Vegetation Changes and Forest-Line Positions in the Swedish Scandes during Late Holocene

Anthropogenic Impact vs. Climate

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Abstract

The aim of this thesis was to elucidate the effect of human impact in contrast to climate on the vegetation in the northern part of the Scandinavian mountain range. The vegetation histories at four treeless Stállo settlement sites were contrasted to the vegetation histories in three forested reference areas at the same altitude as the settlement sites but lacking archaeological evidence of settlements. The Stállo settlement sites were probably established by Sámi people using the mountain areas for hunting and/or reindeer herding. They are generally dated in the range *c.* AD 650 to 1500, although it has been suggested that the main occupation period was confined to *c*. AD 800 to 1050. Peat stratigraphies from mires at the sites were recovered and analyzed for pollen, charred particles and macrofossils and pollen accumulation rates (PAR) were calculated. A statistical analysis was performed to separate the pollen from tree *Betula* and the shrub *B. nana*. In a simulation study the pre-settlement forest cover at one settlement site was explored.

The results indicate that *Betula* trees were present at the Stállo settlement sites when the settlements were established. The settlement establishment was followed by a reduction in *Betula* tree cover at the sites. No such reduction was apparent in the reference areas suggesting that the decrease in tree cover was not due to climatic change. The deforestation during the Stállo settlement period was followed by a period of colder climate during the Little Ice Age, which together with continuing effects of human presence prevented reforestation of these areas. This long term absence of trees may have changed the ecosystem properties, hampering reestablishment of trees in these areas. This thesis demonstrates that historical human impact in the northern part of the Scandinavian mountain range can have a substantial effect on the local vegetation, which is still visible in the landscape today, several centuries after the settlements were abandoned. This long-term legacy in the landscape suggests that these areas are not “pristine” ecosystems, and has profound implications for our understanding of the responses of the tree- and forest-limits in these areas to e.g. climate change.

Keywords: vegetation history, Stállo settlement, human impact, climate change, northern Scandinavia, forest limit, simulation approach, *Betula*, pollen size statistics, climate change

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”When it was all over, 12 000 years ago, and the other great trees were safely home again in the icy Sierra Nevada and the rain-sodden coast to the north, the Monterey cypress was missing. No one can say why. Palaeobotany is often as foggy as the coast of California. At any rate, the cypress stayed put, very sensibly, basking on the beach of Monterey.”

Thomas Pakenham, Remarkable trees of the World

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Karlsson, H., Hörnberg, G., Hannon, G., Nordström, E.-M. (2007). Long-term vegetation changes in the northern Scandinavian forest limit: a human impact-climate synergy? *The Holocene 17*, 37-49

II Karlsson, H., Shevtsova, A., Hörnberg, G. Vegetation development at a mountain settlement site in the Swedish Scandes during the late Holocene - palaeoecological evidence of human-induced deforestation, (Submitted manuscript)

III Karlsson, H., Salmonsson, J., Hörnberg, G. A millenium of human disturbance in the northern Scandinavian mountain range: Long-lasting effects on forest lines, vegetation and ecological processes. Manuscript.

IV Karlsson, H., Bunting, M.J., Middleton, R. Quantitative estimation of pre-settlement forest cover using the multiple scenario approach at a Stállo settlement site in the Swedish Scandes. Manuscript.

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Introduction

It is generally agreed that most ecosystems on earth have been modified to various degrees by human disturbance (Turner *et al*., 1990; Vitousek, 1994). However, there are still some areas where human impact is believed to have been relatively minor and hence has not affected natural disturbance patterns or species distributions. These areas are usually located in remote northern and/or high altitude regions. The lack of human disturbance is usually attributed to a historically low human population density and absence of modern exploitation by forestry or agriculture. These areas are often termed "pristine", "primeval" or "virgin". However, several studies have shown ecosystems that have previously been assumed to be "pristine", including tropical rainforests (see review by Willis *et al*., 2004) and other ecosystems, might in fact have been substantially modified by humans in a historical perspective. These findings have profound implications for our understanding of the resilience and recovery of such ecosystems following disturbance (Willis *et al*., 2004). However, although it may be difficult to find truly pristine ecosystems, there is a need for such ecosystems as references in ecological studies of processes such as natural disturbance dynamics, succession and biodiversity (Callaghan and Karlsson, 1996; Fries *et al*., 1997; Jasinski and Angelstam, 2002).

