 meters, were vegetation predominantly consists of sparsely distributed mountain birch (*Betula pubescens ssp czerepanovii*).

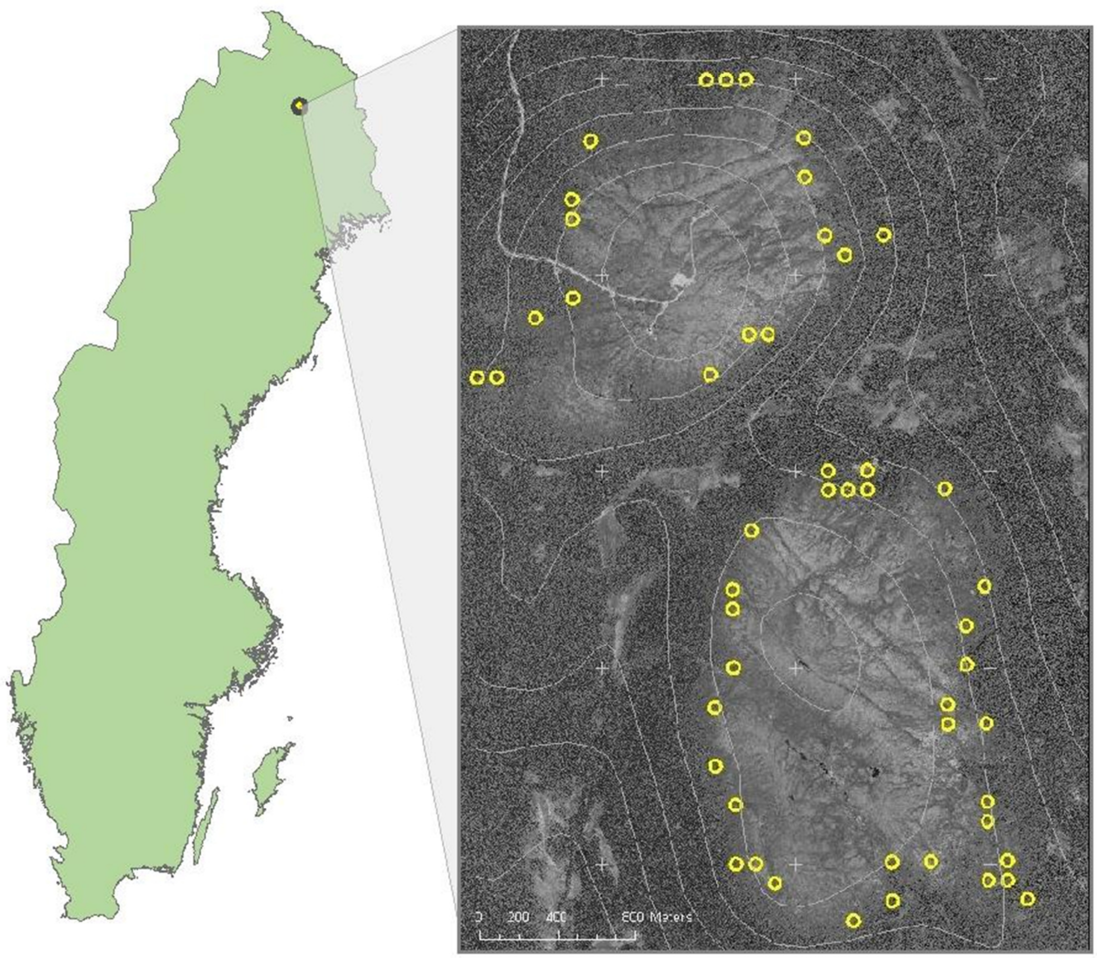

Figure 1. *The study site is a low alpine area consisting of two small mountain tops, Luongastunturi in the county of Kiruna in northern Sweden. The analysis is done in the 50 systematically distributed sample plots (yellow circles) of 30 m* radius.

Aerial photos

Two sets of digitally scanned aerial photos were used in the project, one set of recent colour infrared (CIR) photos from 2009 (modern photos) and one set of black and white (BW) photos from 1960 (historical photos). The aerial photos were originally delivered from the Swedish National Land Survey, together with camera file and orientation data which are used for the rectification and orientation.

