Aerial photo interpretation for change detection of treeline ecotones in the Swedish mountains

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Preface

This report is based on the work done for the project “NILS as platform for monitoring impacts of climate change in the Swedish mountains” (*NILS som platform för övervakning av klimatförändringar i fjällen*). The project was financed by the Swedish Environmental Protection Agency (*Naturvårdsverket*, *överenskommelse* 227 0723, Dnr 721-4698-07Mm). The project is also a contribution to the Swedish activities during the International Polar Year 2007–2009.

The project was carried out at the Department of Forest Resource Management in the Swedish University of Agricultural Sciences (SLU) in Umeå. Janne Heiskanen has been the project leader since April 2008 and is responsible for this report. Sture Sundquist was the project leader in the beginning of the project. Björn Nilsson and Ann-Helen Mäki made the photo interpretations. Anna Allard and Jon Moen (Umeå University) took part in project planning and discussion of the results. Sören Holm has provided advice on statistics. Sture Sundquist and Håkan Olsson have supported the project leader in planning and execution of the project.

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Cover photo: Janne Heiskanen (Vitnjultjåkke, Ammarfjället)

Summary

It is expected that the ongoing climate change will have a strong influence on the Earth's vegetation and cause the advancement of treelines towards the poles and up to higher elevations. In the Swedish mountains, changes in the positions of alpine treelines have already been reported, and major changes due to changing climate are predicted for the near future. Remote sensing techniques have considerable potential to improve the monitoring of spatially complex treeline ecotones, which are likely to show site dependent responses to changing climate. Aerial photos provide the longest temporal record of remote sensing data for studying the historical treeline changes. High spatial resolution and the possibility of interpreting photos in three-dimensions are the main strengths of aerial photos. The National Inventory of Landscapes in Sweden (NILS) is a nationwide environmental monitoring program, which provides sampling infrastructure for monitoring treelines over the Swedish mountains using high spatial resolution remote sensing data.

The aim of this project was to study the feasibility of visual interpretation of aerial photos for monitoring changes in treeline ecotones (transition zones between closed forest and treeless alpine vegetation). More specifically, our aim was to compare possible methods for change detection using recent and historical aerial photos, and to demonstrate a method that is applicable to the Swedish mountains using the NILS sampling infrastructure. We also wanted to evaluate how the technical properties of the aerial photos, particularly the photo scale, affect the change detection. The results were used for evaluating the potential and costs for a more comprehensive change detection study including a greater number of NILS squares.

We compared interpretation methods in three 5×5 km NILS squares and studied in total six 5×5 km NILS squares for changes. Colour infrared aerial photos from two points in time (1975–1980 and 2002–2004) were used. The evaluation of the technical properties of aerial photos is important as the recent photos have been taken from a height of 4600 m (photo scale approximately 1:30,000) and the historical photos from 9200 m (1:60,000). The difference in photo scale could introduce significant errors to the change detection. Therefore the effect of photo scale was studied in two experiments in a separate study site, which had been photographed within a few days from both flying heights.

We assessed three visual interpretation methods: complete cover mapping (polygon interpretation), sample plot method and transect method. To avoid recording false changes and to minimize the effect of different photo scales, we interpreted the recent and historical photos at the same time using scanned photos and digital photogrammetric workstations. The first method, polygon interpretation, was tested by comparing the current NILS interpretations for the central 1×1 km square within the 5×5 km NILS squares with the historical photos, and updating polygon borders and attributes if changes were observed. In the second method the vegetation variables were interpreted for circular sample plots (20 m radius). We used digital land cover data and GIS techniques for defining a buffer zone between the forest and the treeless alpine areas in order to focus the interpretation efforts on the treeline ecotone. The distance between the systematically sampled plots was 250 m within the treeline buffer. In the third method the variables were interpreted along subjectively selected transects across the altitudinal treeline transitions. Transects were also used for interpreting individual trees within the treeline, of which some were measured in the field.

Based on the analyses we can recommend the sample plot method for interpreting tree cover changes within 5×5 km NILS squares. The main advantage with the method is that it can be

applied to any NILS square overlapping the treeline ecotone, and that the sampling can be done objectively. A treeline buffer zone based on digital land cover data provides one possible method for pre-stratification. Delineation of polygon borders is not needed and small sized sample plots are easier to interpret concerning vegetation changes than larger polygons. This is particularly the case when changes are small. The polygon interpretation using change control mapping can also be a cost-effective method for change detection within the 1×1 km squares. The greatest advantage is that in addition to tree cover changes, it can provide information on the spatial patterns (landscape structure). However, the small changes in the borders are subjective and difficult to interpret. The transect method can also provide characterization of treelines, particularly in relation to elevation, but the selection of transects within NILS squares can be difficult. Furthermore, the result cannot be generalised to larger areas similar to the method based on probability sampling.

We conclude that only tree cover changes can be interpreted with sufficient accuracy, because of the relatively small scale historical photos. Larger scale photos and more extensive field control would be necessary to interpret changes in small trees and shrubs. The experiments with photo scale show that the greatest source of uncertainty is related to the different photo scale of the recent and historical photos. The comparison of two independent interpretations made at different scales would lead to detection of substantial false changes, particularly if interpretations would be made by different interpreters. However, we think that concurrent comparison of digital aerial photos from two points in time provides meaningful change detection for tree cover although some errors due to scale effects should be expected.

The interpretation of six NILS squares by the sample plot method suggests that tree cover has increased within the treeline ecotone in three of the squares. The results demonstrate the potential of visual interpretation of aerial photos for treeline change detection. The information on tree cover changes could supplement field based monitoring of treeline elevations. Therefore, we consider that there is potential for a more comprehensive study to examine tree cover changes in a greater number of NILS squares in the Swedish mountains. Then, however, more emphasis should be given to the panchromatic black and white photos from the 1960s, which have been taken from approximately the same flying height (4600 m) as the most recent CIR photos. We estimate that a large scale study, involving the interpretation of approximately 50–60 NILS squares for three points in time would require a budget of about 1 million SEK. Airborne laser scanning and larger scale aerial photos are potential data sources for monitoring future changes in treeline ecotones.

Keywords: treeline ecotone, climate change, aerial photography, colour infrared, change detection, visual interpretation

Sammanfattning

De pågående klimatförändringarna, liksom eventuellt även ändringar i betestryck och antropogen påverkan, förväntas ändra trädlinjens läge i de svenska fjällen. En diskussion pågår även kring i vilken utsträckning detta redan har skett. Etableringen av nya träd i trädgränsekotonen sker dock i ett mosaikartat mönster och det är svårt att mäta dessa förändringar med objektiva metoder som också är representativa för ett större landskap. Historiska flygbilder utgör dock en intressant informationskälla som bör kunna utnyttjas för detta.

I denna metodstudie undersöks möjligheter och begränsningar med ett antal sätt att jämföra nya infraröda flygbilder från 4600 m höjd registrerade 2002–2004 (skala ca 1:30 000) med infraröda färgbilder från 9200 m höjd, registrerade mellan 1975–1980 (skala ca 1:60 000). Utgångspunkten är att flygbildstolkningen görs inom de 5×5 km stora stickprovsområden som definieras av Nationell Inventering av Landskapet i Sverige (NILS).

Tre olika metoder för flygbildstolkning testades.

1. Kartering av polygoner, där befintlig kartering från NILS jämfördes med äldre flygbilder.
2. Tolkning av ett regelbundet rutnät av cirkelytor med 20 m radie. Vid utlägget av cirkelytorna gjordes en stratifiering så att ett tätare grid med punkter användes inom en buffertzon mellan fjäll och skogsmark, som extraherades från Svenska Marktäckedata (GSD-Marktäcke).
3. Tolkning av subjektivt definierade transekter längs fjällsluttningen.

Bilderna skannades till digital form (upplösning 14 mikrometer). Tolkningen av bilder från olika tidpunkter kunde därefter göras genom att i en digital fotogrammetrisk arbetsstation växelvis betrakta stereobilder från två olika tidpunkter.

Baserat på våra erfarenheter från testerna så rekommenderar vi punktgittermetoden om objektiva mått på trädskiktets förändring eftersträvas. Den metod vi använde för tätare punktgrid nära trädlinjen fungerade också bra. Avgränsning av polygoner innehåller fler subjektiva moment än punktgittermetoden. Transektmetoden blir subjektiv redan vid utlägget av transekter, och resultatet kan därför inte generaliseras till hela landskapet.

Det är främst förändringar i trädtäckning (träd högre än 2 m) som vi lyckats tolka. Förändringar i busktäckning bedöms som omöjliga att upptäcka vilket beror av de tidiga bildernas begränsade skala. Det mosaikartade mönster som förändringarna sker inom, samt effekter av sluttningsrikning och latitud, gör också att det är svårare att kvantifiera trädgränsförändringen i termer av meter höjdändring per år än förändring i täckningsgrad för trädvegetationen.

Eftersom de tidiga bilderna var registrerade i skala 1:60 000 och de sena i skala 1:30 000 så innebär skillnaderna i bildskala en potentiell felkälla. Därför gjordes även två studier där bilder i olika skalor från nästan samma datum jämfördes. Dessa studier visade att såväl skillnader i fotoskala, som skillnader mellan tolkare kan vara väsentliga felkällor för denna typ av undersökningar. Sammantaget så bedömer vi ändå den rekommenderade punktgittermetoden som så tillförlitlig att den är meningsfull för uppskattning av förändringar i trädskiktets täckning, givet att tolkarna får tillfälle att kalibrera sina bedömningar.

Studien gjordes inom 6 NILS-rutor belägna på trädgränsen. Inom dessa hade trädskiktets täckning ökat i tre. Det finns ett intresse hos bland annat länsstyrelserna att få ökad kunskap om hur de förändringar av trädgränsen som diskuteras fördelas längs fjällkedjan. För att få närmare kunskap om detta skulle en fullskalestudie på de ca 50–60 NILS-rutor som ligger nära trädgränsen kunna göras. Innan detta sker bör dock även användbarheten av pankromatiska flygbilder från 1960-talet, tagna på normalhöjd (4600 m), undersökas. Ett framtidsinriktat monitoringprogram av detta slag bör dock ej startas innan möjligheterna med att kombinera laserskanning med fältmätningar också har undersökts.

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1. Introduction

The ongoing changes in the Earth's climate are expected to have a strong influence on vegetation communities (IPCC 2007). The changes in climate have been predicted to be greater near the poles than in the tropics (ACIA 2004).Vegetation communities may exhibit changes in the distribution, species composition, biomass and pattern of landscape. Already, a large number of studies provide evidence on the ecological impacts of climate change. A common understanding is that warmer climate, earlier spring conditions and milder winters will cause altitudinal and latitudinal changes in plant distribution (Parmesan & Yohe 2003; Walther 2003). These changes may have significant effects on the structure and function of ecosystems.

The transition zones between adjacent vegetation types (ecotones) are particularly vulnerable to the impacts of climate change; at these locations even small changes are likely to affect the distribution of vegetation communities (Cairns et al. 2007). Therefore, the alpine and arctic treeline ecotones are considered as potentially sensitive indicators of climate change. Assuming that the growth and reproduction of trees at treelines are controlled by the temperature, a rapid colonization of the arctic tundra and alpine areas by trees, and an advance of the forest towards the north and up to higher elevations could be expected in response to global warming (Moen et al. 2004). Although these predictions do not take into account the often slow, transient and counter-intuitive responses of trees to climate change, they indicate the potential for considerable relocation of treelines over a long time period (Callaghan et al. 2002).

Changes in alpine treelines in the Swedish mountains have already been observed and major changes are predicted for the near future. Kullman (2001) has reported that climate warming observed during the 20th century has promoted the upward shift of the treeline as great as 150–165 m at some sites in the Swedish mountains. Moen et al. (2004) simulated treeline advancement by 233–667 m over a 100-year timeframe, depending on the climate scenario used and location within the mountain chain. Such changes would cause drastic fragmentation and an area reduction of treeless alpine heaths.

Remote sensing techniques seem particularly attractive for monitoring treeline ecotones, which are likely to display highly site dependent responses to climate warming (Rees et al. 2002; Stow et al. 2004; Næsset & Nelson 2007). Colour infrared (CIR) aerial photos have been used successfully for vegetation mapping and change detection in the Swedish mountains (Allard 2003; Ihse 2007). In addition to high spatial resolution, stereo-pairs of aerial photos can be interpreted in three-dimensions, which can improve separation of trees and shrubs. Aerial photos are also available for a longer time period than any other remote sensing data. The National Inventory of Landscapes in Sweden (NILS) is a nationwide program for evaluating and monitoring conditions and trends in landscape-level biodiversity (Ståhl et al., in prep.). The NILS permanent sampling plots provide a sampling infrastructure for the objective monitoring of treelines in the Swedish mountains.

1.1 Objectives

The aim of this project was to study how the NILS sampling scheme and CIR aerial photos could be used to monitor vegetation changes in response to climate change influences on treeline ecotones in the Swedish mountains.

More specific objectives of the project were:

1. to study possible methods for treeline change detection using aerial photos and develop a method that is applicable within the NILS statistical design,
2. to evaluate the technical properties of the photos for change detection,
3. to demonstrate the developed method in a small number of NILS squares, and
4. to evaluate possibilities for a more comprehensive change detection study.

As the project focuses mostly on the methodological development, the most important question was whether it was possible to detect changes in vegetation at treelines using available aerial photos. Preferably, the method proposed by the project should utilize the strengths of the NILS sampling and materials as optimally as possible.

2. Background

2.1 Treeline ecotones and terminology

The ecotones between the closed forest and treeless alpine and arctic tundra display a variety of patterns (Callaghan et al. 2002; Holtmeier 2003; Kullman 2005). As thermal conditions become more severe towards the north and at higher elevations, there is a change from the arboreal growth forms of a low latitude and low elevation forest to low tundra vegetation. These transitions may be gradual or sharp and sometimes include intermediate shrub-like trees in a matrix of tundra (Cairns et al. 2007). Usually, these ecotones are transition zones of variable width, where forests, tundra and mires grade into each other. As altitude increases in the mountains, the treeless patches of alpine tundra grow in size and coalesce, while at lower elevations the forested patches are larger and treeless spots occur more rarely. A similar structure also appears towards the poles where a pattern of tundra islands within the forest gradually turn into a pattern of forest islands within the tundra.

The terminology to describe the *treeline ecotones* is ambiguous and varies considerably according to the author and study. It is common to use *treeline* in order to refer to the whole ecotone (e.g., Cairns et al. 2007). The latitudinal treeline between the boreal forests and the treeless tundra is typically called the *arctic treeline*, while the altitudinal treeline on the mountains is called the *alpine treeline*. However, *timberline* is also used sometimes when referring to the treeline ecotone (Holtmaier 2003; Heikkinen 2005). In the Fennoscandian context, Heikkinen (2005) prefers the term *northern timberline* for arctic timberline and *upper timberline* for alpine timberlines on mountains. However, timberline has also been used for defining the limits of continuous forest. Callaghan *et al.* (2002) use *tundra-taiga interface* when referring to the arctic treeline ecotone.

From an ecological point it is relevant to consider treelines as transition zones between the closed forest and alpine tundra. However, for the purpose of field based monitoring it has been necessary to use more practical definitions of the treeline (Kullman 2001, 2005).

Typically, some minimum tree height or forest cover has been used to define the upper treelines (Holtmeier 2003). Therefore, *treeline* often refers to the extreme boundary or altitude where trees still achieve an arboreal form and size, not necessarily to the treeline ecotone. Sometimes this line is called the *tree limit*. *Tree species line* corresponds to furthermost present position of a species no matter what the growth form. The southern or lower limit of treeline ecotone is typically called the *forest line*. Typically, forest line refers to the location where tree cover decreases below a certain threshold, for example, 10 or 30 percent (Allard et al. 2003; Heikkinen 2005).

According to the definition used in treeline monitoring in the Swedish mountains (Kullman 2001, 2005), the treeline (*tree limit*) is the highest elevation at a particular location where an individual tree reaches at least two meters in height. Each tree species occurring in the treeline ecotone has its own treeline. This definition was implemented in treeline monitoring already in the early 20th century which argues for the continuous use of this definition in monitoring (Kullman 2001). However, the tree height of two meters is also motivated by the fact that trees of this size are usually not entirely covered by snow, which facilitates the correlation between treeline elevation and meteorological variables. Furthermore, this definition of treeline should be relatively insensitive to human disturbances as the natural treeline can be defined only by the occurrence of a single or a few trees (Kullman 2001, 2005).

In the Swedish mountains, the treeline is usually a transition zone, ranging from approximately 50–100 m change in elevation, where increasingly shrubby and stunted birch woodland, alpine tundra, and mires grade into each other (Kullman 2005). As in most areas in Fennoscandia, the treeline is usually formed by mountain birch (*Betula pubescens* ssp. *tortuosa*). In the southern Swedish mountains, the birch treeline reaches approximately 1100 m a.s.l., while in the northern part it occurs at approximately 700 m a.s.l. (Kullman 2001). Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) can also form the treeline but are more typical in the lower reaches of the ecotone, where the three species often occur mixed. Rowan (*Sorbus aucuparia*), grey alder (*Alnus incana*) and aspen (*Populus tremula*) occur occasionally in the treelines, sometimes reaching approximately as far upslope as the birch (Kullman 2005). Although the alpine treeline of mountain birch generally occurs at higher altitude than that of spruce and pine, there are local deviations from this. For example, pine may form the alpine treeline in the province of Dalarna in the southern part of the Swedish mountain chain. For all species, treelines are significantly higher on slopes facing south and southwest (Kjällgren & Kullman 1998, 2002; Kullman 2005).

2.2 Impacts of climate change on treelines

The treeline positions and structure are affected by the interaction of current and past macroclimates, local climatic effects and various disturbances (Holtmaier 2003). In the Swedish mountains, the elevation of the treeline decreases notably with increasing latitude and from east to west with rising maritime influence (Kullman 2001). Microtopography is a key factor determining the site pattern. In windy terrain, the uppermost trees are clumped, often in minor depressions or in the lee of low ridges and crests due to the snow protection and available moisture. In addition to climate, the current treeline patterns are shaped by land use and herbivores (reindeer, insect outbreaks). Therefore, the response of the treelines to global climate change depends on the regional and local setting. However, if the future temperatures are distinctly higher than present and if no other factors adversely affect the regeneration and tree growth, climate warming is likely to have an impact on the positions and structure of treelines (Holtmeier 2003).

Kullman (2001) categorized the type of treeline change into phenotypic and genotypic change. The phenotypic change is the change in appearance of already established individuals that occurs when the climate gets more favourable or less favourable, resulting in growth or deterioration of trees. Genotypic change, on the other hand, refers to the establishment of new trees at higher elevations (tree migration) or downhill progression of tree mortality during the deteriorating climate. Although there are many studies that have reported rather stable treeline positions during the past 50 years or so, some studies have reported significant changes in the treeline positions and the establishment of tree seedlings beyond the forest margin. Furthermore, increases in tree density and rate of tree growth have been reported (Kullman 2001).

The treeline dynamics are also influenced by occasional extreme events, such as strong frosts during the growing season, exceptional snow conditions and mass-outbreaks of leaf-eating insects and other pathogens (Holtmeier 2003). Most of the treeline research has focused on explaining the location of the treeline, but the patterns of treelines are interesting as well as they may indicate the acting mechanisms and add knowledge for the prediction of future ecotone dynamics. Although the treelines are hypothesized to be sensitive indicators of climate change in general, the use of disturbance-regulated treeline ecotones to monitor climate change has been questioned (Cairns & Waldron 2003; Kupfer & Cairns 2003). Treelines are also unlikely to respond immediately and linearly to the warming. As a result, there will be regionally and locally different responses of treelines (Holtmeier 2003).