In recent decades there has been increased interest in the effects of climatic changes on species distribution and ecosystem functions, following the recognition that global warming might have profound effects on future ecosystems (e.g. Chapin and Starfield, 1997; Sturm *et al*., 2001; Callaghan *et al*., 2004; Moen *et al*., 2004; Kullman, 2005; Dalen and Hofgaard, 2005, Kullman, 2006; Truong *et al*., 2007). Ecotones are expected to be especially sensitive to changes in climate, since many species are living at their distributional limits in such areas (Aas and Faarlund, 1996; Körner, 1998; Kullman, 2001). Hence, mountain altitudinal tree-line ecotones are often used to study vegetation responses to climate change in a long-term perspective (e.g. Karlén and Kuylenstierna, 1996; Barnekow and Sandgren, 2001; Bjune *et al.*, 2004; Seppä *et al.*, 2004). In this thesis the forest limit is defined as the observed limit of continuous forest or stands with at least 15 trees, and the tree-line (following Matthews *et al*., 2005) as the upper limit at which mountain birch (*B. pubescens* ssp. *czerepanovii* (N.I. Orlova) Hämet-Ahti) trees at least 2.5 m tall occur. However, the study of vegetation responses to climate change in mountain areas might be complicated by human impact, since activities such as grazing by livestock or cutting trees for firewood or constructions in mountain areas are known to to lower the forest limit (Moe *et al.*, 1988; Aas and Faarlund, 1996; Hofgaard, 1997; Holtmeier and Broll, 2005).

Human activities have been recognized as factors that have substantially affected vegetation distribution and composition in mountain areas in densely populated parts of Europe, such as the Alps, the Scottish highlands and the Taurus mountains (e.g. Lotter, 1999; Lotter and Birks, 2003; Carcaillet and Muller, 2005; Gobet *et al*., 2003; Kaniewski *et al*., 2007). They are also widely acknowledged as having been important disturbance factors in the southern parts of the Scandinavian mountain range (Kullman 1976, 2001; Moe *et al.*, 1988; Kvamme, 1988; Aas and Faarlund, 1996; Hoofgard, 1997; Barnett *et al.*, 2001). However, the mountain areas in northern Scandinavia are often viewed by ecologists as pristine ecosystems that have been largely unaffected by humans in a long-term perspective (e.g. Callaghan and Karlsson, 1996). Consequently, human impact is often not considered to have significantly affected the long-term vegetation development in these areas (see e.g. Barnekow, 1999; Barnekow and Sandgren, 2001). However, the validity of this belief depends on whether these areas are truly "pristine" in the sense that human intervention has had very little or no effect on disturbance patterns or species distributions in them, or whether historical human impact has been a considerable disturbance factor, as suggested in some other supposedly "pristine" areas.

It has previously been suggested, mainly by archaeologists, but also by a few ecologists (see for instance Emanuelsson, 1987), that the mountain areas in northern Scandinavia are in fact old "cultural landscapes" and archaeological surveys have revealed that people have lived in these areas for thousands of years (Mulk, 1997; Olofsson, 2000; Olofsson and Olsson, 2001, Edbom *et al.*, 2001; Liedgren *et al*., 2007). Specific types of settlements, called Stállo settlements, are frequently found on treeless alpine heaths today, although situated at altitudes below the current regional forest limit. Charcoal in the Stállo hearths suggest that *Betula* trees were used for firewood during the settlement period (Hellberg *et al*., 2004; Liedgren *et al*., 2007). Moreover, Sámi mountain settlements were traditionally, at least during the 20th century, established in the tree limit ecotone due to the importance of access to local *Betula* trees for firewood and wind shelters (Ruong, 1975). Hence, it is likely that *Betula* trees were also present close to the Stállo settlements when they were established. This raises questions about why so many of these areas are situated on open alpine heaths today if they were originally established in, or close to, the mountain birch forest. If the settlement areas were forested at the time of settlement establishment, how, why and when did the trees disappear from these areas?