Table 1. *Specifications of the aerial photos used in the project. Black and white (BW) photos from 1960 and color infrared (CIR) photos from 2009.*

Aerial photos	1960	2009
Acquisition Date	6/26/1960	7/20/2009
Time	15:54	08:36
Scale	1:29 793	1:41 705
Type	B W	C I R
Camera	Ag3-152.92	DMC050
Pixel size (m)	0.37	0.5
Bit per pixel	8	24

Both sessions were acquired in the summer with 24 days difference in dates. Three stereo-models of each set were used, consisting of four photos with 60 % overlap. Properties of the used aerial photos are showed in table 1.

Stereo equipment

The air photo interpretation was carried out using Delta DBS, a digital photogrammetric station including several modules both for orientation of the digital photos to create stereo-models and for digitalizing maps. Stereo view is enabled by using Planar SD2220, a high definition 3D computer screen consisting of two separate screens and a polarization filter mirror. Using special polarization glasses, the right and left eye are exposed to different screens.

Method

Constructing sample plots

A grid of vector points with 100 meters separation covering the whole study site was built in ArcMap. An approximate forest line was digitalized in Delta and exported to ArcMap where a 150 meter buffer zone was built upslope of the forest line to create a zone equivalent to the treeline ecotone. The buffer was used to extract around 250 vector points from the grid. The points were divided in two sets depending on their north-south position on the mountains, to ensure that equally many sample plots are positioned on the north- and south facing slopes. From each of these two sets 25 points were randomly selected using a random sequence generator (www.random.org). The selected points were given 30 meters buffers, creating 50 circular sample plots with areas of 2827.4 m^2. The total mapped area was about 14 hectare.

Mapping

The orientation of the digital photos is automatically done by Delta DBS and consists of three different phases: inner, relative and absolute orientation. For the inner orientation a camera file is needed to describe the geometrical properties and errors of the camera used. This file is either delivered or created from data that comes along with the digital photos. Relative orientation connects the photos to each other and makes the stereo view possible in picture overlaps. Absolute orientation fits the stereo-models into a known geographical projection. When orientation is done Delta automatically changes between rasters to give optimal stereo view. During mapping the module Delta Digitals allows zooming from full size (~1/30000 depending on the model) to around 1/300. The most useful scale for the mapping done in this project reaches from 1/600 to 1/1000.

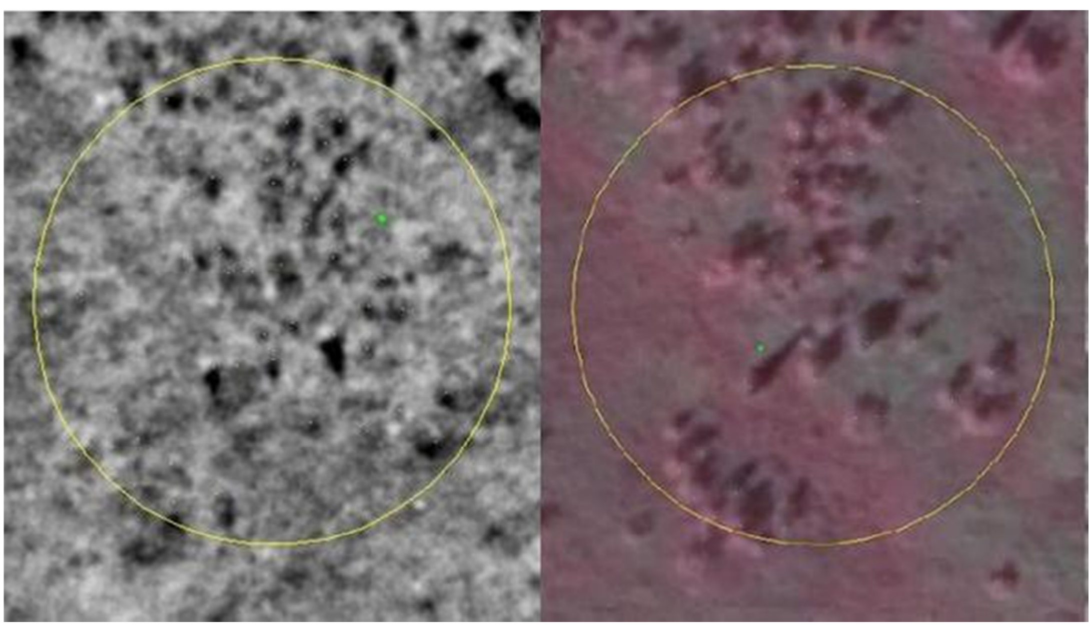

Figure 2. *The figure is showing the same sample plot in the 1960s black and white (BW) photo (left) and in the colour infrared (CIR) photo (right) from 2009. The interpretation is done with stereo view.*

The mapping is carried out by counting trees and interpreting tree heights within the sample plots for both years. This was done first in the CIR models from 2009 and later in the historical BW models, because the colours in the CIR photos gives higher contrasts when mapping vegetation. During mapping in the 1960 models the digitalized trees from the 2009 models were kept visible as reference to enhance detection of differecses, even if all visible trees were mapped in both cases.