Kullman (2001) reviews the results of treeline monitoring in the southern Swedish mountains. The results show that treelines of different species have advanced upslope by 100–165 m (maximum) during the 20th century, which is in agreement with scenarios based on observed climatic changes. The major part of this displacement occurred prior to 1950, followed by stability or slight reversal for some colder mid-century decades. Signs of resumed advancement were recorded during the 1990s. At the local scale, the magnitude of rise varies with topographic complexity and associated geoecological factors. Phenotypic change has been the prevalent type of change. Treeline rise has the character of increased height growth of old established trees (*Betula*, *Picea*) and to a lesser extent upslope migration of trees (*Pinus*). The elevational belt between the historical (early 20th century) and recent (late 20th century) treeline has been progressively treed, mainly by birch (Kullman 2001). The studies carried out for the northern Swedish mountains are considerably fewer than for the southern part of the mountain chain (Hållmarker 2002).

In the Swedish mountains, herds of semi-domesticated reindeer graze the alpine heaths and meadows from spring to autumn and also shape the treeline patterns (Cairns & Moen 2004; Cairns et al. 2007). The grazing poses a problem for using treelines as indicators of climate change, because reindeer browsing can prevent treelines from advancing despite favourable climatic conditions. The outbreaks of leaf eating moths, which occur on a cycle of approximately ten years in Scandinavian mountain birch ecosystems can also affect the treeline positions by causing dieback of the birch trees (Tenow et al. 2001).

Vegetation changes beyond the treeline, in the arctic and alpine areas, have also been reported. For example, Sturm et al. (2001) observed that height and diameter of individual shrubs had increased and shrubs had expanded into previously shrub-free areas in Alaska during the past 50 years. The changes in the extent of the shrub biotopes such as willow shrublands can also occur in the Swedish mountains in response to changing snow conditions, as willows are particularly sensitive to the protection of snow cover (Esseen et al. 2004).

2.3 Aerial photos in treeline mapping and change detection

Although treeline research has been going on for a long time, there is still lack of consistent data on the location, nature and dynamics of treelines at all scales from global to landscape, particularly over the arctic treeline (Callaghan et al. 2002; Rees 2007). As the nature of treeline ecotones shows vast spatial variability and impacts of climate change are likely to be very site dependent, remote sensing techniques seem very attractive for mapping and monitoring purposes. Remote sensing data are available at various spatial resolutions to support mapping and monitoring at different scales (Stow et al. 2004). Coarse resolution satellite data is best suited for the characterization of treelines at the circumpolar scale. High spatial resolution data is needed for case studies, for mapping the spatial structure of ecotones and as training data for coarse resolution analyses (Rees 2007). In order to detect initial treeline changes due to climate change, better spatial resolution than provided by medium and coarse resolution satellite data is considered necessary (Næsset & Nelson 2007).

Aerial photos are an attractive source of remote sensing data because of the high spatial resolution. The stereo interpretation of aerial photos also allows viewing of the landscape in three dimensions, which facilitates the discrimination of trees and shrubs from ground vegetation and shadows. Furthermore, aerial photos provide the longest temporal record of remote sensing data and are therefore an invaluable resource for studying changes in land cover and vegetation over time. The visual interpretation of aerial photos has a long tradition in vegetation mapping and forest inventory. More automatic digital interpretation methods do not usually employ three-dimensional information. Furthermore, the qualities of the aerial photos (photo scale, geometry, light conditions, etc.) can vary considerably between the photo acquisitions, which also hinders the application of automatic methods.

Colour infrared (CIR) film is usually superior to other film types when assessing vegetation type, because the vegetation types typically show the greatest differences in reflectance in the near-infrared spectral region (Ihse 2007). However, the oldest photos are usually black and white photos. In Sweden, the oldest CIR aerial photos date to the 1970s and black and white photos to the end of 1920s. In the 1970s and 1980s the entire country was photographed using CIR film by the Swedish National Land Survey (*Lantmäteriet*). The scale of the photography was 1:30,000 in southern Sweden and 1:60,000 in northern Sweden and in the mountains (Boberg 1993). The photos were taken with a camera having a focal length of 152 mm and overlap of 60% to enable stereo interpretation. Since 2005 the National Land Survey has taken aerial photos using a digital camera, allowing both black and white, true colour and infrared colour photos to be generated at the same time (Ihse 2007).

CIR aerial photos have been used commonly for vegetation mapping and change detection in Sweden (Ihse 2007). The mountain vegetation map (*Vegetationskartan över de svenska fjällen*) at the scale of 1:100,000 is a good example. This vegetation map covers most of the alpine and subalpine areas in Sweden and was produced in the early 1980s by Stockholm University. Photography was taken from an altitude of 9200 m, which gives an approximate scale of 1:60,000. The minimum mapping unit was between 250×250 m and 300×300 m (6 to 9 ha). CIR aerial photos were also used in the biotope inventory of northernmost Finnish

Lapland (Sihvo 2000, 2001). The inventory was made in 1996 to1999 by Metsähallitus (*Forststyrelsen*) and covers an area of 2.6×10^6 ha. That inventory provides baseline data for environmental monitoring of the Finnish treeline regions. The interpretation keys for visual photo interpretation were collected in the field and covered approximately 16% of the area that was inventoried. The mapping scale was 1:20,000 and the smallest mapping unit was approximately 1 ha.

Aerial photos have also been used for treeline mapping and change detection (e.g., Baker et al. 1995; Allen & Walsh 1996). Hållmarker (2002) studied changes in forest area, elevation of forest line and stem density in Abisko (northern Swedish mountains) using aerial photos from 1959, 1978 and 2000. She found that the forest line had moved upwards into the treeless area. In some areas the forest had also become denser. Climate, railway construction in the beginning of the 20th century and reduced intensity of reindeer herding were reported as possible mechanisms for the change.

Tree cover is considered as one of the most important characteristics of treeline ecotones (Callaghan et al. 2002). Documentation of tree cover is commonly subjectively interpreted, however, and is strongly interpreter-dependent (Paine & Kiser 2003). A variety of visual guides are used for estimating tree cover and these help to remove some of the bias. These guides are typically diagrammatic drawings of circular or square plots with various percentages of tree cover. Sometimes dot counting methods are used (Fensham et al. 2002; Paine & Kiser 2003).

The appearance of the trees in the photos is also dependent on the scale of the photos. It is possible that tree cover is underestimated when trees are small and cover is relatively low because of the limited possibilities to detect the smallest trees. In the denser forests, however, it is typical that tree crowns are exaggerated as the photo scale decreases (Fensham *et al.* 2002; Fensham & Fairfax 2007). Small gaps in the canopy are more likely to be detected on large scale than on small scale photos. The temporal record of aerial photos can consist of photos at a range of scales. In the Swedish mountains, the oldest black and white photos usually have a photo scale of 1:30,000 and CIR photos a scale of 1:30,000 or 1:60,000 depending on the year. Therefore, improved understanding of the influence of photo scale on the interpretation of vegetation variables is needed. Otherwise it is possible that changes are erroneously interpreted because of comparing photos at different scales (Fensham & Fairfax 2007).

2.4 National Inventory of Landscapes in Sweden (NILS)

The National Inventory of Landscapes in Sweden (NILS) is a program for evaluating and monitoring the conditions and trends in landscape biodiversity (Ståhl et al., in prep.). The basis for the NILS program is a nationwide, permanent systematic sample of 631 squares. NILS includes all types of terrestrial environments in Sweden (agricultural land, wetlands, populated environments, forests, and alpine areas). Each sample square is 5×5 km in size. The inventory rotation time is five years, and hence, about 120 squares are inventoried every year. The NILS monitoring is based on parallel and combined aerial photo interpretation (Allard et al. 2003) and field inventory (Esseen et al. 2007a). Special emphasis is given to the 1×1 km square located in the centre of each 5×5 km square where more detailed aerial photo interpretation and field inventory is conducted.

In the NILS photo interpretation, homogeneous polygons are delineated and interpreted according to detailed instructions (Allard et al. 2003). CIR aerial photos at the scale of 1:30,000 are used. The minimum mapping unit is 0.05 hectares for point objects and 0.1 hectares for polygon objects. The field inventory is connected as closely as possible to the aerial photo interpretation. The same variables and definitions are used when possible. However, a greater number of variables are recorded in the field inventory. The sample plot inventory within the 1×1 km square consists of 12 systematically designed sample plot blocks (16 plots were sampled in the 2003 field inventory). Each block consists of concentric sample plots with radiuses of 3.5 m, 10 m and 20 m, and smaller vegetation plots (0.25 m^2) for detailed monitoring of field and ground layer vegetation (Esseen et al. 2007a).

For the sampling distribution of the NILS squares, Sweden was divided into ten geographic strata. Alpine areas including the sub-alpine forests are treated as one stratum based on the Nature Conservation Boundary defined by the Swedish Society for Nature Conservation. This stratum (number 10) has 144 squares in total. However, 25 squares are not photographed, and 15 squares of these will not have field inventory, as those squares are mostly (95%) water or located on Norwegian territory. Esseen & Löfgren (2004) evaluated the potential of NILS for assessing alpine Natura 2000 habitats in Sweden. According to their analysis, the NILS sampling should provide representative data for nationwide inventory and monitoring of the most common alpine and subalpine habitats, such as Nordic mountain birch forests, which typically form the treelines.

3. Study sites

The study sites include in total six 5×5 km NILS squares in the mountain area (Figure 1). Three of the squares were used for comparison of photo interpretation methods. After the methodological comparison, three additional squares were selected for further testing of the sample plot method. The NILS squares were selected so that geographical variability and different types of treeline ecotones typical for the Swedish mountains would be represented (Figure 2). At least one square was selected from each of the four counties having mountainous areas (Dalarna, Jämtland, Västerbotten and Norrbotten). The selection of the squares was also adjusted to the availability of the aerial photos at that time.

In addition to the six NILS squares, an additional area in Lake Grövelsjön (Långfjället, county of Dalarna), was used to study the effect of the photo scale and interpreter, and the potential of black and white photographs. The Grövelsjön test site was selected because CIR photos at two different photo scales as well as black and white photos were available. Grövelsjön is also well suited for interpretation experiments because all three of the most common tree species, i.e., birch, spruce and pine, are present in the treeline ecotone (Figure 2).

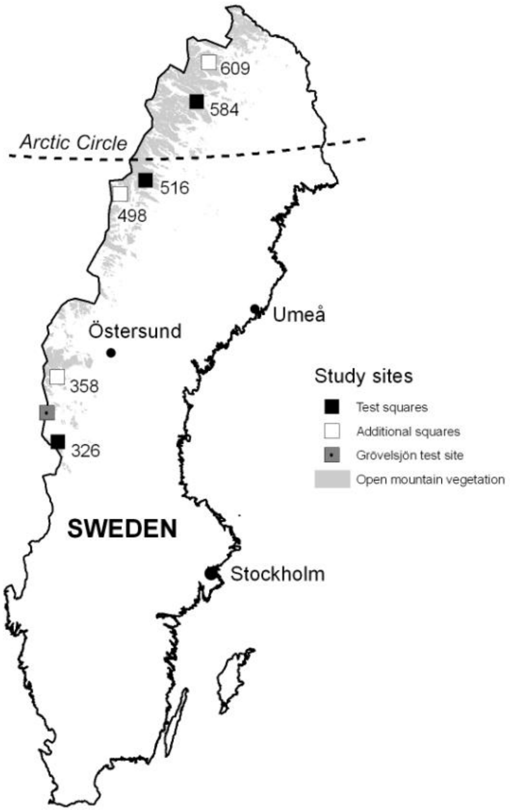


Figure 1.The location of the study sites (six NILS squares and Grövelsjön test site).

326 (Stormovallen, Fulufjället)

516 (Vitnjultjåkke, Ammarfjället)

584 (Jubmotjåkka, Stora Sjöfallet)

Grövelsjön test site

Figure 2. Photos from the study sites taken in the summer of 2008. Photos: Janne Heiskanen (326, 516, Grövelsjön) and Ann-Helen Mäki (584).

4. Materials

4.1 Aerial photos

For interpreting the NILS squares, we used CIR photos for two points in time (Table 1). The recent photos have been taken between 2002 and 2004 for the NILS program (Esseen et al. 2007b). The photos used in this project have been taken by Metria using Leica/Wild RC30 aerial camera. The photography has been made from the altitude of 4600 m above the ground, which results in photo scale of 1:30,000. Each 5×5 km^2 square requires three images with 60% overlap (two stereo models). The ground resolution at this scale is roughly between 0.5 and 1.5 m, depending on the contrast of the object. The photos are available both as scanned digital images and transparent diapositives. The photos have been scanned with a resolution of 14µm, which gives a theoretical ground resolution of about 0.4 m at the scale of 1:30,000. The historical photos were photographed in 1980 or earlier and were derived from the Land Survey's archive. The photos have been taken from the altitude of 9200 m above ground (1:60,000) using Wild RC10 aerial camera. These photos were also available both as scanned digital images and transparent diapositives. Digital orthophotos were also produced for most of the squares.

From the Grövelsjön test site we had CIR photos taken both from 4600 and 9200 m above ground within a few days in 1994 (Table 2). These photos were used to study the effect of photo scale, because it is unlikely that significant vegetation changes would have occurred within a few days. Furthermore, we had also black and white (BW) photos from 1956 at a photo scale of 1:30,000 (Table 2). CIR photos were available as scanned digital images and transparent diapositives. BW photos were used only in digital format.

Table 1. NILS squares and colour infrared aerial photos used for change detection.

NILS square	Location	Year of field inventory	Date of photography (time)	
			Recent	Historical
326	Stormovallen (Fulufjället)	2003	2002/08/04 (10.23)	1979/07/06 (12.11)
358	Övre Daddsjön (Flatruet)	2003	2002/08/04 (9.54)	1975/08/06 (10.54)
498	Stintbäcken (Hemavan)	2005	2003/08/10 (12.56)	1976/08/12 (10.35)
516	Vitnjultjåkke (Ammarfjället)	2003	2002/08/09 (10.48)	1976/07/16 (11.04)
584	Jubmotjåkka (Stora Sjöfallet)	2006	2004/07/22 (14.48)	1980/08/18 (13.24)
609	Lulip Välivare (Rautasjaure)	2003	2004/07/22 (15.21)	1978/07/21 (11.36)

Table 2. The specifications of the colour infrared (CIR) and black and white (BW) aerial photos from the Grövelsjön test site (12°17'40"E, 62°6'40"N).

Photo type	1:30,000 CIR	1:60,000 CIR	1:30,000 BW
Flying height	4600 m	9200 m	4430 m
Date of photography (time)	1994/08/08 (10.41)	1994/08/11 (11.10)	1956/07/03 (11.56)
Camera	Zeiss LMK 005A		Wild AG41
Film	"IR-Färg-43"		"Ortochr. acetat"
Filter	500		-
Grade	-	-	3+

4.2 Other materials

Additional materials included the Swedish GSD-Land and Vegetation Cover database (*GSD-Marktäcke*). This nationwide land cover database is the higher resolution and refined version of the European-wide CORINE Land Cover 2000 product. The base year of the database is the year 2000 and it has 58 classes (Ahlcrona 2003). Most of the classes are based on a combination of digital map data and classification of Landsat ETM+ satellite images. The generalized raster product was used (the minimum mapping unit is 1–5 ha depending on the land cover class). The land cover data were used for stratification of NILS squares into treeline ecotone and areas below and above it. The other digital map data was the digital elevation model (DEM) produced by the Swedish National Land Survey. The DEM has a spatial resolution of 50×50 m.

The field reference data were available for the sample plots of NILS field inventory (Esseen et al. 2007a). Some field data were also collected during field visits to test squares in July and August 2008. Furthermore, accurate field measurements on tree and shrub cover from an airborne laser scanning study were used for training purposes (Holmgren et al. 2008).

5. Photo interpretation equipment

The regular photo interpretation in the NILS program is carried out through stereo viewing of CIR photos on digital photogrammetric workstations (Allard et al. 2003; Esseen et al. 2007b). Using such equipment, the stereo model is presented on a high resolution screen and the stereo effect is obtained through a polarisation filter and special glasses. At present, the software DAT/EM Summit Evolution is used for stereo observation and delineation, and ArcGIS is used for polygon generation and for registering the interpreted data into the database. The same equipment and software were used for most of the interpretations in this project.

A Zeiss Planicomp P3 analytical photogrammetric instrument was also available as an alternative and complementary means of interpretation. This instrument was equipped with AP32 Photogrammetric Software and DAT/EM Super/Imposition and DAT/EM Capture software. ArcGIS was available for handling vector data. However, the transparent diapositives and analytical photogrammetric instrument were used mainly in the first experiment on the effect of photo scale and interpreter.

6. Selection of variables

The project was launched at a workshop in March 12, 2008 in SLU in Umeå. In addition to the project working group, the reference group members participated in the workshop. The purpose of the workshop was to discuss the project plan and objectives. The main focus was the discussion of the indicators of climate change to be studied in the project. Several expectations for the project were outlined. The project should provide methods to answer the following questions:

- How has the position of the treeline changed in the Swedish mountains at the regional and national level?
- What kind of structural changes have occurred in treeline ecotones?
- What are the reasons for changes?

The treeline position and distribution of shrubs and willow thickets have been suggested as the most important indicators of climate change to be monitored in the alpine environments using the NILS infrastructure (Esseen et al. 2004). Although change detection of treeline position was considered interesting, the structural changes in the treeline ecotone were considered ecologically more important than changes in individual trees making up the treeline. It was also unclear if changes in the treeline should be studied as changes in the elevation of treeline or if changes in areal distribution would be a more relevant measure or easier to detect from the aerial photos. Furthermore, it was decided that in this project it would be more important to concentrate on the change detection than on the possible causes of the change.

At this point, several terms such as treeline and forest line also needed better definition. After the workshop, the most essential terms were defined (Table 4). We also selected a set of variables for the first photo interpretations (Table 5). In general, the definitions of the terms and variables follow the definitions used in the regular NILS interpretation (Allard et al. 2003). In this project, we decided to concentrate on the continuous variables and not categorical variables such as land cover type. The variables were estimated either using one per cent or one meter accuracy depending on the variable. In addition to the quantitative vegetation data, all the information on possible disturbances (reindeer browsing, insect outbreaks, human disturbance) and reasons for change were recorded as free form comments.

Table 4. The definitions of the terms used in the project.

Term	Definition	Comments
Tree	All the wooded plants having height greater than 2 m. The most typical species include mountain birch, pine and spruce.	The 2 m height value has been commonly used for the mountain birch. It should also correspond approximately to the minimum tree height that can be interpreted from the aerial photos (photo scale 1:30,000).
Small tree, shrub (bush)	All wooded plants having height less than 2 m. The minimum height for a shrub was 0.3 m. The most typical species include the willows, juniper and saplings of the trees.	The definition is different than the one used in the NILS field inventory.
Forest	Trees have to be at least 2 m tall and the crown cover has to be at least 10%.	This definition corresponds to “alpine birch forest” in the NILS program. The higher crown cover of 30% was used for the closed forest to define the lower boundary of treeline ecotone.
Treeline (tree limit)	Treeline is the uppermost elevation of trees (height >2 m) at particular location.	Sometimes treeline is used in more general sense to refer to the treeline ecotone.
Forest line	Forest line corresponds to the uppermost elevation of forest at particular location.	
Treeline ecotone	The transition zone between the treeline (the uppermost trees) and closed forest.	

Table 5. The definitions of the vegetation variables considered in the project.

Variable	Definition	Comments
Tree (crown) cover, 0–100%	Percent of the ground area covered by a vertical projection of the tree crowns (the diffuse tree crown cover).	Estimation is based on visual guides.
Tree density, trees, trees/ha	The number of trees inside the sampling unit or per hectare.	This variable has not been interpreted in the regular NILS photo interpretation.
Species composition, 0–100%: - proportion of coniferous trees - proportion of pine - proportion of spruce - proportion of broadleaved trees	Tree crown cover proportion of species or species group.	If the proportion of pine and spruce is estimated, the proportion of conifers can be calculated as their sum. The proportion of broadleaved trees can be calculated if the proportion of conifers is known.
Cover of shrubs and small trees (shrub cover), 0–100%	The diffuse cover of shrubs and small trees.	Cover of shrubs and small trees is not interpreted if tree cover is >30%.
Tree height (m)	Basal area weighted mean height.	In aerial photo interpretation, ground and crown level heights were recorded separately and tree height was calculated relative to ground height.
Substrate cover (0–100%)	The cover of substrate (ground not covered by vegetation). The smallest lichens are not considered as vegetation.	