There is an apparent lack of knowledge concerning the effects of humans on the ecosystems in the northern Scandinavian mountains in a long-term perspective. Such knowledge could be valuable, since it might help to foster a more balanced view of the ecosystems in these areas as not entirely “pristine”, and to ensure that they are not used inappropriately as ecological reference areas in studies of climate change (see Hofgaard, 1997). In addition, such knowledge has wide ranging implications for our understanding of settlement patterns and past human subsistence in high altitude ecotones in northern regions (Bergman *et al*., 2008).

Objectives

The overall aim of the studies underlying this thesis was to elucidate the effects of human activities, and distinguish them from effects of climatic changes, on the vegetation in the northern part of the Scandinavian mountain range.

More specifically the following questions were addressed:

1. What vegetation prevailed in the Stállo settlement areas prior to establishment of the settlements (Papers I-IV)?

2. What effects did human activities have on the vegetation in the settlement areas (Papers I-III)?

3. Is it possible to detect a general pattern of vegetation changes caused by people in the settlement areas (Papers II-III)?

4. What changes in vegetation (separate, synergistic or otherwise) have climate and humans caused in a long-term perspective, i.e. during the last 1500 years, in these areas (Papers I-III)?

5. What short and long term effects may human activities have had on ecosystem properties in the settlement areas (Papers I-III)?

Study area

The study area is situated in the northern part of the Scandinavian mountain range in north-western Sweden (fig. 1). The forest limit in the region is formed by *B. pubescens* ssp. *czerepanovii* (N.I. Orlova) Hämet-Ahti at ca. 640-800 m a.s.l., the variation in elevation depending on local factors such as slope and aspect. *Pinus sylvestris* L. forms forests at sites up to ca. 500 m a.s.l., and occurs as scattered trees in the *B. pubescens* ssp. *czerepanovii* forest at up to ca. 550 – 600 m a.s.l. (Chentouf and Grönvall, 1985). Although *Picea abies* (L.) Karst does not form forests in the area a few scattered trees can occur up to ca. 575 m a.s.l. and at lower elevations *Betula pubescens* Ehrh. may also be found. Above the forest limit the most common vegetation is alpine heath, characterised by *Betula nana* L. /ericaceous dwarf-shrubs or graminoids (Carlsson *et al*., 1999).

The climate is characterized as intermediate between oceanic and continental (Wielgolaski, 2001). The mean annual temperature during the period 1961 to 1990 was – 2º C at the closest meteorological station, at Mierkenis (614 m a.s.l., 66º41'N 16 º07'E) (Alexandersson, 2001). The warmest month is July and the coldest is January, with mean temperatures of 10.3º C and -13.1º C, respectively. The mean annual precipitation is 647 mm, of which 255 mm falls during the coldest months, namely November to April.

Study sites

In order to answer the questions posed above, the vegetation histories in four settlement sites at which there was archaeological evidence of human presence in historical times in the form of Stállo constructions, and three

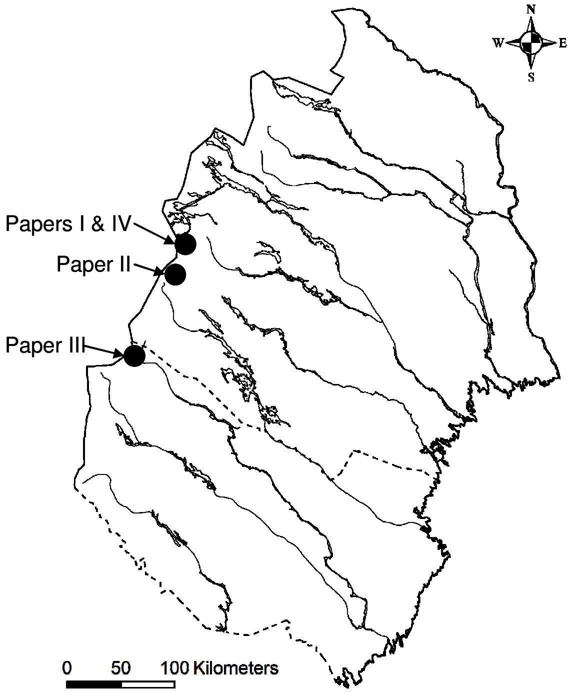


Figure 1. Map indicating the locations of the studied areas in Sweden, close to the Norwegian border.