Table 2. *Definitions of the object attributes used for the aerial photo interpretation.*

Attributes	Definition	Comments
Species	1 = Birch (Pine, Willow , Row an) 2 = Spruce	Def ault = 1
Height	Interpreted tree height	Meters, 2 decimals
Crow ns	Counted tree crow ns of object	Def ault = 1

Individual trees were digitalized within the sample plots as simple vector line objects consisting of two nodes being the start node on ground level and end node on tree top level. The line length (i.e. the tree height) is automatically stored in the objects attributes. Most object lengths were controlled once or more and the dissipation was observed to be mostly within 0,5 meters. However, no statistical test was done on the personal consistence of the tree height interpretation. There are two benefits from measuring the tree heights: it enables comparing sample plots regarding tree heights and trees shorter than two meters can alternatively be excluded from the data to match the definition of Mountain birch forest in the NILS program (Heiskanen et al 2008).

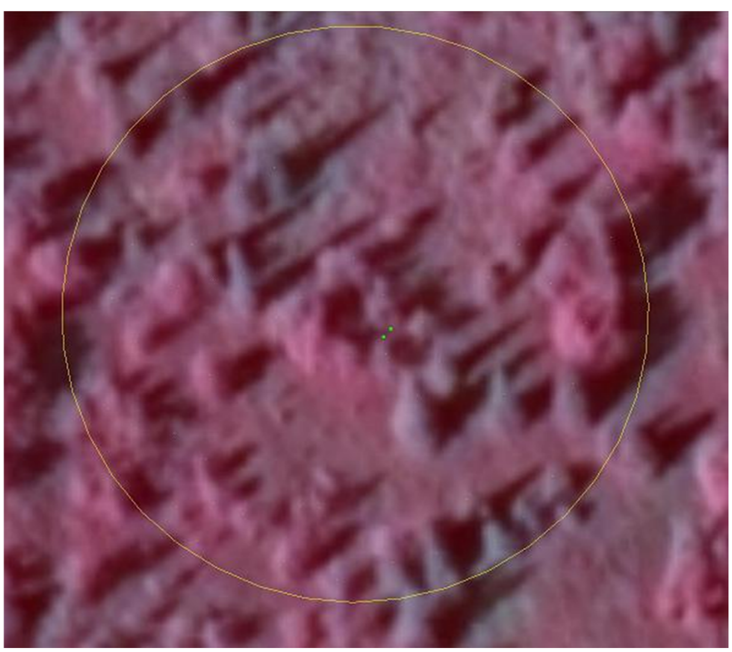

Figure 3. *The colour and shape of spruces makes them easily identified in the mountain birch forests. Spruces have spire-like crowns which cause systematic under-estimations when interpreting tree height and are therefore recorded so they optionally may be excluded from the data.*

Spruces are due to differing structure and colours easily identified (fig. 3) and were recorded to enable exclusion from the final dataset, since their narrow tops cause large (up to 2.5m) underestimations in tree height (Axelson & Nilsson 1993). All other trees were recorded as birch by default, even if both willow and pine were observed in small numbers. If a tree consisted of several clustered stems, these were counted and recorded in ‘crowns’. This was only done if clustered trees were of approximately same height and too dense to easily be digitalizes as single objects, thus default value was 1. Used attributes are shown in table 2.

The data was exported as two shapefiles to ArcMap where identity overlay was performed with the sample plot layer, to add information of which sample plot the tree grows in. The attribute tables were exported as datasets. The number of trees and tree heights were summed for each of all the sample plots, giving two datasets á 50 values per year for 1960 and 2009.