7. First test on the effect of photo scale

7.1 Experiment

First we conducted an experiment to determine which variables we could interpret using the CIR photos at scales of 1:30,000 and 1:60,000, and how the difference in scale between the recent and historical CIR photos could affect the interpretations. The experiment was made at the Grövelsjön test site, where CIR photos had been taken at both scales within a few days of each other (Table 2). Another objective was to evaluate the differences between the photo interpreters before the change detection. Furthermore, this test gave us insight on the use of the Zeiss Planicomp P3 analytical photogrammetric instrument.

The systematic grid of circular sample plots had a placement to the south of Lake Grövelsjön and on the mountain slopes on the western and eastern sides of the lake (Figure 3). The distance between the sample plots was 250 m. Sample plots which were mostly water (lake or river) were excluded before the interpretations. In total 113 sample plots were interpreted for this area.

The vegetation attributes were interpreted for the circular sample plots with a 20 m radius. All the vegetation attributes given in Table 5 were estimated. The proportions of pine and spruce were estimated separately. The 20 m radius corresponds to the collection of NILS field data for tree cover (Esseen et al. 2007a) and it was also used by Allard et al. (2007) to study the feasibility of sample plot interpretation. We used a Zeiss Planicomp P3 analytical photogrammetric instrument because we assumed that it would be used for interpreting the historical photos. In addition to sample plots, the number of trees was calculated from two squares the size of 250×250 m (Figure 3). Every tree was recorded as a point object.

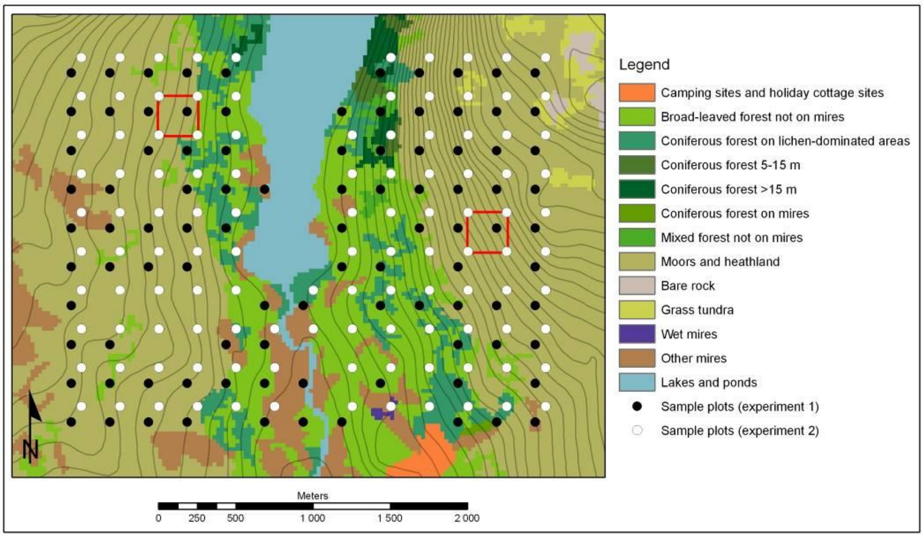


Figure 3. The land cover map of Grövelsjön test site. White circles (N=113) correspond to the first experiment and black circles (N=85) to the second experiment (see section 10). The red squares show the areas used for counting trees.

Three photo interpreters were involved in the project (A, B and C). All of them are skilled photo interpreters although C has considerably more experience on the estimation of forest attributes and NILS protocol than the others. No “calibration exercise” was made before the experiment in order to normalize the interpretations. The interpreters had no previous experience from the particular study site. All three interpreters interpreted all the sample plots. The variables were first interpreted by using the smaller scale photos (1:60,000) and then using the larger scale photos (1:30,000). Interpreter A had four days between the two interpretations and B and C had one day.

In the statistical analysis of the results, we compared the interpretations made using the smaller scale photos (1:60,000) to those made using the larger scale photos (1:30,000). As there was no field data (“ground truth”) for the sample plots, we assumed that variables were estimated more accurately from larger scale photos (higher resolution). Paired t-tests were used in order to test if there was a difference between the scales and between the interpreters.

7.2 Results

The differences of the interpretations made at the two scales are shown as box-and-whisker plots in Figure 4 and as scatterplots in Figure 5. The comparison of the mean values of the estimates is presented in Table 6.

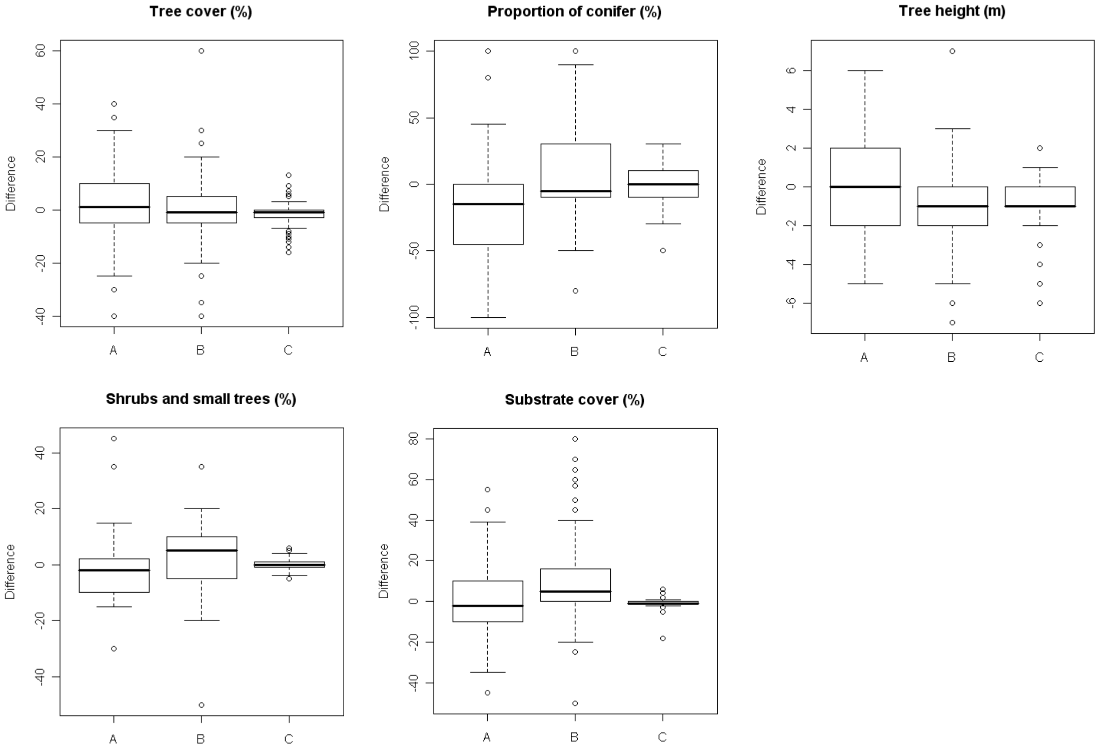
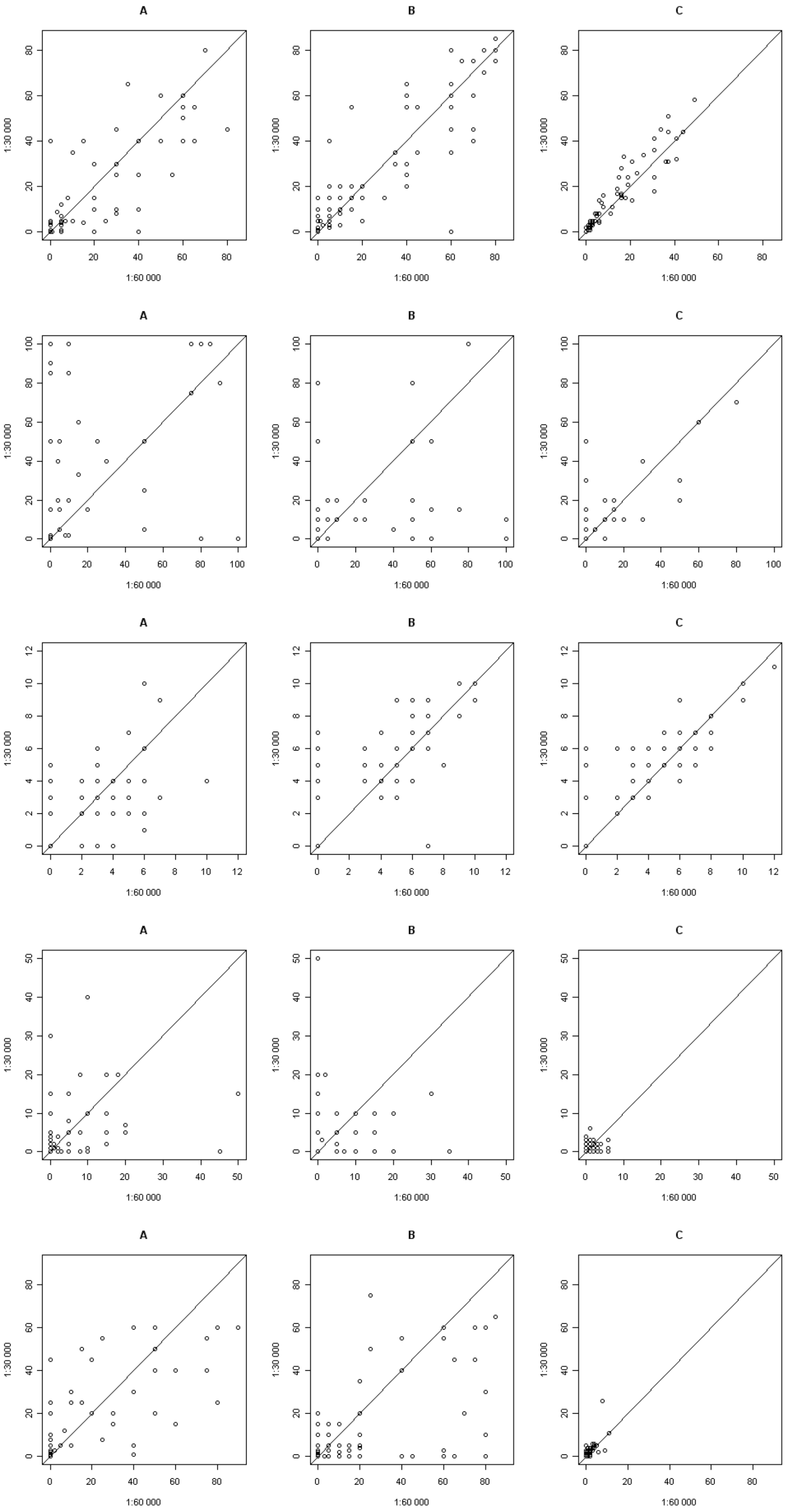


Figure 4. The differences in the vegetation variables interpreted at 1:30,000 and 1:60,000 scale by three interpreters (A, B and C). If difference is negative, the estimate was smaller at 1:60,000 scale and vice versa. The sample plots which were interpreted as zero at both scales are excluded.



Tree cover
(%)

A: r = 0.77
B: r = 0.87
C: r = 0.94

Proportion of conifers
(%)

A: r = 0.18
B: r = 0.12
C: r = 0.69

Tree height
(m)

A: r = 0.33
B: r = 0.53
C: r = 0.74

Cover of small trees
and shrubs (%)

A: r = 0.11
B: r = -0.23
C: r = -0.07

Substrate cover
(%)

A: r = 0.66
B: r = -0.58
C: r = -0.64

Figure 5. The relationships of the vegetation variables interpreted at the two scales by three interpreters. Correlations (Pearson r) were calculated excluding the observations which were zero at both scales.

Table 6. The mean differences in the vegetation variables interpreted at the two scales. Negative mean difference indicates that the variable was underestimated at 1:60,000 scale relative to 1:30,000 scale. The sample plots which were interpreted as zero at both scales were excluded. In total 113 plots were interpreted.

Variable	Interpreter A			Interpreter B			Interpreter C		
	Mean diff.	Std. dev.	N	Mean diff.	Std. dev.	N	Mean diff.	Std. dev.	N
Tree cover (%)	2.4	14.9	59	0.0	14.1	71	-2.0*	5.0	69
Proportion of conifers (%)	-15.4*	43.9	34	8.9	38.4	37	-2.2	15.6	27
Tree height (m)	0.0	2.4	59	-1.2*	2.2	71	-0.6*	1.6	69
Shrubs and small trees (%)	-1.5	11.9	55	1.1	11.9	61	0.25	1.8	76
Substrate cover (%)	1.3	20.3	50	12.4*	23.9	65	-0.9*	2.8	58

*statistically significant (p<0.05, t-test)

Tree cover estimates seem to be relatively insensitive to photo scale (Figures 4 and 5). However, interpreter C has underestimated tree cover significantly (p<0.05) at 1:60,000 scale relative to 1:30,000 scale (Table 6). On the other hand, the estimates of A and B at the two scales did not differ significantly (p>0.05). In fact, A interpreted somewhat larger tree cover values at 1:60,000 scale than at 1:30,000 scale, contradictory to C. However, in comparison to B and C, A found trees from only 59 sample plots in comparison to 71 and 69 plots by B and C. Furthermore, C has considerably less variability in the tree cover estimates than the other two interpreters. The tree cover estimates of C were also smaller than those of A and B.

The proportions of pine and spruce were summed to the total proportion of conifers, because pine was identified in only a very few sample plots. In fact, interpreter A did not interpret pine trees at all, B found pine trees at three plots and C at 14 plots. Interpreter C estimated the proportion of conifers rather consistently at both scales. The difference between the scales was not significant and the correlation was relatively good (r = 0.69). However, the correlation of the estimates was poor for A and B, 0.18 and 0.12 respectively. The estimates of A were also significantly lower at 1:60,000 scale.

Ground level elevation was interpreted for the sample plot and crown level heights for a few representative trees to determine tree heights for the sample plot. The tree height estimates of B and C were significantly smaller at 1:60,000 scale than at 1:30,000 scale. Those sample plots that were interpreted as being treeless at 1:60,000 scale but had trees at 1:30,000 scale have the largest effect on the deviations.

The cover of shrubs and small trees and substrate cover show the largest variation between the interpreters. Particularly, the estimates of interpreter C are much smaller than those of A and B. The cover of shrubs and small trees is very difficult to estimate, even from the larger scale photos. The correlations between the estimates made at the two scales are very poor. Substrate cover has been interpreted more consistently between the two scales. The estimates made by B are significantly larger at 1:60,000 scale and estimates by C are significantly smaller.

It is apparent from Figure 5 that there are large differences between the interpreters for some variables. Most of the differences between the interpreters were also statistically significant (Table 7). The differences between the interpreters are mostly explained by the lack of a “calibration exercise” and differences in the amount of previous experience.

Table 7. The mean differences of the estimated vegetation variables between tree interpreters. The sample plots which were interpreted as zero by all the interpreters were excluded.

Variable	1:30,000			1:60,000			N
	A-B	A-C	B-C	A-B	A-C	B-C	
Tree cover (%)	11.6*	1.4	12.9*	9.6*	5.2*	14.8*	73
Proportion of conifers (%)	17.9*	23.1*	5.2	2.0	12.3*	14.3*	43
Tree height (m)	2.7*	2.9*	0.2	1.6*	2.4*	0.8*	73
Shrubs and small trees (%)	0.6	3.5*	2.9*	1.1	2.4*	3.4*	90
Substrate cover (%)	1.6	12.3*	10.6*	8.0*	13.8*	21.9*	77

*statistically significant (p<0.05, t-test)

The tree crown counts for two 250×250 m squares are shown in Table 8. The first square was rather forested, as approximately 600 trees (100 trees/ha) were interpreted by B and C. For comparison, in the NILS photo interpretation “scattered trees” corresponds to a maximum of 10 trees per hectare (Allard et al. 2003). The second square was located further upslope but also had greater tree density than 10 trees per hectare. The results also show differences between the scales and the interpreters. Interpreter A identified considerably fewer trees than B and C (Table 8, Figure 6). Interpreter A also had a smaller difference between the scales and identified more trees at 1:60,000 scale than at 1:30,000 scale. On the other hand, the interpretations of B and C show a very clear effect due to photo scale as considerably more trees were identified at 1:30,000 scale.

Table 8. The number of trees counted for two 250×250 m squares by three interpreters.

Square	Photo scale	Trees (trees/ha)		
		Interpreter A	Interpreter B	Interpreter C
1	1:30,000	142 (23)	624 (100)	586 (94)
	1:60,000	177 (28)	210 (34)	369 (59)
	Difference	-35 (-5)	414 (66)	217 (35)
2	1:30,000	52 (8)	143 (23)	164 (26)
	1:60,000	56 (9)	38 (6)	73 (12)
	Difference	-4 (-1)	106 (17)	91 (14)

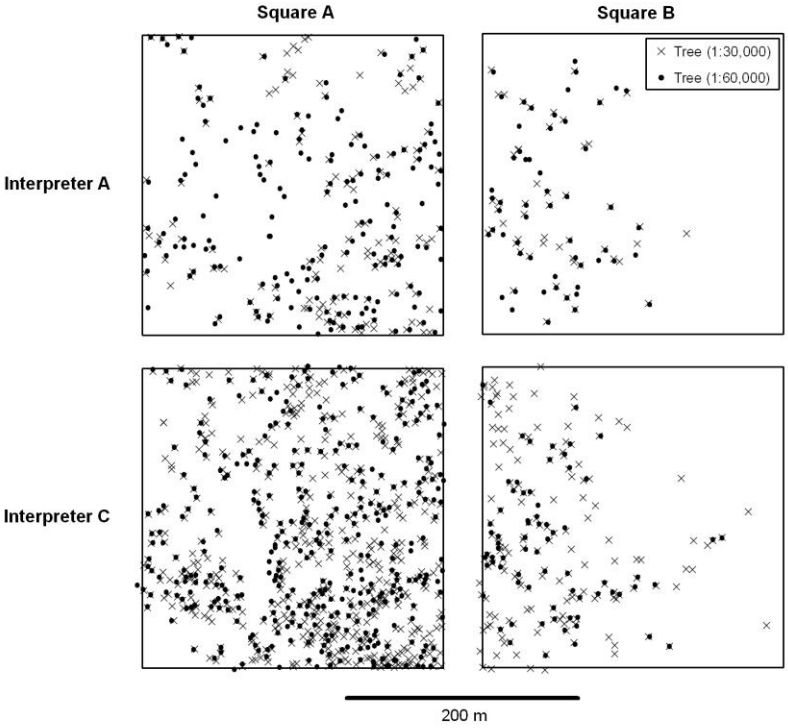


Figure 6. The trees identified by interpreters A and C at the two scales. Square A corresponds to the western and square B to the eastern square in Figure 3.

Although the results were not consistent between all the interpreters, it is indicated that photo scale has an effect on the interpretations. The significant underestimation of tree cover at 1:60,000 scale by C and the considerable differences in the number of trees identified from the photos, show that fewer trees can be detected from 1:60,000 scale photos. One reason for the large differences between the interpreters, particularly in the case of shrub cover and substrate cover, could also be related to the definitions of the variables and familiarity of the interpreters with them. The effect of the experience is also evident as C, who has more experience with estimation of forest attributes (tree cover, species composition and height), had consistently lower standard deviations between the estimates made at the two scales. It is also possible that differences between the tree counts are explained by the different perception of trees (height > 2 m). Interpreter A probably recorded only the larger trees in comparison to B and C who included also the smaller trees. Furthermore, some of the variables, such as substrate cover, could be very sensitive to the amount of light used in the photogrammetric instrument and differences in the colours of the photos.

After the test, we decided that interpreters will practice together in order to “calibrate” their interpretations. Therefore interpreters A and C, who carried out the rest of the interpretation work in the project, practiced against accurate field measurements of tree and shrub cover from Gårdshult in Southern Sweden (Holmgren et al. 2008). During the project, the interpreters have also discussed how to make the interpretations, which should make the estimates more similar. We also decided to concentrate on tree cover, proportion of conifers and cover of small trees and shrubs in the continuation of the project. Although the first interpretations of shrub cover were not encouraging, it was kept among the interpreted variables because it is considered an important indicator of climate change (Esseen et al. 2004).