"reference" sites were examined. The settlement site at Adamvalta (Paper I) has also previously been extensively studied, from both archaeological and ecological perspectives (e.g. Hellberg, 2004; Berglund, 2004; Liedgren *et al.*, 2007; Bergman *et al.*, 2007, 2008; DeLuca and Zackrisson, 2007). Two of the Stállo settlement sites, at Adamvalta (Paper I), Hiednikvalta (Paper II) are now situated on dry alpine heath characterized by Ericales and *B. nana*, albeit at altitudes below the current regional forest limit. Varenodjukke settlement site (Paper III) is also positioned below the regional forest limit, although the alpine heath is characterized by *B. nana* shrubs. At the Gieddeålge settlement site (Paper III) the vegetation is characterized by graminoids, *Rumex* sp. and *Pleurozium schreberi* feather mosses. Gieddeålge is located at the upper forest limit. The selected reference areas – Ajdevaratj (Paper I), Avvuhatjåhkkå (Paper II) and Vindelvagge (Paper III) – are positioned within the same region as the settlement sites, and at the same altitudinal elevation, but they are today forested with *B. pubescens* ssp. *czerepanovii* and there are no Stállo settlements indicating the historical presence of humans.

Stállo settlements

Stállo settlements are found throughout the northern part of the Scandinavian mountain range from the 65th to the 69th parallel, on alpine heaths and in the upper parts of the mountain birch forest (Kjellström, 1983; Mulk, 1994; Storli, 1994). The settlements consist of Stállo constructions (fig 2 and 3); remains of round huts consisting of a flat floor area dug slightly into the ground, with a hearth in the middle, surrounded by a low soil embankment. Each settlement often contains several constructions, commonly two or three in a row (Bergman *et al*., 2007). Radiocarbon dates indicate that the settlements were established and used between ca. 600 and 1500 AD (Kjellström, 1983; Mulk, 1994; Storli, 1994). However, Liedgren *et al*. (2007) have suggested that this timespan is too wide, due to erroneous dating, and that the main occupation period was between ca. 800 and 1050 AD.

Figure 2. Stállo construction from Adamvalta; surrounded by a low soil wall with a hearth in the middle.

The prevailing view is that the Stállo settlements were established by Sámi people using the mountain areas either for hunting (Hansen, 1990; Mulk, 1994) or reindeer herding (Storli, 1993; 1994; Bergman *et al*., 2007), although it has also been suggested that they may have been established by Vikings for hunting, trading and collecting taxes from the

Sámi population (Kjellström, 1983). The settlements are generally believed to have been used seasonally during the summer (Mulk, 1994; Storli, 1993, 1994), although this view has been recently challenged by Bergman *et al.* (2007), who suggested that the Stállo constructions may have been used during the winter.

Figure 3. A Stállo hut. The construction is made of mainly *Betula* wood. Reconstruction by Lars Liedgren, at the Silver Museum in Arjeplog.

Free- lying hearths

Other archaeological remains that are commonly found in the study areas include free- lying hearths. In contrast to the Stállo constructions, the free-lying hearths consist of fireplaces that are not surrounded by a soil embankment, and they are not connected to permanent settlement structures, but might have been used in connection with portable tents (Mulk, 1994). In the study area they have been dated mainly from the Viking age (ca. 800 to 1050 AD) up to the present, although some are of older origin (Hellberg, 2004; Lars Liedgren, pers. comm.).

Reindeer herding

Reindeer herding is an integral part of Sámi lifestyle and culture today and has been for many centuries. The timing of the emergence of the first reindeer herding societies is a matter of debate; it has been suggested that they date back to some time between 200 and 1000 AD (e.g. Aronsson, 1991; Storli, 1993; Bergman et al., 2007) or from ca. 1400-1600 AD (Hansen, 1990; Mulk, 1994; Wallerström, 2000). However, it is known from historical sources that intensive reindeer herding with small herds of domesticated reindeer was practiced in the study region at least from the 17th century up to the early 20th century (Manker, 1953; Hultblad, 1968; Djupedal, 1987; von Düben, 1989), when the common practice changed to the extensive form of reindeer herding seen today, with large herds of semi-domesticated reindeer.