Statistical analysis

All data

To analyse the differences between 1960 and 2009 in counted trees and total tree height per sample plot, paired samples t-test were performed in SPSS. The data were grouped into four categories and the analyses were done for each of the four categories:

1. All tree heights, all species

2. All tree heights, only birches

3. Trees over two metres, all species

4. Trees over two metres, only birches

North & south data

The 25 northern and 25 southern sample plots were analysed with individual samples t-tests to detect overall differences in tree numbers and tree heights between the north and south side. This was done for the datasets of 1960 and 2009 respectively.

To see if tree density had behaved different between the north and south sides paired sample t-tests were run separately for the 25 northern and 25 southern sample plots. All species were included in the tests. Separate tests were done for trees in all heights and trees taller than two meters.

Results

In total within the 50 sample plots, 1245 and 1781 trees repectively were digitalized in the historical 1960 photos and the modern 2000s photos, which is an increase with 43,1 %. Mean tree amount per hectare raised from 88 in 1960 to 126 in 2009. The increase of trees taller than two meters between 1960 to 2009 was 57,5%, a mean increase from 50 to 79 trees per ha (table 3, figure 4)

The total summed tree height within the sample plots was 2839 meters in the historical photos and 4542 in the modern photos meaning an increase of 60% or a mean increase 120 meters per ha. For trees taller than two meters the increase in summed tree height between 1960 to 2009 was 77,6% or a mean increase with 111 meters per ha (table 4, figure 5).

Table 3. *Summed numbers of all recorded trees and the amount of trees within each species. Trees taller than 2 meters are presented separately. The increase from 1960 to 2009 is shown as total numbers of trees in the study site, mean increase per hectare and total increase in percent.*

Counted trees

All trees

Year	*All*	**Species** *Birch*	*Spruce*	*Mean Trees/plot*	**Increase** *trees*	*per ha*	*%*
1960	**1245**	1197	48	24.9	536	37.9	**43.1%**
2009	**1781**	1729	52	35.6			

Trees over 2 m

Year	*All*	**Species** *Birch*	*Spruce*	*Mean Trees/plot*	**Increase** *trees*	*per ha*	*%*
1960	**708**	682	26	14.2	407	28.8	**57.5%**
2009	**1115**	1063	52	22.3			

Table 4. *Summed tree heights of all recorded trees and the height sums for each species. Trees taller than 2 meters are presented separately. The increase from 1960 to 2009 is shown as total tree height in meters in the study site, mean increase in meters per hectare and total increase in percent.*

Summed tree height (metres)

All trees

Year	*All*	**Species** *Birch*	*Spruce*	*Mean height/plot*	**Increase** *metres*	*per ha*	*%*
1960	**2839**	2728	111	56.8	1702	120.4	**60.0%**
2009	**4542**	4279	262	90.8			

Trees over 2 m

Year	*All*	**Species** *Birch*	*Spruce*	*Mean height/plot*	**Increase** *metres*	*per ha*	*%*
1960	**2027**	1953	75	40.5	1572	111.2	**77.6%**
2009	**3596**	3334	262	71.9			

The mean birch high height was 2.27 meters in 1960 and 2.42 meters in 2009. Mean birch heights taller than two meters were 2.86 meters and 3.09 meters .48 and 52 spruces with summed heights of 111 m and 262,5 m each were recorded respectively from the historical and the modern photos. When excluding spruces shorter than two meters the numbers were 26 respectively 52 (table 3 & 4).

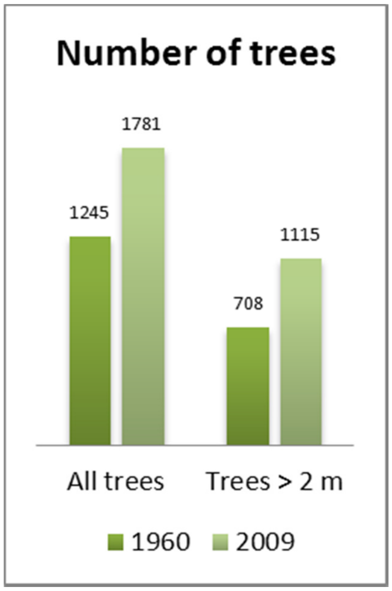

Figure 4. *Bar chart of the change during time period 1960 - 2009 in total tree numbers in the sample plots.*