8. Change detection methods

8.1 Change detection approach

The alternatives for change detection using visual interpretation include basically three possible approaches. In the first approach, the photos from the different points in time are interpreted separately, followed by the comparison of interpreted maps or estimates. In the second approach, the baseline mapping is done using photos from one point in time and only changes are recorded for the other points in time. Ihse (2007) called this “change control mapping”. The third approach is to compare photos from different points in time concurrently and to record only changes. The change detection approach employed in this project is a combination of the second and third approach.

The advantage of the change control mapping is that it is time efficient and minimizes the errors that are typical for the comparison of two separate interpretations (Ihse 2007). For example, if two maps are made separately, it is common that the spatial mismatch of the polygon borders due to the differences in two delineations and geometric errors of photos will lead to the overestimation of changes. Similarly, the variability in the interpretation of attributes can cause detection of false changes. The amount of these errors is emphasized when interpretations are made by different interpreters, which is usually the case in long term monitoring programs as new interpreters become involved. Therefore, we considered that it would be important to be able to compare the photos from two points in time simultaneously. This could also reduce the bias due to the variable photo scale. Furthermore, the same person would automatically interpret the NILS square for both points in time.

In the first experiment, the work with the analytical photogrammetric instrument was relatively slow in comparison to digital photogrammetric workstations, which are used in the regular NILS photo interpretation. It is also easier to compare two stereo models on a digital workstation. Therefore, we decided to use digital photos for change detection. However, because transparent diapositives could provide better colours and spatial resolution than scanned photos, those were available as ancillary data. For example, some of the individual tree interpretations were controlled from the diapositives.

We evaluated three methods for change detection at three NILS squares: 1. complete cover mapping (polygon interpretation), 2. sample plot interpretation and 3. transect and treeline interpretation. The methods are described more in detail below.

8.2 Complete cover mapping (polygon interpretation)

The first method that we tested, complete cover mapping, is probably the most traditional visual interpretation method for vegetation mapping. It is also the method used in the NILS program for mapping the central 1×1 km squares (Allard et al. 2003).

In the NILS photo interpretation, the delineation of polygons is based on the identification of clearly visible borders in the landscape. Once the delineation is done, the land cover characteristics are determined for each object. The natural borders are determined so that the variability within a polygon does not exceed certain threshold values. However, sometimes the delineation must be made by considering the threshold values of certain parameters, resulting in the so-called obligatory borders. Moreover, there are some biotopes and “hotspots” which should be noticed during the delineation. Normally, a single polygon has to be at least 0.1 ha ($1000m^2$) to be delineated. The minimum width for terrestrial polygons is 10 m (Allard et al. 2003).

In this project we tested complete cover mapping within three 1×1 km NILS squares. The amount of forest and treeless areas differed considerably between the squares. Squares 326 and 516 were located in the middle of the treeline, but square 584 was located mostly above it. The delineations made in the regular NILS interpretation were used as data for the recent photos (Figure 7). The NILS interpretations based on recent photos were checked against historical photos to see if there had been changes in the borders of the polygons or vegetation attributes. Because of the relatively small minimum mapping unit, the NILS polygons should provide very detailed description of treeline ecotones. The NILS interpretations were also used in order to gather information on the potential change detection methods for the NILS program. Detailed NILS mapping according to the 1×1 km routine has been considered to be too time demanding for interpretation of the 5×5 km squares (see also Marklund et al. 2007).

In order to interpret historical photos, a copy of the NILS photo-interpreted polygons (shapefile) was made. To reduce the interpretation time we concentrated only on open forests and treeline ecotone, and excluded all the polygons having tree cover more than 30%. As the recent interpretation was used as a baseline, this could mean that some of the polygons had less than 30% tree cover in the historical photos. This reduced the number of polygons to be interpreted in squares 326 and 516. All the remaining polygons were checked for changes by systematically comparing each polygon in the recent and historical photos. If change was identified between the photos, the borders and attributes were updated. If the interpreter disagreed on the previous interpretation, but no change was observed between the photos, the borders or attributes were not changed. In case the interpreter observed that attributes were changed but disagreed on the attributes of the recent map, the interpretation was made relative to the recent attributes.

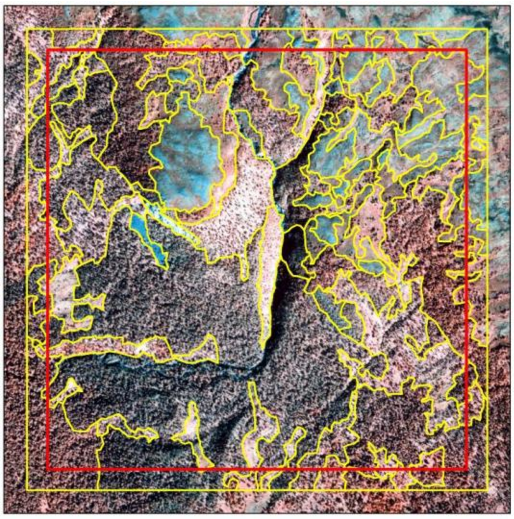


Figure 7. An example of NILS polygon delineations based on photos from 2003 (square 516).

If necessary, the polygon borders were updated using the NILS instructions for photo interpretation (Allard et al. 2003). If change in the borders was observed, the interpreter considered how the historical photographs would be interpreted in NILS. Therefore, the change detection should result in two separate databases, both following the NILS practice. This would probably be the case also in the regular NILS change detection. Furthermore, the use of different rules for interpreting the historical photos would make the map comparison difficult. The polygon change detection for three test squares was made by interpreter C, who is very familiar with NILS. One of the recent photo interpretations (square 326) was made earlier by him, one interpretation (square 516) was made by another interpreter, and one square (square 584) was newly interpreted for both dates during this project.

The resulting maps were analyzed by overlay analysis in order to visualize changes in vegetation attributes. The overlay analysis was made using the Union-tool in ArcGIS 9.2. The differences in the attributes were calculated to a new column by subtracting the historical values of attributes from the recent values. Therefore the positive values indicate increase and negative values indicate a decrease in the attributes between the two points in time.

8.3 Sample plot method

In the second method, the vegetation variables were interpreted for circular sample plots similar to the first interpretations. The sample plot method has been used relatively seldom in comparison to the polygon interpretation. Allard et al. (2007) tested the sample plot method for inventory of Natura 2000 habitats and a selection of NILS variables. Reese et al. (2008) used the sample plot method to collect reference data for mapping of mountain vegetation with satellite data. Salehi et al. (2008) used a similar method for detection of tree cover changes in a semi-arid environment in Iran.

Here we used circular sample plots of 20 m radius for interpreting the 5×5 km NILS squares. The radius corresponds to the NILS field inventory for tree cover (Esseen et al. 2007a), which should enable the comparison of tree cover estimates. The interpreted variables included tree cover, proportion of conifers and shrub cover. Variables were estimated using the recent photos, and also using the older photos if changes were observed between the two dates. If changes were not observed, the interpretation of the recent photo was assumed to be valid also for the earlier date. Free form comments were made on the possible uncertainties in the interpretation and reasons for the observed changes. For example, some plots could not be interpreted because of dark topographical shadows and some plots were clearly affected by humans (clear-cut, path, etc.) or natural hazards (insect outbreaks).

The NILS layout of the sample plots was based on systematic sampling. As we focused on the treeline ecotone, we needed a denser sample for that particular area. Therefore we used GSD-Land and Vegetation Cover data to create a buffer zone to the boundary between the forested and non-forested areas. Several tests were made in order to define the width of the buffer zone including evaluations against the high resolution orthophotos. Eventually, a 250 m wide buffer zone was used, 100 m towards the forest and 150 m towards the treeless alpine areas. The distances were calculated as surface distances instead of horizontal distances as treeline ecotones are typically narrower in the steep slopes. The cost-distance function in ArcGIS 9.2 was used for calculating distances. Secant of the slope (the ratio of ground and horizontal distance) was calculated from the DEM and used for weighting. Because of the weighting, 250 m is the maximum horizontal width of the buffer zone. However, because treelines are not necessarily sharp, but often consist of patches of the forest and alpine vegetation, the zone was much wider in many locations. Furthermore, the smallest patches (area < 20 ha after buffering) outside the more continuous treeline buffer zone were removed. We also removed the open mires from the buffer zone (Figure 8).

The layout of the sample plots followed a regular grid with 250 m spacing between the plots. The spacing was 250 m within the buffer zone and one sample plot per one square kilometre outside it. The outside areas were sampled because of possible errors in the buffer zones. The origin of the grid was defined by the sample plots from the NILS field inventory, which have 250 m distance between the plots. The NILS field plots were interpreted in all the squares.

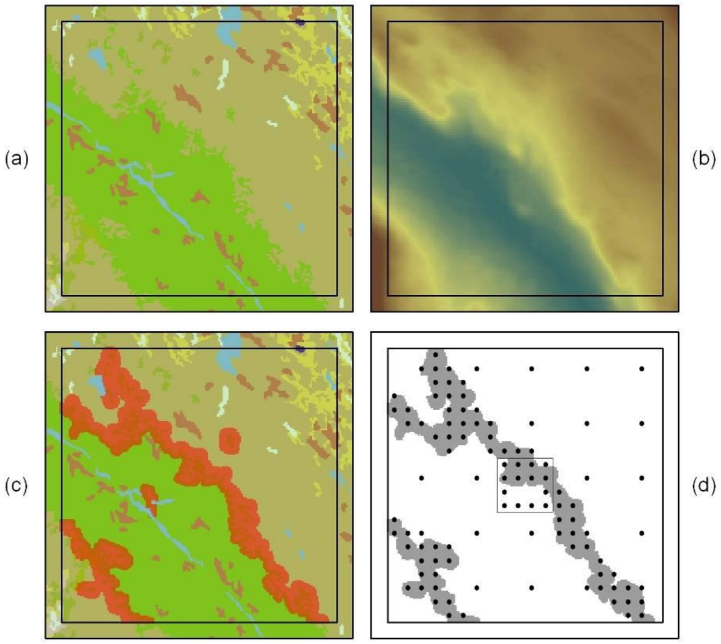


Figure 8. The procedure used for defining the treeline buffer zones using land cover data and digital elevation model (DEM). (a) Land cover classification for square 516. Green corresponds to the mountain birch forest. (b) DEM showing the topography. (c) The initial treeline buffer zone on top of land cover classification. (d) The final buffer zone and layout of sample plots.

8.4 Transects and treelines

The third method is based on transects from the closed forest to treeless alpine areas. Transects are subjectively selected from the mountain slopes. Tree cover is estimated along transects and the position of the forest line can be defined by using a specific threshold value. The identification of the uppermost trees in transects provides the treeline positions for those locations. Transects have been commonly used in field-based monitoring, but applications in remote sensing are rare. Cairns and Waldron (2003) used transect-based sampling for the characterization of treelines using binary classifications (trees, no trees) produced by density slicing of panchromatic aerial photos.

In this project, we used 100 m wide transects, which consisted of 50 m long blocks. The size of one sampling unit, hence, was 100×50 m. The 100 m width should represent a mountain slope, but it is still narrow enough for field control. The 50 m length should give a good resolution in terms of elevation. Transects were set on mountain sides that had a complete transition from closed forest to treeless alpine areas within the NILS 5×5 km squares. Transects were set perpendicular to the contour lines across the treeline. A digital topographic map (1:100,000) and orthophotos were used as ancillary data in order to select locations. Transecting mires, ponds and creeks were avoided. An aim was also to use slopes where the elevation would rise consistently from one block to another. The length of transects varied because of the topography. The maximum transect length was 2 km.

Transects were documented in the downhill direction. First, the uppermost tree along the transect was identified using the recent photos. Zero tree cover was given for the block above to define the beginning of the transect. The tree cover, proportion of conifers and cover of small trees and shrubs were estimated subsequently for the blocks at lower elevations. Transects were finished when three blocks considered as closed forest (tree cover > 30%) were recorded successively. The blocks were simultaneously checked against the older photos and changes were recorded if necessary, similar to the sample plot method. The positions of the uppermost trees were recorded as points to separate files. Only one point per transect was needed if the tree was the same in both photos. Two points were recorded if the tree was different. For field checking, we also marked trees that were found above the treeline trees but where the minimum height of 2 m was uncertain. Elevation of the trees was recorded in order to define the treeline position (m a.s.l). The DEM was used for calculating the mean elevation of the blocks in order to define the elevation of the forest line.

9. Results of change detection

9.1 Complete cover mapping

The results of the polygon interpretations are shown in Figure 9 for three test squares. Although all the central 1×1 km squares overlap the treeline ecotone, the squares 326 and 516 are rather forested and the number of treeless polygons is small. Square 584 is located mostly above the treeline and treeless polygons are in the majority.

At squares 326 and 516 tree cover has increased in many polygons between the late 1970s and 2002, but in square 584 such changes are negligible (see Figure 1 for the location of squares). Most of the changes were made to the attributes and no significant changes were made to the borders of the polygons. Only borders of two polygons at square 516 and one polygon at square 584 were edited. At square 326, the small increases in tree cover (1–4%) are common, whereas tree cover has decreased only in one polygon (-3%). At square 516 tree cover has increased slightly in many polygons close to the treeless areas. The maximum increase is 8%. In one large polygon tree cover has decreased by 7%, which is most probably due to an insect outbreak. The other small decreases occur in places where polygon borders were updated between the photos. Changes in shrub cover were considered difficult to interpret, and only very minor changes were recorded. No changes in tree species composition were observed inside the central 1×1 km squares in square 326, where both mountain birch and conifers were present.

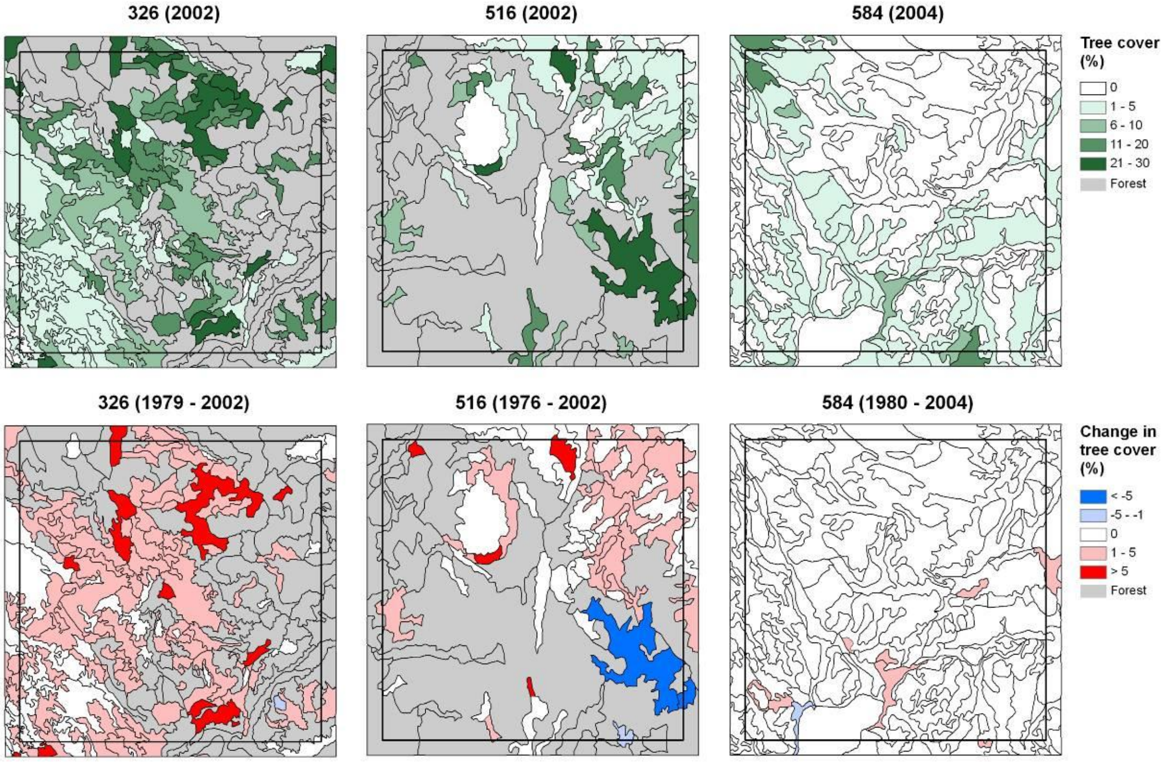


Figure 9. Recent tree cover and tree cover changes interpreted by the polygon method (1×1 km square). Red corresponds to the increase and blue to the decrease in tree cover. Polygons in gray were not interpreted (tree cover > 30%).

Because the polygon delineation and interpretation was available for recent photos, the change detection using this method was made rather quickly for the 1×1 km squares. However, the time used depends heavily on the complexity of the landscape and number of polygons to be interpreted. The number of interpreted polygons was 140 in square 326, 88 in square 516 and 154 in square 584. The change detection for one square took approximately one working day (8 hours). Regular NILS interpretation for one 1×1 km square usually takes something between one and five days.

9.2 Sample plot method

Tree cover changes interpreted by the sample plot method are shown in Figure 10. The tree cover increase was interpreted in many sample plots within the treeline buffer zone in squares 326 and 516, but in square 584 tree cover changes were very few. Large increases in tree cover appear also below the buffer zone in square 326 because of forest growth in the old clear cuts. Furthermore, increase in tree cover in some sample plots was interpreted in square 326, which is mainly due to the increasing proportion of mountain birch, which can be detected through measures of decreased proportion of conifers (Figure 11). The treeline buffer zone seems to cover the treeline ecotone relatively well since the sample plots above the zone usually are treeless. Changes in the shrub cover were interpreted only for a small number of sample plots and those interpretations were considered unreliable.

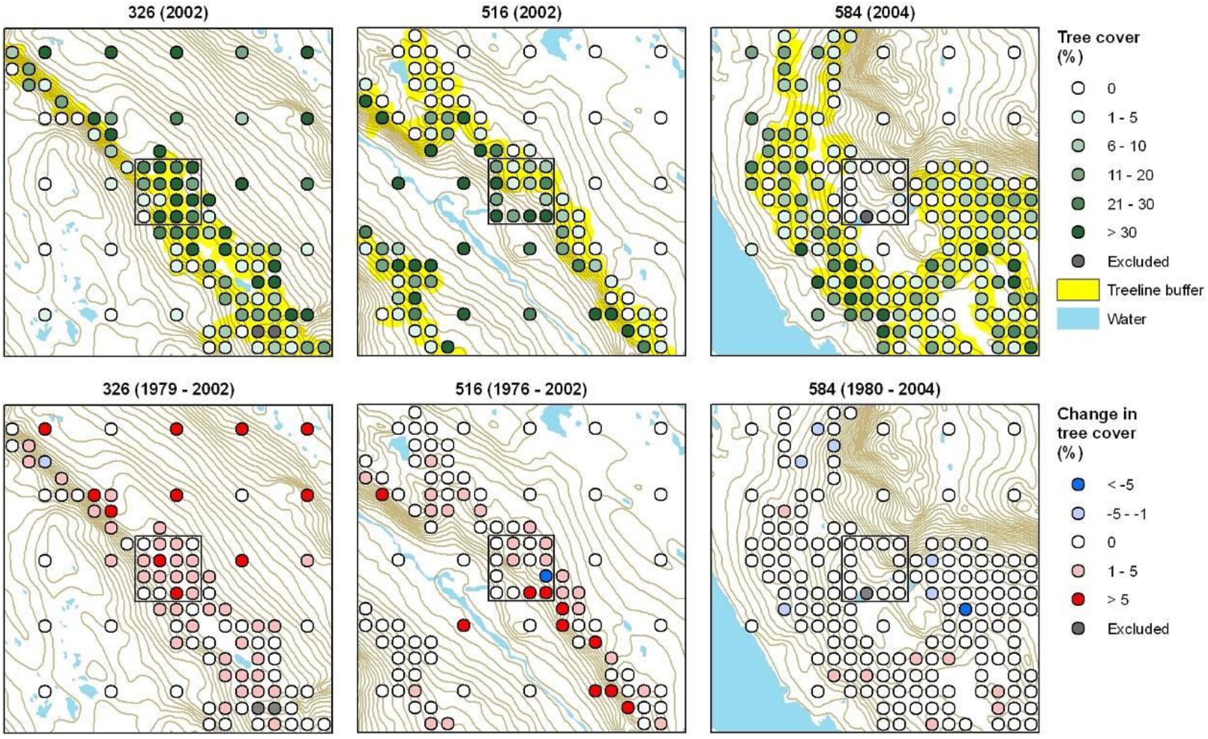


Figure 10. Recent tree cover and tree cover changes interpreted by the sample plot method (5×5 km square). The sample plots were converted to points to increase their size for visualization.