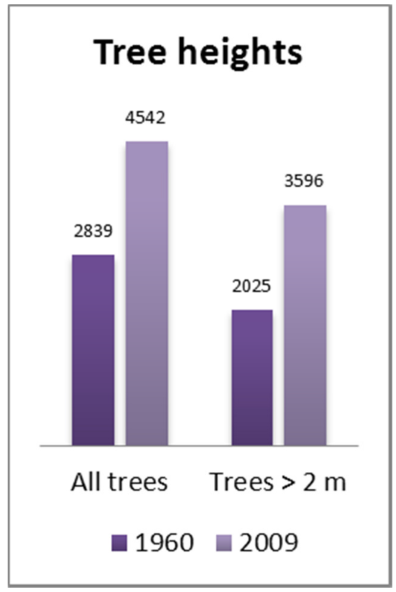

Figure 5. *Bar chart of the change during time period 1960 - 2009 in summed tree height in the sample plots.*

Statistical analysis

All data

The datasets followed normal distribution thus parametric statistical tests could be used.

Categories 1 and 2 – All tree heights
For categories 1 (all species) and 2 (birches only), the results from the paired samples t-tests shows mean increases in tree numbers with 43.1 % and 44.4 % respectively, which is approximately 38 trees/ha. The mean increases of total tree height for categories 1 and 2 are 60.0 % and 56.9 %, or 120.4 m/ha and 109.7 m/ha. The statistical significances for categories 1 and 2 were over 99.9 % (table 5 & 6).

Categories 3 and 4 – Trees taller than two meters
The mean increase for category 3 (all species) was 57.5 % or 29 trees/ha in tree numbers. For summed tree height it was 77.4 % or 111.2 m/ha. For category 4 (birches only) the mean increase was 55.9 % or 27 trees/ha in tree numbers, and 70.7 % or 97.9 m/ha in summed tree height. The statistical significances for categories 3 and 4 were over 99 % (table 5 & 6).

Table 5. *Statistics from the paired samples t-tests on the increase in tree numbers in the sample plots between 1960 and 2009. The tests are done for both height classes and separately for the two species classes. Mean increase is shown as trees per sample plot (≈0.3 ha) with standard deviation and statistical significance.*

Tree numbers - Changes from 1960 to 2009

	Species	Mean Increase percent	Mean Increase per ha	Mean Increase per plot	St Dev.	Df	Sig. (2-tail.)
All tree heights	All	43.1%	37.8	10.7	13.8	49	0.000
	Birch	44.4%	37.6	10.6	13.8	49	0.000
2m min. height	All	57.5%	28.9	8.2	15.6	49	0.001
	Birch	55.9%	27.0	7.6	15.2	49	0.001

Table 6. *Statistics from the paired samples t-tests on the increase in summed tree heights in the sample plots between 1960 and 2009. The tests are done for both height classes and separately for the two species classes. Mean increase is shown as meters tree height per sample plot (≈0.3 ha) with standard deviation and statistical significance.*

Summed height - Changes from 1960 to 2009

	Species	Mean Increase percent	Mean Increase per ha	Mean Increase per plot	St Dev.	Df	Sig. (2-tail.)
All tree heights	All	60.0%	120.4	34.0	54.8	49	0.000
	Birch	56.9%	109.7	31.0	51.6	49	0.000
2m min. height	All	77.4%	111.2	31.4	61.5	49	0.001
	Birch	70.7%	97.9	27.7	57.9	49	0.001

North & south data

Comparing the 25 sample plots respectively on the north and south side of the mountains with individual samples t-tests showed no significant difference in neither tree numbers or summed tree height (sig.= 0.512- 0.909).

The separate paired samples t-tests for the north- and south-facing slopes shows that tree density changes has occurred in slightly different rates for the north and south side (table 7), with northern slopes having larger changes and a higher statistical significance.

Table 7. *Statistics from paired samples t-tests on the tree numbers increase from 1960 to 2009, done separately for the sample plots on north- and south-facing slopes to compare the growth rates for different aspects. All species are included and the tests are done for both tree height classes. Mean increase is shown in percent, trees per hectare and trees per sample plot with standard deviation and statistical significance.*

Changes in tree numbers on North and South slopes (1960-2009)

		Mean Increase					Sig.
		percent	per ha	per plot	St. D.	Df	(2-tail.)
All tree heights	**North**	46%	43.0	12.2	12.9	24	0.000
	South	40%	33.7	9.5	16.9	24	0.010
2m min. height	**North**	68%	32.8	9.3	14.8	24	0.004
	South	47%	23.9	6.8	14.4	24	0.027

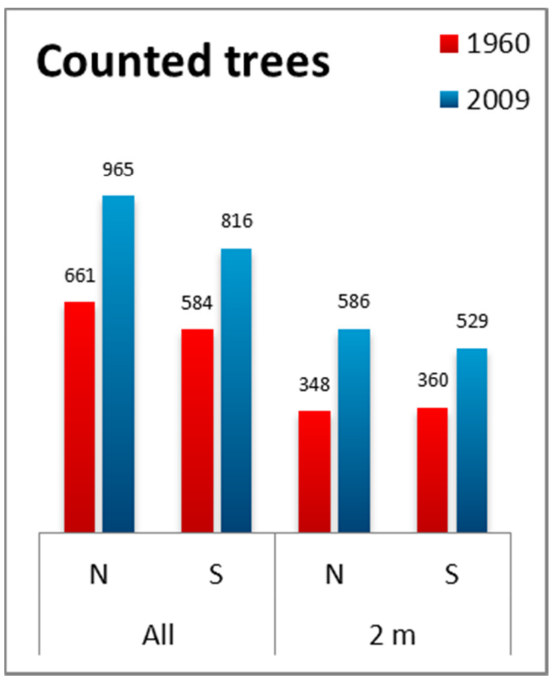

Figure 6. *Bar charts comparing the changes in tree numbers from 1960 to 2009 between sample plots the north and south side of the mountains.*

Discussion

The results show that a significant densification of trees has been occurring between 1960 and 2009. Even though the expected interpretation accuracy is lower for measuring tree heights than for counting individuals, a proportionally higher increase of summed tree heights implies a noticeable height growth in existing individuals heights (60,0 % vs. 43,1 % for all trees and 77,6 % vs. 57,5 % for trees taller than two meters). This could be interpreted as signs for phenotypic changes. For a close-up study focused on tree height growth, the comparison between different years should be done only for individuals recorded in both the recent and the historical photos. Thus, in this project the rise in tree summed heights is to a large extent explained by the increase of measured individuals. Tree height interpretation is also justified because it enables selections based on height.

The forest line position is likely to be determined by roughly the same factors as the treeline. Since the sample plot distribution follows the forest line instead of an isoline, the data is not suitable for detecting evidence of different treeline elevations etc. between north- and south-facing slopes.

In the present study, the overall difference in number and height of trees did not vary between north- and south-facing slopes. This indicates that data from north respectively data from south facing slopes may be merged and used together in the analysis of changes in treeline. It also allows comparisons on the rate of tree densification on the respective side. A comparative study of treeline structure between the north and south sides could have been done e.g. by counting trees in systematically distributed sites of the same elevation (m.a.s.l.) on both sides of the mountains.

The increase of trees is larger and statistically more significant on the northern sides of the mountains. This agrees with research by Kullman (2001) and can be explained with north-slopes being ecologically more delimited by a later beginning of the growth season, as an effect of temperature and slower snow-melting, thus more affected by an increased temperature. Hållmarker (2002) had similar results in Abisko and had similar conclusions. Local variations in topography should be further examined before major conclusions are made since slope aspect influence both insolation and snow accumulation (Kullman 2001, Holtmeier 2009).

No other aerial photos than those from 1960 and 2009 were used. It would have been interesting to study the rate of the increase by the use of aerial photos taken sometime between the photos used for this project. The CIR aerial photos used in the change detection mapping by Heiskanen et al (2008) were from the two time periods 1975–1979 and 2002–2004 and three of the six study sites showed significant increases in tree cover. Hållmarker (2002) used digitally scanned aerial BW photos from 1959 and CIR photos from 1978 and 2000. She concluded that the forest line had advanced from 1959 to 2000 but that almost no difference was visible between 1959 and 1978. Even if photos earlier than 1975 was not used by Heiskanen et al (2008), the fact that both studies recorded changes from the late seventies to present harmonize well with the research done by Kullman (2001) where the treeline advanced essentially before the 1950s and during the 1990s. However, it is declared in both studies that 1960s photos are superior to 1970s photos, in spite of the CIR colours of the later, because of the differing scale (1:60000) of the seventies photos. The scale of the BW 1960 photos is equivalent to the CIR 2009 photos (1:30000). Hence, equal scale is of greater importance than colour for change detection (Heiskanen et al 2008, Hållmarker 2002). The disadvantage of the colours is also compensated by stereovision and the higher spatial resolution of the BW photos, which means that e.g. height measuring should be more accurately done in the BW photos.