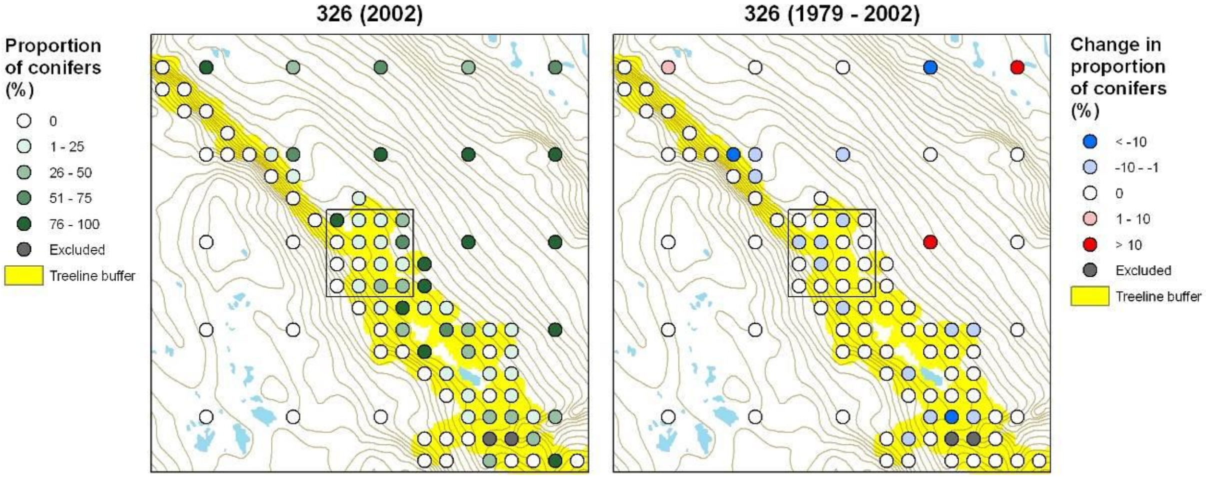


Figure 11. Proportion of conifers in square 326 in 2002 and changes between 1976 and 2002.

The width of the buffer zone varies considerably between the squares. The area of the buffer zone is the smallest in square 326 and the greatest in square 584, where the treeline ecotone is patchy because of topography. The number of sample plots was 95 in square 326, 104 in square 516 and 166 in square 584. The interpretation of all three variables for 100 sample plots and change detection relative to historical photos was estimated to take approximately one working day, without any data preparations. The preparations specific to the sample plot method consist of the treeline buffering and sampling of the sample plots.

A number of sample plots were visited in the field in the summer of 2008; 14 in square 326, 12 in square 516 and 22 in square 584. Both interpreters participated in the field trip to square 584 (Stora Sjöfallet). It is difficult to directly validate the change detection results in the field, but the field visits gave valuable training and field data for calibration of photo interpretation. For example, we noticed that shrubs were usually much more abundant in the field than estimated from the photos. However, in some plots we observed dead birch trunks and branches, and young trees and saplings indicating possible changes.

9.3 Transects and treelines

Tree cover changes interpreted along transects are shown in Figure 12. Four transects were interpreted in square 326, eight transects in square 516 and four transects in square 584. Similarly to the results reported above, tree cover has increased in squares 326 and 516, whereas only marginal changes were detected in square 584. Some small changes in the proportion of conifers (326) and shrub cover (326 and 516) were detected as well.

Transects also enable the assessment of the treeline buffer zones used in the sample plot method, because these should cover the complete tree cover gradient from the closed forest (tree cover > 30%) to the uppermost trees. In square 326, the uppermost trees are not included in the buffer zone but transects continue far beyond it. Tree cover is very sparse and trees are generally of low height above the buffer zone. The lower limit of the zone corresponds to the forest in most transects. In square 516, the treeline trees and upper limit buffer zone have better correspondence than in square 326, because the treeline is relatively narrow and well defined. The correspondence is also better in square 584, where the treeline is very patchy and, hence, the zone is wider. However, in transects two and three (square 584) the uppermost part of the transect is not included in the buffer zone.

The locations of the treeline trees are shown in Figure 12 and the elevations of the trees in Table 9. We also checked some of the trees during the field visits in order to know how small trees we can identify from recent photos; 10 out of 16 transects were visited in July and August 2008 and heights of the uppermost trees were measured. In addition to the uppermost trees, we also identified many objects as possible trees (small trees most likely lower than 2 m) and measured some of those (not shown in Table 9).

In squares 326 and 584, the treeline trees were the same individuals in both photos. The field visits showed that there were usually no trees above those identified from the photos. In general, the height of the identified trees ranged from approximately 1.5 m to 4 m. The appearance of the trees can be very variable in the treeline, which affects to which minimum height those can be identified (Figure 13).

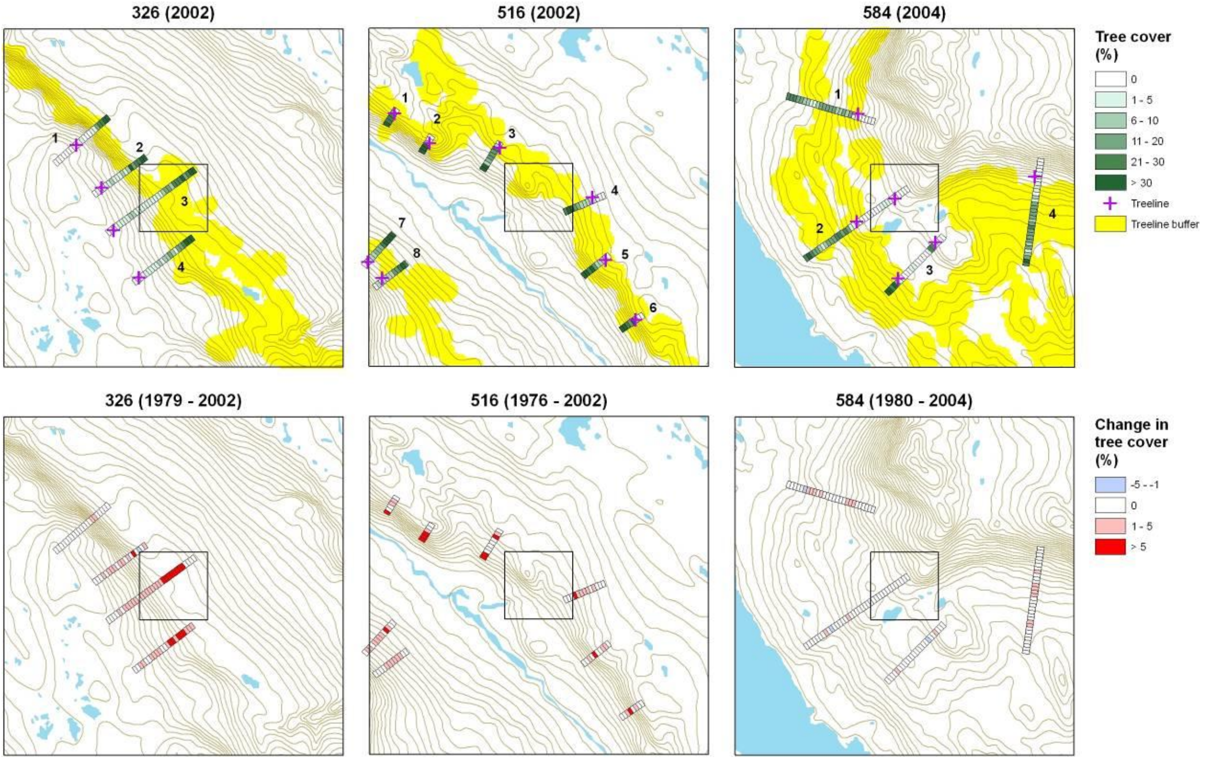


Figure 12. Recent tree cover and tree cover changes along transects. The positions of the treeline trees corresponding to the recent photos and treeline buffer zone are also shown.

Table 9. The elevation of treeline trees interpreted from the aerial photos. The height and crown width of 11 trees were also measured in the field in the summer of 2008.

Square	Transect	Treeline (m a.s.l.)		Tree height (m)	Crown width (m)
		Recent	Historical		
326	1	918	918	3	5
	2	919	919	1.5–1.8	10
	3	922	922	1.5	5
	4	907	907	2	6
516	1	792	787		
	2	767	766		
	3	747	740		
	4	794	793	5	4
	5	777	777	4	several trees
	6	766	754		
	7	746	748		
	8	756	784		
584	1	652	652	7	6–7
	2 (upper)	673	673	5	-
	2 (lower)	612	612		
	3 (upper)	667	667	3.5	3
	3 (lower)	597	597	4	3
	4	749	749	5.5	3–4

Figure 13. The height and shape of treeline trees can vary considerably from bush-like birches that are approximately 2 m tall, to tall single stemmed trees. Photos: Janne Heiskanen and Ann-Helen Mäki.

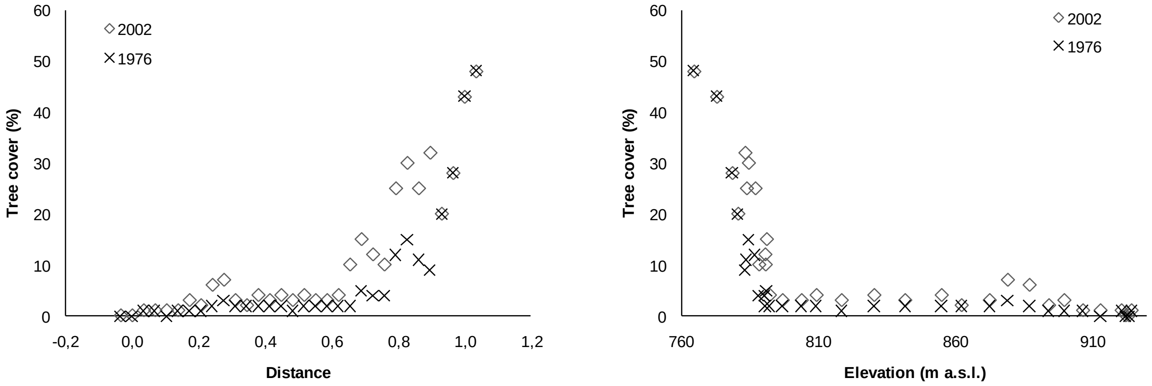
All the four transects and altogether 26 trees interpreted in square 326 were visited. The height of the uppermost trees varied between transects. The smallest trees identified were only 1.5 m tall. Most of the trees interpreted being small trees were 2 m or less in height (16 out of 22). Although the trees were small, they were mostly bush-like and had many trunks. Therefore the “crowns” were very wide, typically 4–6 m but sometimes even 10 m.

Only very few trees were successfully located and measured in square 516. Although the smallest of these trees had a height of approximately 2 m, most of the trees interpreted as small trees had considerably greater height than that. For example, in transect 5 the height of the smallest trees was between 4 and 7 m. However, the number of measured trees in this square was small.

In square 584, 27 trees and small trees were visited and measured. Most of the small trees were between 2.5 and 5 m in height. Also in this square it was clear that the crown width affected height estimation. The average tree in this square had a height of 4 m and a crown width of 3 m. Some small trees, which could not be found in the field, were also recorded. These misinterpretations were mainly considered juniper, willow or dwarf birch bushes, but may also be stones casting tree-like shadows.

Transects across treeline ecotones have also been used for describing the structure of treelines (Cairns & Waldron 2003). Two examples of tree cover gradients against distance and elevation are shown in Figure 14.

326 (transect 3)



516 (transect 2)

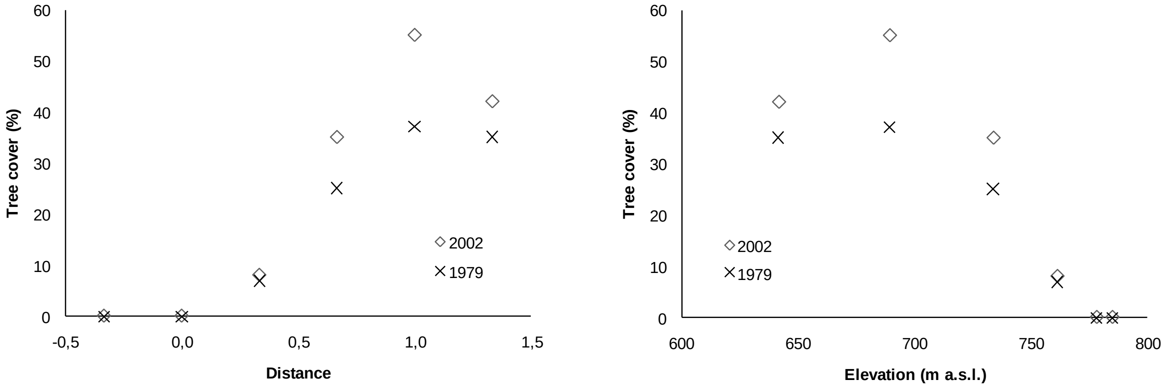


Figure 14. Two examples of tree cover gradients. On the left, tree cover is plotted against distance along the transect (zero corresponds to the first block with trees and one to the first block having a tree cover greater than 30%). On the right, tree cover is plotted against elevation.

9.4 Comparison of the change detection results by different methods

The change detection methods produce different types of outputs, but the results of change detection were quite consistent for three test squares. In general, the increase in tree cover was observed in squares 326 and 516, whereas the changes were small in square 584. Similar results were obtained although the interpreter varied between the methods; none of the squares were interpreted by the same person for the three different methods (Table 9). The comparison of the results within the central 1×1 km square (326) in Figure 15 demonstrates the consistency of the change detection.

Table 9. The interpreters of the test squares.

Method	Square		
	326	516	584
Polygon interpretation	C	C	C
Sample plot method	C	A	C
Transects and treeline trees	A	A	A

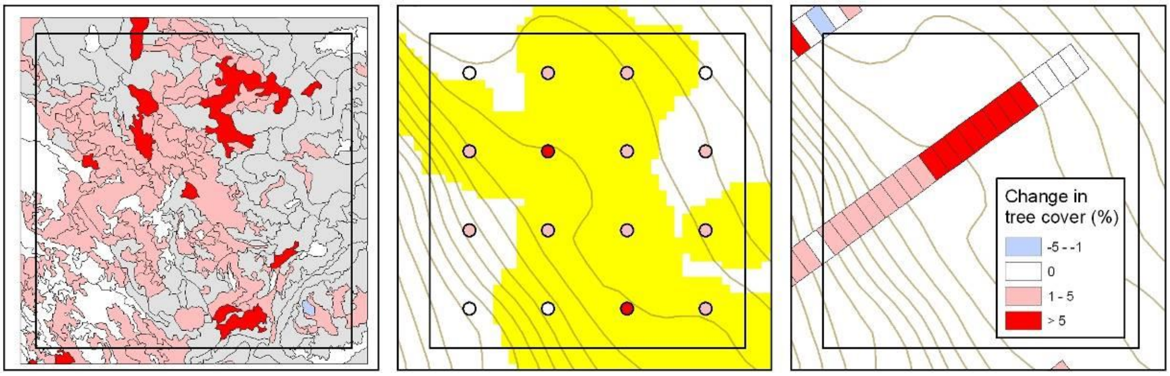


Figure 15. Tree cover changes interpreted by three methods (square 326, 1×1 km).

9.5 Application of the sample plot method to three additional squares

After testing the change detection methods, we interpreted three additional squares by the sample plot method. The sample plot method was selected because we considered that it had the greatest potential for change detection using the NILS sampling infrastructure. The advantages and limitations of the different methods are discussed in detail in the discussion part of the report (section 12.2).

The three new squares interpreted here are shown in Figure 1 and Table 1 (squares 358, 498 and 609). These interpretations were made similarly to three test squares. Here we put the main focus on the tree cover changes although the interpreted variables included also coniferous cover and cover of small trees and shrubs. Squares 498 and 609 were interpreted by interpreter A and 358 by interpreter C.

Tree cover changes in the additional squares are shown in Figure 16. The number of the sample plots was 174 in square 358, 119 in square 498 and 95 in square 609. Within the treeline buffer zone, tree cover changes were detected in square 358, but changes in squares 498 and 609 were small. However, in square 498 there were both large positive and negative changes outside the buffer zone related to forest management (clear-cuts, re-vegetation). In the new squares there were also some problems that were not encountered in the test squares. In squares 498 and 609, several sample plots could not be interpreted because of very dark shadows. Therefore, almost all the sample plots on the northern slope in square 609 were not interpreted (shown as “excluded” in the map). Furthermore, in some of the steep slopes, for example in the southern slope of square 609, the buffer zone turned out to be too narrow and therefore lacked sample plots.

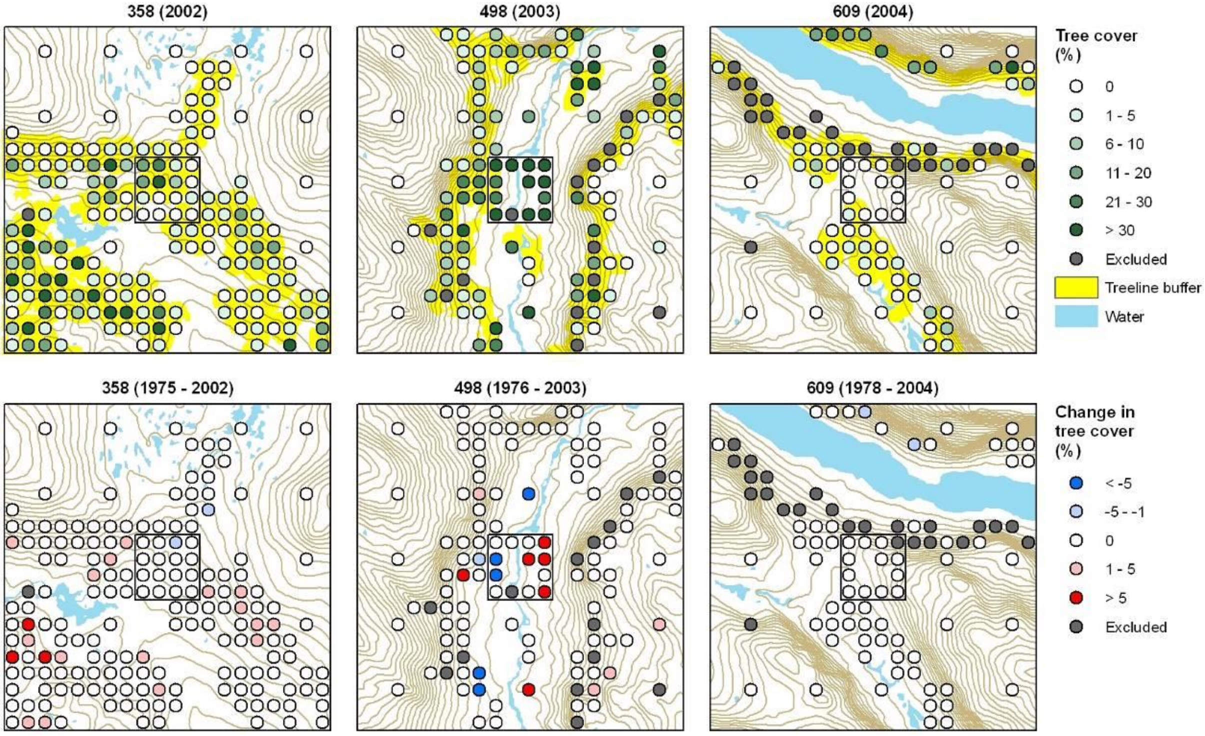


Figure 16. Recent tree cover and tree cover changes in the three additional squares (5×5 km).

Table 10. Summary of the tree cover change detection for six NILS squares. Only the sample plots within the treeline buffer zone were included in the analysis.

Square	N	Mean change (%)	St. dev.	t	p
326	67	2.3	3.3	5.68	<0.001
358	153	0.4	1.4	3.57	<0.001
498	82	-0.8	4.4	-1.58	0.12 (n.s.)
516	76	1.4	2.9	4.26	<0.001
584	141	0.02	1.1	0.23	0.82 (n.s.)
609	47	-0.2	1.0	-1.43	0.16 (n.s.)

The results of tree cover change detection for altogether six squares interpreted by the sample plot method are summarized in Table 10, which shows the mean change in tree cover within the buffer zone. The statistical significance of the change was tested using paired t-tests. Only the treeline buffer zone was considered and all the plots that were mostly water or not interpreted due to dark shadows or some other technical reason (lack of stereo cover) were excluded. The results show that tree cover in the treeline buffer zone increased significantly in three out of six NILS squares studied in the project.

In the sample plot method the change in the treeline position would be visible as sample plots that are wooded at one point in time but treeless at another point in time. If treeline altitude would have increased, there should be sample plots that have trees in the recent photos but are treeless in the historical photos (Table 11). In square 516 there were eight such plots, all of them located in the south-western slope of the square. A few similar plots were observed also in squares 498 (2) and 584 (1). All except one of the plots were located on the outer edge of the treeline buffer zone. The sample plots in square 516 were checked also by another interpreter who confirmed the interpretation. Although it is possible that trees have grown larger in those sample plots, the changes in the position of the treeline should be regarded with care since photo scale effects are likely to be considerable when interpreting single trees. These results are also very sensitive to the density of sampling.

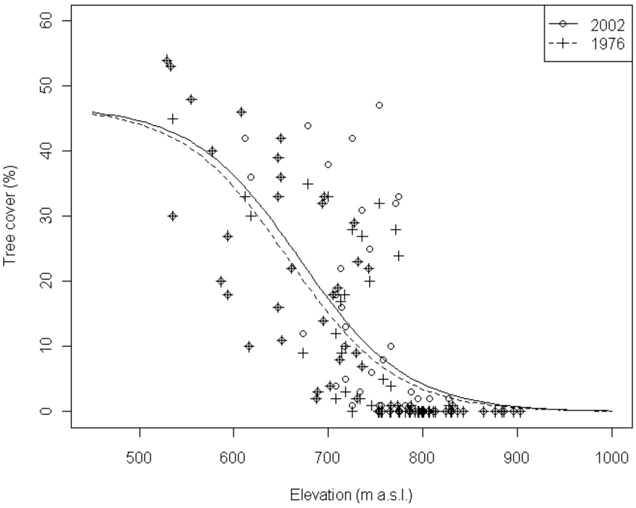
The statistical relationships of elevation and tree cover were studied by linear regression analysis (Table 12). Some non-linear functions were also tested (Figure 17; Cairns & Waldron 2003; Hufkens et al. 2008). The aim of these tests was to see whether regression analysis could summarize the changes in the treeline (or forest line) position relative to elevation. However, the statistical relationships between the elevation and tree cover were rather weak, at least for the most squares. One reason for this is the size of sample plots as the treeline ecotone appears often as a mosaic of wooded and treeless patches. Therefore, wooded and treeless patches can occur all the way down from the upper parts of the ecotone to more forested areas. Furthermore, aspect and other environmental conditions can vary considerably within 5×5 km squares.

Table 11. The highest elevation of tree covered and forested sample plots, i.e. the elevation of treeline and forest line (tree cover >10%, tree cover >30%) interpreted from the recent and historical photos. Elevation in historical photos is shown only if it differs from the recent interpretation.

Square	Treeline (m a.s.l.)		Forest line 10% (m a.s.l.)		Forest line 30% (m a.s.l.)	
	Recent	Historical	Recent	Historical	Recent	Historical
326	915	-	867	-	813	-
358	932	-	924	-	922	-
498	846	751	711	-	693	-
516	832	823	774	-	774	754
584	743	-	663	-	608	-
609	764	-	702	-	653	-

Table 12. The coefficients of determination (R^2) for the linear regression models fitted between the recent tree cover and elevation. Only the sample plots in the treeline buffer zone were used. Also the effect of including aspect to the models was tested.

Square	N	R^2	
		excluding aspect	including aspect
326	67	0.24	0.25
358	153	0.02	0.08
498	82	0.33	0.34
516	76	0.40	0.42
584	141	0.16	0.23
609	47	0.33	0.38
All squares (square number as dummy variable)	566	0.23	0.23 (aspect n.s.)



$$f_t(x) = \frac{a}{e^{-b(x-c_t)} + 1} \qquad t=1,2$$

Parameter	Estimate	Std. error
a	46.9	5.5
b	-0.018	0.003
c_1 (2002)	669.6	19.1
c_2 (1976)	657.9	19.5

Figure 17. Data from square 516 showed the strongest relations between the tree cover and elevation. The non-linear regression analysis was used to fit the sigmoid functions. The parameter c (the centre of the curve) was estimated separately for 2002 and 1976 (the difference between c_1 and c_2 is not significant, p=0.30). Sample plots interpreted as mire have been excluded (N=100).

9.6 Comparison between the sample plot interpretations and NILS field data

We also studied how the photo interpretation relates to the NILS field inventory. Hence the NILS field sample plots within the central 1×1 km square were interpreted. In practice, however, the comparison of the datasets may be difficult because the variables are defined slightly different in the field inventory and photo interpretation (Allard et al. 2007).

We used circular sample plots of 20 m radius, which corresponds to the radius used in the NILS field inventory for tree cover (Esseen et al. 2007a). In the NILS field inventory, the circular plot can be divided into sub-units if land cover within the plot is not homogeneous. However, here we did not divide sample plots, but estimated one value for each attribute (compare with Allard et al. 2007). In the NILS field data, areas of sub-units are provided only for the 10 m radius plots, which do not provide the calculation of tree cover for the sample plots of 20 m radius. Therefore only those sample plots that have not been divided into sub-units were considered here (N=66).

The comparison of tree cover estimates is shown in Figure 18a. The correlation between the estimates is rather good, with Pearson r being 0.88 ($p < 0.001$) for all the field plots (N=66) and 0.81 ($p < 0.001$) when excluding the treeless plots (N=44). In general, the photo interpreted estimates are smaller than the field estimates, with the mean difference being 9.1% if only wooded plots are considered (Figure 18b, Table 13). The mean difference is statistically significant from zero. However, it is important to note that NILS tree cover estimates are based on ocular estimation, not on tree cover measurements. Because ocular tree cover estimates can be severely biased (Korhonen et al. 2006), it is not possible to objectively validate photo interpretation using NILS field data. The comparison of tree cover interpretations by interpreters A, B and C and tree cover measurements from the Gårdshult area suggest that the root mean square error of aerial tree cover estimates is approximately 10% with a very small or insignificant bias (results not shown here). Because of these results, we consider that NILS tree cover estimates used in the previous comparison are most probably overestimates of the true tree cover.

The NILS field inventory provides information also on the tree species composition and cover of small trees and shrubs (Esseen et al. 2007a). However, coniferous trees occurred only in ten sample plots, which was a too small sample to make any comparison. Furthermore, the cover of shrubs and small trees has been defined differently in NILS field inventory in comparison to the aerial photo interpretation. In the field inventory, the shrub cover includes certain species no matter their size (Esseen et al. 2007a), but in the photo interpretation, shrubs include all woody species having a height between 0.3 and 2 m, although it is noted that the smallest shrubs are not visible in the photos at 1:30,000 scale (Allard et al. 2003). Therefore the direct comparison of the estimates is not possible. It is clear, however, that the average shrub cover and its variability are much greater in the field inventory data than in photo interpretation (Figure 19).

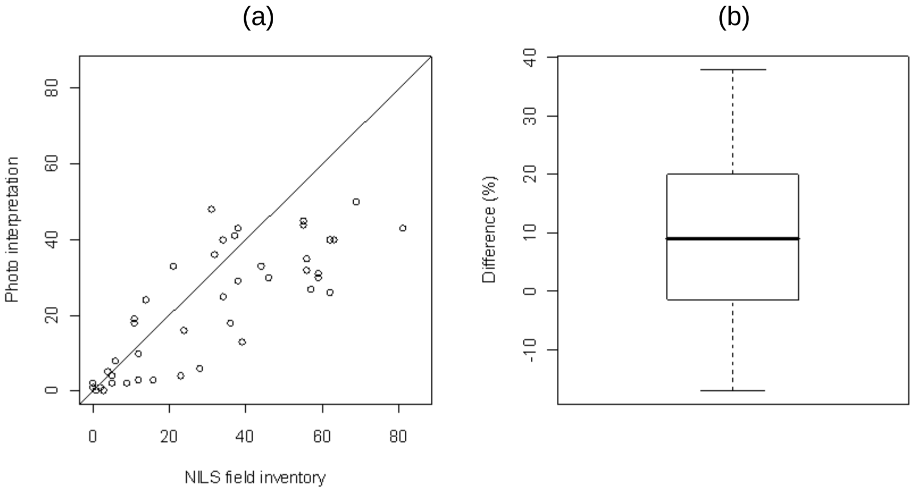


Figure 18. (a) The comparison of tree cover estimates from the NILS field inventory and aerial photo interpretation. The line corresponds to 1:1 line. (b) Box-and-whisker plot of differences (field inventory - photo interpretation).

Table 13. The tree cover according to the NILS field inventory and aerial photo interpretation. Treeless plots were excluded (N=44).

	Mean	Std. dev.
NILS field inventory	31.5	22.7
Photo interpretation	22.4	16.1
Difference	9.1	13.5
t (p)	4.5 (<0.001)	

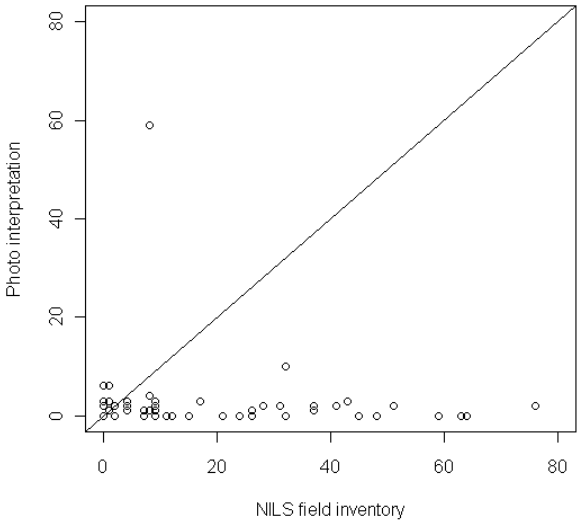


Figure 19. The comparison of shrub cover (%) estimates from NILS field inventory and aerial photo interpretation. Sample plots having tree cover >30% were excluded (N=45). Note that shrub cover has not been defined similarly in the two inventories (see text).

10. Second test on the effect of photo scale

10.1 Experiment

In addition to the first test on the effect of photo scale, we made another test after the change detection. This test focused on tree cover, which was recognised as the variable having the highest potential for treeline monitoring. The experiment was made using the digital photogrammetric workstations and scanned photos instead of the analytical photogrammetric instrument and transparent diapositives. Furthermore, the interpreters had acquired more experience with treeline environments. The training included photo interpretation of the study sites, calibration against Gårdshult training data and field excursions (Stora Sjöfallet, NILS field excursion to Åre in autumn 2008). Moreover, all the informal communication between the interpreters (e.g., on the definitions of the variables) added to their experience.

This experiment was also made in Grövelsjön test site. We designed a new systematic grid of sample plots on the southern part of the Lake Grövelsjön and the mountain slopes on the western and eastern sides of the lake (Figure 3). Sample plots which were mostly water (lake or river) or were clearly affected by humans (plots transected by roads, major paths or buildings) were not interpreted. The total number of sample plots was 95.

The sample plots were interpreted by two interpreters (A and C). Similar to the previous experiment, the tree cover was first interpreted from 1:60,000 scale photos and later from 1:30,000 scale photos. The time between the two interpretations was approximately one week. The plots were interpreted in a random order, which was different from one scale to another. This method was applied to reduce the ability of the photo interpreters to remember individual sample plots during the second interpretation.

10.2 Results

The results show that the scale of the photos can have a considerable effect on the photo interpretation (Figure 20, Figure 21). Although the mean difference is small for interpreter A (less experience), interpreter C (longer experience) underestimates tree cover significantly at 1:60,000 scale relative to 1:30,000 scale (Table 14). Both interpreters found trees at 58 sample plots although both had one wooded plot that was not found by the other interpreter. Interpreter A interpreted tree cover more consistently in this experiment than in the first experiment. Although interpreter C still has a somewhat lower standard deviation and better correlation between the tree cover estimates, the difference between A and C was small. The training in the project clearly improved the interpretations of A, but did not have that much of an effect on the interpretations of more experienced C. It also seems that the training and experience gathered in this project did not help reduce the scale effects when making two independent interpretations.

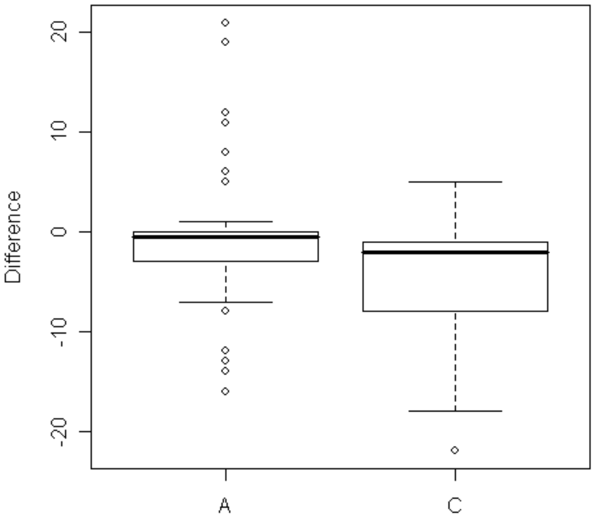


Figure 20. Differences in tree cover estimates interpreted at 1:30,000 and 1:60,000 scale by two interpreters (A and C). If difference is negative, the estimate was smaller at 1:60 000 scale and vice versa. The treeless sample plots are excluded.

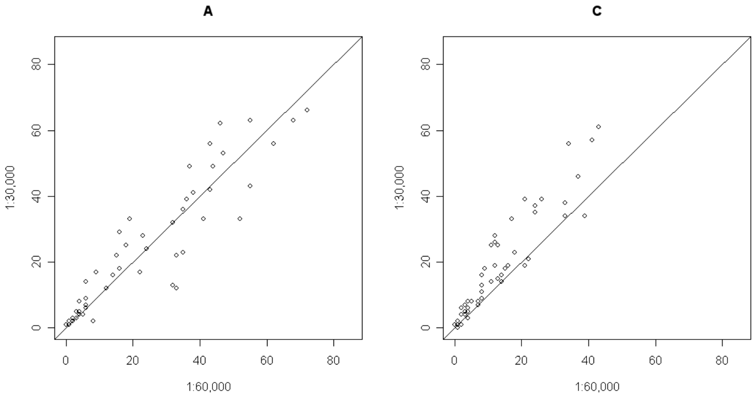


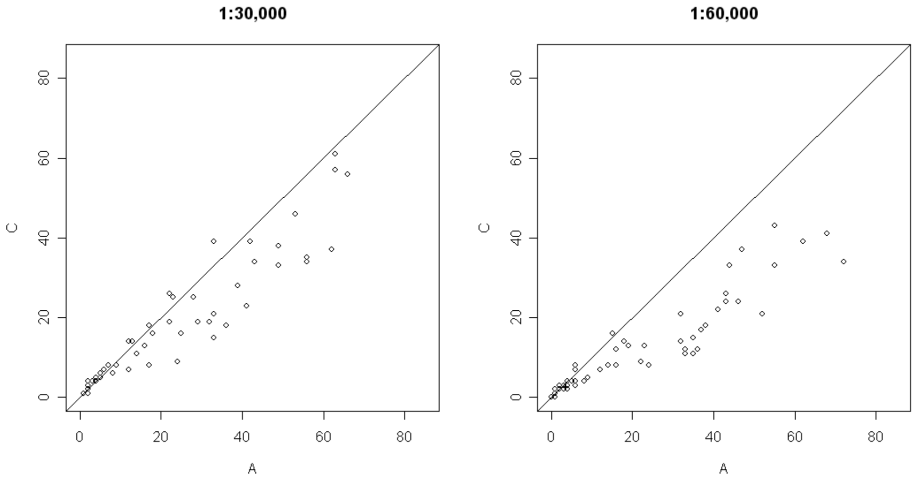
Figure 21. Tree cover interpreted at the two scales by two interpreters (A and C). Pearson r: A=0.933, C=0.944.

Table 14. Mean difference in tree cover interpreted at the two scales. Negative difference means that tree cover was underestimated relative to 1:30,000 photos. Treeless sample plots were excluded (in total 95 plots were interpreted).

Variable	Interpreter A				Interpreter C			
	Mean diff.	Std. Dev.	N	t (p)	Mean diff.	Std. Dev.	N	t (p)
Tree cover (%)	-0.3	7.5	58	-0.32 (n.s.)	-4.71	6.11	58	-5.87 (<0.001)

The results also show that the photo interpretation was interpreter-dependent, because the estimates of interpreter A were significantly larger than the estimates of interpreter C at both scales (Figure 22, Table 15). The difference is larger at 1:60,000 scale than at 1:30,000 scale. Because differences between the interpreters are so large, it seems that the "calibration" between the interpreters was not enough to decrease the differences. These results also emphasize how important it is that change detection is made by the same interpreter.

After the experiment (two independent interpretations), we also checked some of the sample plots simultaneously from recent and historical photos, similar to the change detection. The aim was to check whether differences due to photo scale could be avoided by the simultaneous comparison of photos. Those sample plots that were interpreted as treeless at 1:60,000 scale and wooded at 1:30,000 scale would not have been interpreted as changed, because trees were visible in both photos. There were two such plots interpreted by A and three by C. It was also evident that the largest differences in tree cover estimates were unrealistically large. Some screenshots of aerial photos are given in Figure 23. However, it was also apparent that some sample plots could have been interpreted as changed because of photo scale although there would not have been changes in tree cover in reality.


1:30,000

1:60,000

Figure 22. Tree cover interpreted by two interpreters (A and C) at the two scales. Pearson r: 1:30,000=0.946, 1:60,000=0.936.

Table 15. The mean differences of tree cover between two interpreters at the two scales.