The number of spruces has not changed remarkably regarding the total numbers. Note that twice as many spruces over two meters tall were found in the 2009 photos than in the 1960 photos. The total height of spruces in the study area has more than doubled from 1960 with an increase from 111 m to 262,5. The difference is remarkable and could be a result of extensive growth of stunted individuals induced by a warming climate. It is on the other hand unreliable to draw any conclusions of spruces tree heights since they are difficult to interpret (Axelson & Nilsson 1993) and spruces in this biotope are even more spire-like than in other parts of the country, due to wind caused stem and branch breakage (Kullman 2005). The impacts from a relatively low number of spruces on the total tree height are notable. More data than 50 trees are needed to enable conclusions to be drawn from the differences.

The lack of field validation is of course a source for uncertainty and the accuracy of the results in this analysis is dependent on my interpretation. Heiskanen et al (2008) concludes that validation with field data is important for large scale use of the methods they described. The method used for this project is largely the same as their sample plot method, thus quite simple and straight-forward. It is important that change detection is done by the same interpreter, in the same way all comparative studies fail if there are differences in method (Heiskanen et al 2008). Since this project is done by only one interpreter, the execution can be assumed to be consequent in method. The highest uncertainty is the assessment of tree heights, which probably could be trained and calibrated anywhere with stereo-models of equal properties. Field data from both photo dates are impossible to gain. A field validation of the present situation would be time-consuming and difficult minding the modern photos are taken eleven years ago. Choosing the study site by the availability of ground information could be a solution, i.e. where field studies previously are performed and results can be compared. Another would be to have test areas in easily accessed places for field visits.

Figure 7. *A reindeer fence was observed in the 2009 photos (upper right corner). Browsing herbivores can in different ways have major impacts on the growth and structure in the treeline ecotone. The development of the reindeer management during the studied time period must be taken in consideration when discussing vegetation changes.*

The aim of this study is to observe and document a possible change in tree abundance rather than speculating about the underlying reasons. Even if the observed increase of trees is well in line with the model-based future projections (Moen et al 2004), little is known about other factors influencing the treeline structure in the region.

Fuel harvesting and other human disturbances are more likely to occur lower down in the sparse mountain birch forest than close to the treeline. Cutting in the treeline ecotone is though often done in small quantities (Kjällgren & Kullman 1998) and should not affect the result remarkably concerning whole study site. The photo interpretation showed no signs of outbreaks of autumnal moth (Epirrita autumnata) and winter moth (Operophtera brumata). Additional photos from half-between the photo dates may have provided some extra info on that. More information of structural changes could maybe be achieved by constructing two threedimensional GIS models of the digitalized trees. Theoretically this would be possible with the data obtained in this project, but such studies would probably demand larger areas than the 30 meter radius sample plots used. The potential for studies of structural changes will improve in the future with the use of high resolution airborne laser scanning (ALS) (Næsset & Nelson 2007).

The influence of reindeer management has to be taken in concern. Two reindeer migration pathways pass the fringe of the study area, and the mountain tops are used as winter grazing areas from October-November until March-April (Kalla 2010). It would be interesting to know how the grazing intensity has developed in the area from 1960 to 2009. A reindeer fence of approximate size as a sample plot was observed in the year 2009 photo (fig. 7). A raised browsing pressure would be in contradiction with the increased tree density. Increased grazing may however also have the effects of lowering the competition among plants to the benefit of growing saplings, but typically reindeer grazing has a negative impact on treeline advance in mountain birch forests (Cairns & Moen 2004, Cairns et al 2007).

Conclusions

1. During the studied time period 1960 – 2009, tree abundance have increased in the sparse mountain birch forest of the study area
2. From 1960 to 2009, the mean amount of trees per hectare has raised from 88 to 126. Mature size trees (> 2m) have increased from 50 to 79 trees per hectare.
3. Tree height interpretation indicates a growth in previously existing trees.
4. The densification is more significant and with slightly higher rates on the northern sides of the mountains than on the southern.

Acknowledgements

I want to thank Tommy Löfgren and NaturGIS AB for invaluable consultation, as well as for providing me with the aerial photos and the stereo equipment used in the project. I want to thank Karin Hall and Margareta Johansson for valuable comments. Last, I want to thank friends and family for the encouragement.

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