Variable	1:30,000			1:60,000			N
	Mean diff.	Std. Dev.	t (p)	Mean diff.	Std. Dev.	t (p)	
Tree cover (%)	4.5	7.3	4.72 (<0.001)	9.1	10.2	6.74 (<0.001)	59

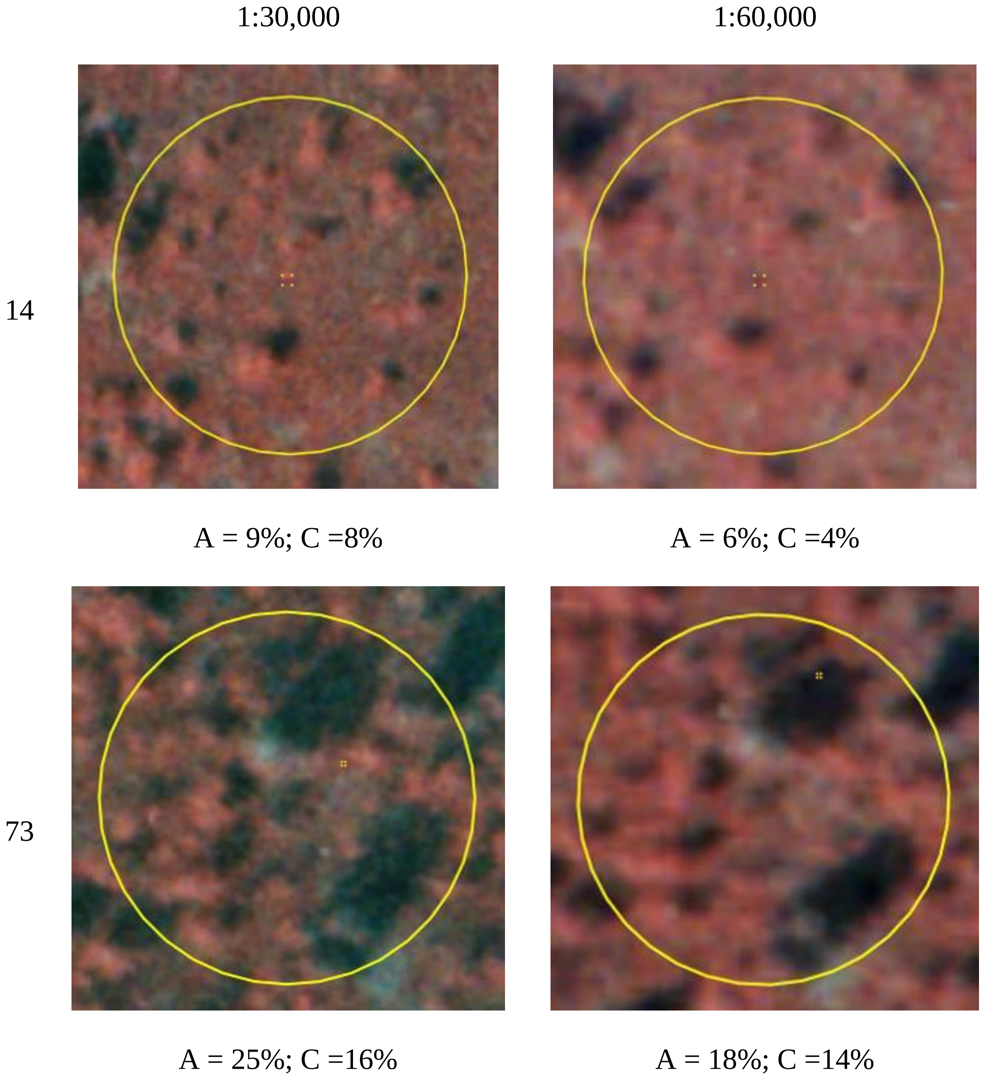


Figure 23. Screenshots of two sample plots (#14 and #73) at 1:30,000 and 1:60,000 scales. Also tree cover values interpretations are shown (interpreters A and C).

11. Assessment of historical black and white photos

The historical black and white (BW) photographs from the late 1950s and 1960s are available over most parts of the Swedish mountain chain at the scale of 1:30,000. According to an inquiry to the Swedish Land Survey (Lantmäteriet) and their GeoLex database, the historical BW photos would be available for all the six NILS squares studied in this project. This suggests that the availability of historical BW photos over the Swedish mountains in general is good. Therefore, we wanted to make a preliminary assessment of the potential of BW photos to extend the length of the time series. BW photos were available for the Grövelsjön test site (Table 2). It is important to note that orthochromatic film was used instead of later more commonly used panchromatic film. For the test, we randomly selected some sample plots to compare between BW and CIR photos. Because of the approximately same photo scale, the BW photos were compared with the 1:30,000 scale CIR photos.

The assessment showed that small tree cover values (< 5–10%) are very difficult (or even impossible) to estimate from the BW photos (Figure 24). However, the comparison of the BW photos and the CIR photos improves the identification of single trees. If BW photos would be interpreted independently, it is likely that tree cover estimates would have low accuracy in comparison to CIR photos. Larger tree cover values (5–30%) are easier to estimate. In this range it should be possible to identify at least the largest tree cover changes (changes greater than 5%). However, smaller changes are unlikely to be reliably interpreted. Also the type of background and ground vegetation can affect the identification of tree crowns considerably. It is more difficult to identify trees if the background is variable and light in colour, than if it is dark and smooth.

The quality of the photos can be very important for the accuracy of the photo interpretation. The BW photos used in this comparison were taken using orthochromatic film, which is sensitive only to blue and green light. As films and cameras have improved between the 1950s and 1960s, it is likely that the quality of the photos from the 1960s in general is better. Panchromatic film, which is also sensitive to red light has been used more commonly in the 1960s and can provide better quality photos. Furthermore, the subjective mark given to the photos is also rather low (3+/7), which suggests that photo quality could be considerably better in another set of photos. The very light shadows in the BW photos used here are not necessarily characteristic of all the BW photos from the 1950s and 1960s. For example, the weather conditions during the photography can affect the photo quality.

14

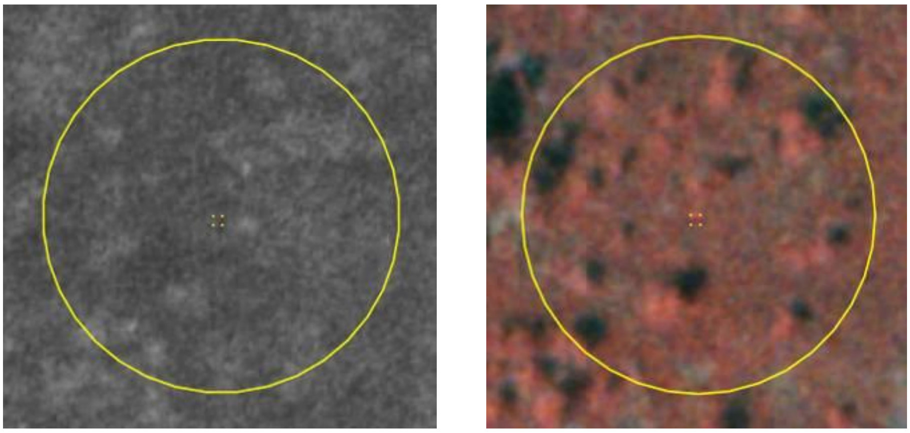


Figure 24. One of the sample plots (#14) in BW and CIR photos.

12. Discussion

12.1 Changes in vegetation variables

The significant increase in tree cover was detected in three of the six NILS squares studied by comparing aerial photos corresponding to two time periods, 1975–1979 and 2002–2004. Changes in tree cover composition were also observed in one of the squares, where the proportion of conifers was interpreted as having decreased as mountain birch had become more abundant. Although the validation of the change detection is difficult without field data from both points in time, the results are in line with the changes that are predicted to occur in the treeline ecotones (Moen et al. 2004) and also previously reported in the literature (Kullman 2001; Öberg 2008). Therefore, we consider that change detection based on aerial photo interpretation has potential to complement the field based treeline monitoring in providing information on tree cover changes.

Changes in the treeline positions were not observed; at least they were too small to be detected. Tree cover and density within the treeline ecotones are likely to respond more quickly to rising temperature than what it would take for the treeline to migrate (Holtmeier 2003). The smallest trees detected in this study were found to have a height of 2–4 m. Also the width of the tree crown affects the identification of single trees in the photos. Some trees can have very wide crowns and are visible as “trees” in the photos although they are shorter than 2 m. Furthermore, mountain birches often grow closely together or have several stems, which affect the identification of individual trees.

We conclude that changes in the cover of shrubs and small trees cannot be detected reliably using aerial photo interpretation as it was employed in this project. The observation of small trees and shrubs seems to be difficult even at the scale of 1:30,000. Marklund et al. (2007) have noted that change in the cover of shrubs and small trees has to be rather large before it can be observed from the aerial photos at 1:30,000 scale. For example, changes from <10% to 10–30% could be required for the change to be determined. However, the appearance of the shrubs varies considerably between the species. Therefore, it is possible that cover of some species, for example willows, could be estimated more accurately with better interpretation keys and field control. Nevertheless, change detection using 1:60,000 scale photos is impossible. In the biotope inventory of northernmost Lapland in Finland, shrub cover could be estimated successfully using 1:20,000 scale CIR photos (Sihvo 2001, 2002).

In this project, we concentrated on the detection of tree cover changes. However, in order to evaluate the effect of climate change to the treelines, it should be possible to separate climate induced changes from those due to other reasons. In addition to climate change, changes in tree cover can occur due to forest management, insect outbreaks, and reindeer browsing and trampling. Also other disturbances, such as avalanches and landslides can affect treelines. For example, in square 584 we observed in the field that tree cover change in one sample plot was due to a landslide.

In some squares, we interpreted that tree cover had increased in clear cuts and managed forests. These changes were observed mostly below the treeline ecotone. However, in one of the squares there were also clear signs of harvested trees in the mountain birch forests in the recent photos. The effect of forest management can usually be identified easily from aerial photos and controlled in the analysis of the results.

The outbreaks of autumnal moth (*Epirrita autumnata*) and winter moth (*Operophtera brumata*) occur on a cycle of approximately ten years in the Scandinavian mountain birch ecosystems (Tenow et al. 2001). The outbreaks usually take place at the beginning of the growing season and can result in the severe defoliation of mountain birch and affect the field and ground layer vegetation. Usually, the birches are at least partly re-foliated later in the growing season. The outbreaks affect the position and structure of the treelines as they can cause dieback of the birches, which usually requires several years of repeated defoliations. Because the outbreaks can be either temporary or cause more permanent changes to the structure of treelines, and furthermore can have very different appearance depending on the severity of the outbreak and amount of re-foliation, they can complicate the interpretation of tree cover changes. Because birches usually recover from the defoliation, the date and year of photography can have a large effect on the results. Recent outbreaks are usually identified in the aerial photos, and sample plots affected by the outbreak can be excluded from the analysis. However, the temporary defoliations can be difficult to separate from the outbreaks that have a more permanent effect on the forest structure. Therefore, it would be very useful to have either field or satellite-based monitoring data on the outbreaks as ancillary data. The proposal for such a system is presented by Marklund (2008).

Reindeer herbivory can also affect the response of treelines to climate change (Cairns et al. 2007). Reindeer browsing of the saplings and birch trees can in particular hinder the potential upslope migration of the treelines. The effect of reindeer cannot be interpreted from the aerial photos. Therefore, the impact of reindeer grazing has to be studied separately and taken into account in the analysis of the change detection results, for example, by considering the changes in the amount reindeer in different parts of the mountain chain using separate field studies on grazing intensity or statistics on reindeer herding.

12.2 Change detection methods for treeline monitoring in NILS

All the change detection methods are likely to have their potential application, advantages and limitations for treeline change detection. However, in this project we focused on the applicability of the methods within the NILS framework, which provides a nationwide systematic sample of 5×5 km squares. In order to summarize the methods, we have listed the advantages and limitations of each of the change detection methods in the Table 16.

The sample plot method has many advantages to provide tree cover change detection for treeline ecotones within the 5×5 km NILS square. The method can be applied to any square overlapping the treeline ecotone in a straightforward and cost-effective way. Sampling of the plots can be done objectively either for the entire square or by using pre-stratification, such as treeline buffer zones, as applied in this project. No subjective delineations of polygon borders are necessary and relatively small sample plots are easier to interpret for changes than larger polygons. This is particularly the case when changes are marginal. The 20 m radius plot was considered suitable for tree cover change detection at photo scales of 1:30,000 and 1:60,000. The statistical significance of the mean changes can be tested using standard statistical tests. The major limitation of the sample plot method is that it does not provide information on the spatial structure of treeline. Furthermore, the method utilizes only a small fraction of information available in the photos and the results are not particularly visual in comparison to maps. If using the treeline buffering method for pre-stratification, it is also difficult to determine such criteria, which are valid over a range of treelines. The buffering of the treeline is also sensitive to errors in land cover data.

Table 16. The advantages and limitations of the change detection methods. See chapters 8.2–8.4 for the description of the methods.

Method	Advantages	Limitations
Complete cover mapping (polygon interpretation)	• Provides the description of spatial patterns (landscape structure) • Relatively quickly applied to the 1×1 km square, which has been inventoried by regular NILS photo inventory • Results are effectively visualized as maps	• Polygon delineations are subjective • Small changes in polygon borders are difficult to interpret • Size and form of polygons vary, which can affect the estimation of vegetation attributes • It can be difficult to detect small changes in vegetation attributes if polygons are large • Application to the NILS 5×5 km square would be expensive and time consuming • Involvement of several interpreters can complicate change detection
Sample plot method	• Straightforward and cost effective to apply to any relevant NILS 5×5 km square • Circular plots are relatively small and have standard form • Sampling can be based on an objective method • Sampling can be made more efficient by pre-stratification (treeline buffer) • The results of change detection can be easily analyzed statistically	• Sparse sampling does not provide information on spatial patterns (landscape structure) • Only a small fraction of information in photos is utilized • Results are not easy to visualize • General criteria to define treeline buffer zone can be difficult to determine and buffering is sensitive to errors in land cover data
Transects	• By subjective sampling the analysis can be directed towards the most interesting mountain slopes • Provide information on the structure of tree cover gradients	• Selection of transects can be difficult. • Subjectively selected transects cannot be generalized to an area in which sampling has been done • Ideal slopes are not necessarily found within NILS squares although there would be interesting treeline ecotones or parts of them to be studied
Treelines	• Similar to the approach used in the field based monitoring • Gives the elevation of treeline if trees are reliably located	• The identification of single trees is difficult at the scale of CIR photos used in NILS and this project

Polygon interpretation using change control mapping is a cost-effective method for change detection of the 1×1 km squares, which are continuously inventoried in NILS. The greatest advantage is that in addition to changes in tree cover, polygon interpretation provides information on the spatial patterns (landscape structure) in the treeline. However, the problem of the polygon interpretation is the subjective delineation of polygon borders. Small changes along the polygon borders are also difficult to delineate, despite the small area of minimum mapping unit in NILS (0.1 ha). The size and form of polygons also vary, which can make the interpretation difficult in comparison to small sample plots. The possibilities for simplified polygon interpretation for 5×5 km square were studied by Marklund et al. (2007), who concluded that a simplified approach could decrease the probability of observing the smallest changes. The interpreter might also disagree considerably with a previous interpretation made by someone else. By viewing both the recent and historical photos concurrently, it is possible to interpret changes relative to another interpretation and avoid false change identification. However, in the case of clear mistakes it should be possible to make corrections on the NILS maps. In order to compare the maps from two points in time, those should be based on the same interpretation criteria. However, the NILS criteria for delineating polygons are not necessarily optimal for treeline change detection. For example, it could be better to delineate borders based on threshold values of the tree parameters instead of delineating polygons based on natural boundaries of the landscape (Allard et al. 2003).

The transect method also has advantages to treeline studies because transects can be set on the most interesting slopes to study tree cover gradients. The data from single slopes might also provide better possibilities to study relations between tree cover and elevation than the sample plot method. However, transects are not necessarily the best method for interpreting tree cover changes in NILS squares. For example, there can be interesting sparse forests, which are difficult to sample by using transects, because the slope towards a certain aspect does not cover the whole transition from treeless areas to the closed forest, or because transects are interrupted by mires or creeks. Therefore, such slopes which are easily sampled by transects are not necessarily easy to locate within NILS squares. Furthermore, the result of transect interpretation cannot be generalised to larger areas similar to the method that is based on the probability sampling. The interpretation of the treeline trees does not provide a potential change detection method at the photo scales used in the project. Larger scale photos would be required. However, the interpretation of single trees can be used for studying how tall trees can be identified from various scales of aerial photos.

12.3 Factors affecting the accuracy of change detection

The greatest source of uncertainty in the change detection is related to the difference in photo scale between the recent and historical photos. Additionally, the accuracy and precision of the interpreted data depends on the quality of the photos, the stereo instrument and the experience of the interpreter. Also the development stage of the vegetation at the time of photography can be of major importance (Allard et al 2003). The treeline buffer zone determines the amount and location of the sample plots to be interpreted. Therefore, also the selection of the land cover data set, the criteria used for defining the buffer zone, the errors of the land cover data, and the density of the sample plots influence the change detection.

The tree cover is probably less sensitive to photo scale than some other variables, such as tree density (Paine & Kiser 2003). However, several studies have shown that tree cover estimates depend on the photo scale (e.g. Fensham et al. 2002). In this project, we studied the effect of photo scale in two experiments. The significant underestimation of tree cover at 1:60,000 scale relative to 1:30,000 scale by one interpreter was observed in both experiments. The experiments show that there is a high risk of detecting false changes if interpreting photos from two points in time separately at different scales. The errors in the single sample plots and larger tree cover values could be substantial. The underestimation of tree cover at

1:60,000 scale can be expected because the smallest trees are not necessarily detectable. However, the scale difference is not likely only a question of resolution. Scale can also affect the other photo qualities, such as colours and deepness of the shadows. The results of this study disagree with the results of some other studies that have shown that tree cover is exaggerated at smaller scale photos, which causes the overestimation of tree cover relative to larger scale photos (e.g. Fensham et al. 2002).

Photo scale and stand density are the principal factors contributing to the accuracy of crown counts (Paine & Kiser 2003). The results of the crown counts in the first experiment showed that two of the three interpreters interpreted many more trees from the larger scale photos. This could be the case particularly in treeline ecotones where mountain birches often have several trunks or several trees grow very closely together. Therefore, the counting of tree crowns is difficult even if larger scales photos were to be used. The use of photos of a larger scale (1:15,000 or larger) has also been recommended in the literature for studying changes in tree density (e.g., Baker et al. 1995).

The difference in photo scale also limits the ability to detect changes in treeline positions. In the sample plot method, the changes in the treeline position are seen as the recruitment of trees on previously treeless sample plots. Then the elevation of these plots determines the new treeline position. However, sometimes there is only one single tree observed in the 1:30,000 photos, which is not visible in 1:60,000 photos. Such changes were observed in two squares. When changes are this small, the scale difference between the photos can have a large effect on the interpretation of the treeline changes. The field measurements showed that the smallest trees identified from the recent photos have a height of less than 2 m to 4 m, which means that small changes cannot be determined reliably using small and medium scale aerial photos.

The reduction of the scale effects can be difficult. Fensham & Fairfax (2007) developed statistical models between the field measured and photo interpreted tree cover estimates made at different scales to calibrate tree cover estimates for change detection. This requires field measurements. Models should be made separately for each interpreter and updated regularly as interpreters become more experienced. In this project, we applied a change detection approach, in which the photos were compared simultaneously on a digital workstation. This approach is likely to reduce the scale effect since the interpreter can compare the pattern of tree crowns within the plot to identify if tree cover has changed. A relatively safe approach is to record sample plots as changed only if the changes are obvious. Here we found only minor changes in three squares, which also indicates that the interpreters were able to compensate for differences in photo scale in change detection.

The digital photogrammetric workstations were used for change detection, because they were more convenient to work with than analytical photogrammetric instruments. For example, the sample plots are more difficult to locate using a P3 as lines are rather thick in superimposition. However, the transparent diapositives provide somewhat better resolution and colours than scanned digital photos (Allard et al. 2003). In order to study the effect of the stereo instrument and differences between the diapositives and digital photos, we checked the treeline trees in square 584 also with analytical photogrammetric instrument. No changes were made to the interpretations suggesting that the instrument has only a small effect on the detectable size of the smallest trees. If an analytical photogrammetric instrument would be used for change detection, the comparison of photos from two points in time simultaneously becomes difficult as it would require two photogrammetric instruments. Furthermore, more time should be reserved for data preparations in comparison to digital workstations.

The interpretation tests in the Grövelsjön test site also demonstrate the effect of interpreter on the estimation of vegetation variables. We tried to reduce this effect by increasing the training, which considerably improved the estimates of the less experienced interpreter. Although the experience can affect the tree cover estimates, the effect on the change detection should be relatively small as the recent and historical photos were interpreted simultaneously by the same interpreter. However, the interpreter could affect to the magnitude of the change observed. This effect could be reduced by two interpreters interpreting the same plots.

Most of the photos used in this project were photographed between mid-July and mid-August, which corresponds to the time when vegetation in the mountains is fully developed (Table 1). The longest time difference in the date between the recent and historical photos was one month (square 326, historical photos taken on 6 July and recent on 4 August). Although the leaves of mountain birch should be fully developed already in the beginning of July, it is possible that photography date differences affect the change detection at the square 326. It is also recognized that small differences in solar angles can cause large differences in the patterns of shadows, and possibly affect the ocular estimates and therefore the change detection.

In this project, we used GSD-Land and Vegetation Cover data (GSD-Marktäcke) for mapping treeline buffer zone. The advantage of these data is that it has been produced using consistent methods for all of Sweden. The spatial resolution is also relatively good. Therefore, when the treeline consists of small forest patches those are connected to make larger areas in the buffering. Some obvious classification errors were observed in the visual assessment against the orthophotos, but in general those were few. However, for example, in square 516 some small wetlands (mires) were classified as forest, which affected the positioning of the treeline buffer zone. An alternative land cover data set could be “mountain vegetation map”, which also covers most of the mountain chain (but not NILS strata 10 completely). As the mountain vegetation map is more generalized, the buffer zones would become generalized too. However, because of the greater level of generalization, the width of treelines could be substantially underestimated. An even more generalized data set for buffering is provided by the digital road map at scale of 1:100,000 (Esseen & Löfgren 2004).

The forest classes of GSD-Land and Vegetation Cover data have according to the definition a tree cover greater than 30% and tree height more than 5 m. The buffering both downwards and upwards was considered necessary in order to cover the whole treeline ecotone. However, the 250 m wide buffer in combination with a 250 m distance between the sample plots was too narrow on some slopes. In particular, the distance towards the treeless alpine areas could have been greater as the uppermost trees were often omitted. The increase in the buffer width would also increase the interpretation time. However, many sample plots above the current buffer zone would be treeless in reality (quick to interpret), and hence, the extension of the buffer zone towards alpine areas should have only a small effect on the total interpretation time. We also aggregated all the forest classes and made the buffer the boundary between the forest and non-forest areas. Therefore, the treeline buffer was made most often along the boundary of mountain birch forest and alpine vegetation. However, sometimes there is another transition from the coniferous forest to mountain birch below this border. Furthermore, we did not consider changes on mires within the treeline ecotone although those could also be of interest.

12.4 Potential for a larger scale study using NILS sampling

This project showed how visual interpretation of aerial photos provides information on the tree cover changes in the treeline ecotones. There are also other potential sources of remote sensing data for monitoring future changes in treelines (discussed in 12.5), but aerial photos provide the longest temporal record of remote sensing data over the Swedish mountains. Therefore, we consider that there is potential for a larger scale study to examine tree cover changes in treelines using aerial photos although the small and medium scale photos available from the Swedish mountains have limited capabilities for interpreting the smallest tree cover changes. The NILS sample of the study sites and the sample plot method provide an available basis for such a larger scale study.

Geographically, the sampled area in the larger scale study could be defined as a treeline ecotone determined by buffering the GSD-Land and Vegetation Cover data. The sample would then consist of those NILS squares, or parts of them, that coincide with the defined treeline ecotone. According to Esseen & Löfgren (2004), subalpine forest occurs in 94 of the 5×5 km NILS squares and in 56 of the 1×1 km squares in stratum 10 of the NILS sample (alpine areas and sub-alpine forests). Based on the visual assessment of GSD-Land and Vegetation Cover data and digital road map at 1:100,000 scale, we estimate that approximately 50–60 squares (5×5 km) have potential for treeline change detection.

Aerial photos from three points in time could be used in the larger scale study: the most recent CIR photos (2000s), CIR photos from the 1970s and 1980s, and black and white (BW) photos from the 1950s and 1960s. In comparison to this project, more emphasis should be placed on the BW photos photographed with panchromatic film in 1960s. Although the test on the potential of BW photos in this project did not give very encouraging results, we consider that those results are partly due to the poor quality of the photos used from 1950s (orthochromatic film, low quality mark). The advantage of the BW photos is that those have been taken from about the same flying height as the most recent CIR photos, producing approximately the same photo scale (1:30,000). Furthermore, it is possible that changes between the 1960s and 2000s are greater than between 1970s/1980s and 2000s, which should enable the more reliable determination of the direction of change. However, the spectral information content of the BW photos is reduced in comparison to CIR photos. Therefore more tests on panchromatic photos are needed in order to make conclusions on their feasibility. We also suggest that change detection should be made using digital photogrammetric workstations, which enable simultaneous comparison of the photos.

We recommend a sample plot based method as a basic method for a more comprehensive study. It is necessary to extend a buffer zone towards alpine areas and preferably also to use a denser sampling than 250 m distance between the sample plots. In addition to the sample plots, it might be interesting to map and describe specific phenomena that are discovered, like apparent changes in the treeline. A larger scale study would, with reservation of the error sources, provide statistics on treeline change as well a description of the frequency of those squares that have experienced significant change in tree cover. NILS sampling has been designed to provide information on the vegetation condition and changes on the national level. The data from NILS squares is not necessarily extensive enough for determination of treeline changes at a county or regional level, but it should be possible to estimate changes separately for the southern and northern parts of the mountain chain (Esseen & Löfgren 2004).

The results of visual interpretation depend on the experience of the interpreter. Therefore, the photo interpreters are being trained continuously in the NILS program. However, further training and calibration exercises including field visits to different parts of the Swedish mountains would be necessary in a larger scale study. Now the estimation of tree cover was based on visual guides. In a larger scale study it would be important to measure calibration plots in the field, which could be used for calibration exercises. At the moment, such data are not available for mountain birch forests and treeline regions. Maybe also field inventory data collected in NILS could be used more effectively in the photo interpretation. However, the applicability of tree cover estimates is limited by the unknown accuracy of the ocular estimates made in the field inventory.

We roughly estimate that interpreting one NILS square for three time periods using the sample plot method costs 10 000–12 000 SEK (approximately 100 sample plots per square). In addition, the funds for preparations, data analysis and reporting would be needed. Funds should also be reserved for the field visits and acquisition of additional photos and scanning. Thus, a large scale study, involving 50–60 NILS squares would require a budget of about 1 million SEK. The feasibility of interpreting the available black and white photos should be studied more in detail before the larger scale study.

12.5 Future remote sensing methods for treeline monitoring

Visual photo interpretation is costly and dependent on the interpreter. More objective methods are needed for deriving quantitative estimates for vegetation attributes for change detection over time. Aerial photo interpretation provides the best possibilities for studying historical vegetation changes. Larger scale aerial photos taken from considerably lower altitudes than photos considered in this project could improve the mapping of trees and shrubs in the future. However, airborne laser scanning (ALS) provides probably the greatest potential for tree cover and shrub cover monitoring (Holmgren et al. 2008). Although the applications of ALS for mapping and change detection of treelines are still rare, the potential of the method has been demonstrated (Næsset & Nelson 2007; Rees 2007).

Marklund et al. (2007) discussed the potential of ALS for interpreting vegetation data for 5×5 km NILS squares. For future monitoring, ALS can become a very powerful method for capturing vegetation data at the landscape scale as it provides possibilities to automatically measure vegetation height and structure with good accuracy. ALS data can be analyzed using automatic methods, but it can also be used as ancillary data to support the visual interpretation of aerial photos. The utility of ALS data is dependent on the density of returned laser pulses, which determines the size of the smallest objects that can be identified and measured. Typical ALS data consist of one to twenty returns per square meter (it can also be less), which provides the derivation of accurate digital elevation models and measurement of vegetation height, density and structure. In order to identify individual trees, 5–10 returns per square meter are required. In addition to measurements of tree locations, it is possible to measure tree height and crown shape, which provide possibilities for tree species identification.

Recently, Holmgren et al. (2008) investigated the potential of using ALS for the estimation of crown cover of trees and shrubs in a study site in southern Sweden. In the estimation of tree crown cover (tree height > 3.0 m) the root mean square error (RMSE) was 4.9%. The low RMSE was achieved despite a mixture of different tree species on the field plots. The results indicate that ALS is an excellent technique for obtaining objective measures of tree crown cover. The methods used in the study were not sufficient for high accuracy estimations of the amount crown cover of shrubs (height 0.3–3.0 m) under the tree canopy. However, the possibilities to extract shrub cover in sparsely wooded and treeless areas close to treeline could be better with ALS.

Næsset & Nelson (2007) studied whether it was possible to use high resolution ALS data (7.7 pulses per square meter) to detect small trees in treelines. The results indicate that almost all trees having a height of more than 1 m and hit by the laser pulse are detected in the laser data. By using a high density of laser sampling, and assuming a fixed systematic underestimation of tree height from one inventory to another and annual tree height growth of 5 cm, it is likely that tree height changes can be observed over short time periods. Furthermore, the authors conclude that it would be possible to detect a sufficient portion of newly established trees over a ten year period to claim that tree migration is taking place.

The five-year interval used in NILS is enough for monitoring changes due to climate change, but monitoring of more dynamic phenomena, such as insect outbreaks, requires data with better temporal resolution. Such information could be provided, for example, by Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA’s Terra and Aqua satellites at a spatial resolution of 250 m – 1 km (Marklund 2007). The better information on insect outbreaks would also be useful for visual interpretation of aerial photos and treeline change detection.

13. Conclusions

1. All the change detection methods tested in this project, complete cover mapping, sample plot method and transect method, are likely to be useful for particular applications in treeline mapping and change detection. However, the sample plot method is the most promising method for tree cover change detection within NILS 5×5 km squares. Treeline buffering based on digital land cover data provides one possible approach to limit the number of sample plots to be interpreted.

2. The greatest sources of uncertainty in the change detection are related to the relatively small scale of available aerial photos and to the different photo scales between the recent and historical photos. However, we conclude that simultaneous comparison of aerial photos from two points in time provides meaningful change detection for tree cover. Changes in the cover of small trees and shrubs could not be interpreted with sufficient accuracy in this project.

3. The interpretations made by the sample plot method suggest that tree cover has increased within the treeline ecotone in three out of six NILS squares. The results demonstrate the potential of visual interpretation based on aerial photos and the applied methods for treeline change detection in the Swedish mountains.

4. There is potential for a more comprehensive study interpreting a greater number of NILS squares for treeline changes. The sample plot method provides cost-effective methods for such study. Airborne laser scanning is likely to provide improved data for treeline monitoring in the future.

References

ACIA (2004). Arctic Climate Impact Assessment. Impacts of a warming Arctic. Cambridge University Press, Cambridge. 1042 p.

Ahlcrona E (2003). Svenska CORINE Marktäckedata. Nomenklatur och klassdefinitioner. Available online: http://www.lantmateriet.se/upload/filer/kartor/kartor/SCMDbil.pdf

Allard A (2003). Vegetation changes in mountainous areas. A monitoring methodology based on aerial photographs, high-resolution satellite images, and field investigations. PhD thesis. The Department of Physical Geography and Quaternary Geology, Stockholm University. 14 p. + appendices.

Allard A, B Nilsson, K Pramborg, G Ståhl & S Sundquist (2003). Manual for aerial photo interpretation in the National Inventory of Landscapes in Sweden NILS. Year 2003. SLU, Department of Forest Resource Management and Geomatics. 80 p.

Allard A, P-A Esseen, S Holm, M Högström, L Marklund, B Nilsson, H Reese & J Wikberg (2007). Fångst av vegetationsdata och Natura 2000-habitat i fjällen genom flygbildstolkning med punktgittermetodik. Arbetsrapport 172, Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning. 47 p.

Allen TR & SJ Walsh (1996). Spatial and compositional pattern of alpine treeline, Glacier National Park, Montana. Photogrammetric Engineering and Remote Sensing 62, 1261–1268.

Baker, WL, JJ Honaker & PJ Weisberg (1995). Using aerial photography and GIS to map the forest-tundra ecotone in Rocky Mountain National Park, Colorado, for global change research. Photogrammetric Engineering and Remote Sensing 61, 313–320.

Boberg A (1993). Flygbildens framställning och egenskaper. In: Flygbildsteknik och Fjärranalys, 13–50. Nämden för Skoglig Fjärranalys.

Cairns DM & JD Waldron (2003). Sigmoid wave transitions at alpine treeline. Geografiska Annaler 85 A, 115–126.

Cairns DM & J Moen (2004). Herbivory influences tree lines. Journal of Ecology 92, 1019–1024.

Cairns DM, C Lafon, J Moen & A Young (2007). Influences of animal activity on treeline position and pattern: implications for treeline responses to climate change. Physical Geography 28(5), 419–433.

Callaghan TV, B Werkman & RMM Crawford (2002). The tundra-taiga interface and its dynamics. Ambio Special Report 12, 6–14.

Esseen P-A & P Löfgren (2004). Vegetationskartan över fjällen och Nationell Inventering av Landskapet i Sverige (NILS) som underlag för Natura 2000. Arbetsrapport 124, Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning. 31 p.

Esseen P-A, A Glimskär, J Moen, B Söderström & A Weibull (2004). Analys av informationsbehov för Nationell Inventering av Landskapet i Sverige (NILS). Arbetsrapport 132, Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning. 73 p.

Esseen P-A, A Glimskär, G Ståhl & S Sundquist (2007a). Field instruction for the National Inventory of the Landscape in Sweden. SLU, Department of Forest Resource Management. 194 p. + appendices.

Esseen P-A, B Nilsson, A Allard, H Gardfjell & M Högström (2007b). Landskapsdata från Nationell Inventering av Landskapet i Sverige (NILS). Flygbildstolkning av 1 km × 1 km rutan för år 2003. Arbetsrapport 169, Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning. 63 p.

Fensham RJ, RJ Fairfax, JE Holman & PJ Whitehead (2002). Quantitative assessment of vegetation structural attributes from aerial photography. International Journal of Remote Sensing 23(11), 2293–2317.

Fensham & Fairfax (2007). Effect of photoscale, interpreter bias and land type on woody crown-cover estimates from aerial photography. Australian Journal of Botany 55, 457–463.

Heikkinen O (2005). Boreal forests and northern and upper timberlines. In Seppälä M (ed.): The physical geography of Fennoscandia, 185–200. Oxford University Press, Oxford.

Holmgren J, F Johansson, K Olofsson, H Olsson & A Glimskär (2008). Estimation of crown coverage by using airborne laser scanning. Proceedings of SilviLaser 2008, September 17–19, 2008, Edinburgh, UK.

Holtmeier F-K (2003). Mountain timberlines: ecology, patchiness, and dynamics. 384 p. Springer, Dordrecht.

Hufkens K, R Ceulemans & P Scheunders (2008). Estimating the ecotone width in patchy ecotones using a sigmoid wave approach. Ecological Informatics 3, 97–104.

Hållmarker M (2002). Skogsgränsförändringar i Abisko. Examsarbete i Miljövetenskap, Göteborgs Universitet. 37 p. + 3 appendices.

Ihse M (2007). Colour infrared aerial photography as a tool for vegetation mapping and change detection in environmental studies of Nordic ecosystems. Norsk Geografisk Tidsskrift 61, 170–191.

IPCC (2007). Climate Change 2007: The Physical Science Basis. University Press, Cambridge, New York. 996 p.

Kjällgren L & L Kullman (1998). Spatial patterns and structure of the mountain birch tree-limit in the southern Swedish Scandes - A regional perspective. Geografiska Annaler A 80(1), 1–16.

Kjällgren L & L Kullman (2002). Geographical patterns of tree-limits of Norway spruce and Scots pine in the southern Swedish Scandes. Norwegian Journal of Geography 56, 237–245.

Korhonen L, KT Korhonen, M Rautiainen & P Stenberg (2006). Estimation of forest canopy cover: a comparison of field measurement techniques. Silva Fennica (40)4, 577–588.

Kullman L (1998). Tree-limits and montane forests in the Swedish Scandes: sensitive biomonitors of climate change and variability. Ambio 27(4), 312–321.

Kullman L (2001). 20th century climate warming and tree-limit rise in the Southern Scandes of Sweden. Ambio 30(2), 72–80.

Kullman L (2005). Mountain Taiga of Sweden. In Seppälä M (ed.): The physical geography of Fennoscandia, 297–324. Oxford University Press, Oxford.

Kupfer JA & DM Cairns (2003). The suitability of montane ecotones as indicators of global climatic change. Progress in Physical Geography 20(3), 253–272.

Marklund L (2007). Förslag på system för övervakning av fjällbjörkmätarangrepp och andra förändringar i fjällbjörkskog. Rapport för länstyrelsen i Norrbotten och Naturvårdsverket.

Marklund L, A Allard, M Egberth, J Holmgren, M Högström, B Nilsson, H Olsson, H Skånes, F Walter & S Sundquist (2007). Utveckling av metodik för flygbildstolkning inom NILS landskapsrutor (5x5 km). Arbetsrapport 173, Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning. 90 p.

Moen J, K Aune, L Edenius & A Angerbjörn (2004). Potential effects of climate change on treeline position in the Swedish mountains. Ecology and Society 9(1), 16.

Næsset E & R Nelson (2007). Using airborne laser scanning to monitor tree migration in the boreal–alpine transition zone. Remote Sensing of Environment 110, 357–369.

Paine DP & JD Kiser (2003). Aerial photography and image interpretation. Second edition. John Wiley & Sons, Hoboken, New Jersey. 632 p.

Parmesan C & G Yohe (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 37–42.

Rees G, I Brown, K Mikkola, T Virtanen & B Werkman (2002). How can the dynamics of the tundra–taiga boundary be monitored? Ambio Special Report 12, 56−62.

Rees WG (2007). Characterisation of Arctic treelines by LiDAR and multispectral imagery. Polar Record 43 (227), 345–352.

Reese H, M Nilsson, A Allard & H Olsson (2008). Mapping of mountain vegetation with reflectance calibrated SPOT data and NILS data. Final report to Naturvårdsverket and Rymdstyrelsen (Dnr: 721-1631-06Mm).

Salehi A, E Wilhelmsson & U Söderberg (2008). Land cover changes in a forested watershed, southern Zagros, Iran. Land Degradation & Development 19(5), 542–553.

Sihvo J (2001). Ylä-Lapin luonnonhoitoalueen ja Urho Kekkosen kansallispuiston luontokartoitus. Loppuraportti osa 1. Projektikuvaus. Metsähallitus, Vantaa. 76 p. (in Finnish).

Sihvo J (2002). Ylä-Lapin luonnonhoitoalueen ja Urho Kekkosen kansallispuiston luontokartoitus. Loppuraportti osa 2: Ylä-Lapin luontotyypit. Metsähallitus, Vantaa. 175 p. (in Finnish).

Stow DA, D McGuire, D Verbyla, J Gamon, F Huemmrich, S Houston, C Racine, M Sturm, K Tape, L Hinzman, K Yoshikawa, C Tweedie, B Noyle, C Silapaswan, D Douglas, B Griffith, G Jia, H Epstein, D Walker, S Daeschner, A Petersen, L Zhou & R Myneni (2004). Remote sensing of vegetation and land-cover change in Arctic Tundra Ecosystems. Remote Sensing of Environment 89, 281–308.

Sturm M, C Racine & K Tape (2001). Increasing shrub abundance in the Arctic. Nature 411, 546–547.

Ståhl G, A Allard, P-A Esseen, A Glimskär, A Ringvall, J Svensson, S Sundquist, P Christensen, Å Gallegos Torell, M Högström, K Lagerqvist, L Marklund, B Nilsson & O Inghe (in prep.). National Inventory of Landscapes in Sweden (NILS) – Scope, design and experiences from establishing a multi-scale biodiversity monitoring system.

Tenow O, H Bylund & B Holmgren (2001). Impact on mountain birch forests in the past and the future of outbreaks of two geometrid moths. In Wielgolaski FE (ed.): Nordic mountain birch ecosystems, 223–239. Man and the Biosphere Series, vol. 27. Parthenon Publishing, New York.

Walther G-R (2003). Plants in a warmer world. Perspectives in Plant Ecology, Evolution and Systematics 6(3), 169–185.

Öberg L (2008). Trädgränsen som indikator för ekologiska klimateffekter i fjällen. En metodstudie för långsiktig miljöövervakning. Rapport 2008:01 Miljö/Fiske Miljöövervakning. Länstyrelsen Jämtlands län, Länstyrelsen Dalarnas län. 34 p. + appendices.