Methods

The study of small-scale human impact in the tree-line ecotone is associated with several challenges that can only be addressed (currently at least) using several methods;

- *Pollen analysis* is essential for detecting trends in local vegetation changes. However, small-scale changes in the tree line are difficult to detect using this approach, due to the large contributions of non-local tree pollen to the total pollen pool.

- Differences in size between pollen from tree species of *Betula and B. nana* are used to determine whether the *Betula* pollen pool in the palynological record is dominated by tree or shrub pollen, and hence predominantly originated from forests or other ecosystems such as alpine heaths or a mire.

- Calculation of *pollen accumulation rates* (PARs) and *macrofossil analysis* are important complementary methods for detecting local tree cover. However, the PAR thresholds that should be used to distinguish between the presence and absence of trees may vary between regions and depend on tree density.

- The *use of reference areas* provides a way to evaluate potentially valid threshold PAR values to distinguish between times and areas with forested conditions in the region. Comparison of vegetation changes between the reference areas and settlement sites also makes it possible to evaluate if detected vegetation changes are likely to have been caused by human impact or climate.

- In order to assess change, it is important to have knowledge about the baseline conditions, e.g. the extent of the local forest cover prior to human-induced deforestation. In order to obtain quantitative estimates of pre-settlement forest cover of the Stállo settlement site Adamvalta, a *modelling approach* was adopted.

- Furthermore, in order to detect fires (ground fires or fires due to humans burning fuel in hearths), charred particles were analyzed.

Pollen analysis

Pollen analysis is a commonly used method to study distributional changes of past vegetation zones (Lowe and Walker, 1997). The method is based on the assumption that there is a relationship between vegetation composition and pollen loading at a site, and hence that a change in the vegetation surrounding the sample site will be reflected in the palynological record by a change in the pollen composition (Moore *et al*., 1991). However, this relationship is complicated by the fact that pollen can be transported vast distances in the atmosphere by wind. Hence, in areas with low local pollen production such as the tree-line ecotone or tundra, non-local pollen might make substantial contributions to the pollen pools (see e.g. Hicks, 2001; Jensen *et al*., 2007; von Stedingk *et al*., 2008). Von Stedingk *et al*., (2008) found that in the tree-line ecotone in the central part of the Scandinavian mountain range, ca. 60% of the total pollen consisted of background pollen, mostly from high pollen-producing tree species such as *Betula* and *Pinus*. Hence, since pollen data are traditionally presented as percentage values, this makes it difficult to detect local changes in tree abundance at or near the tree-line using pollen analysis alone (Birks and Birks, 2000; Davis, 2000; Bennett and Hicks, 2005).

Separation of pollen from tree- and dwarf-birch

Both tree (*B. pubescence* ssp. *czerepanovii*) and dwarf-shrub (*B. nana*) species of the genus *Betula* are present in the area, and changes in *Betula* tree cover could be due to either human disturbance or climate change. Thus, it is essential to be able to differentiate between the pollen from *B. pubescens* ssp. *czerepanovi* trees and *B. nana* L shrubs in the palynological record. The former defines the upper tree- and forest-limits in the area, while the latter is part of the forest floor vegetation, but is mainly found in alpine heaths and mires. Previous studies have indicated that pollen grains from these *Betula* trees and shrubs can be separated according to their size, since the tree-forming *Betula* produces larger pollen grains than *B. nana* (Eneroth, 1951; Birks, 1968; Mäkelä, 1996, 1999; Caseldine, 2001). In the studies underlying this thesis (Papers I-III) *Betula* pollen grains were divided into two size classes, and those with diameters ≥ 25 µm and < 25 µm were assumed to originate largely from *Betula* trees and *B. nana*, respectively, although glycerin was used as the mounting medium, which may affect the size of the pollen (Andersen, 1960). Hence in order to validate this approach fossil *Betula* pollen grains were mounted in silicon oil, measured and their size distributions were analysed according to the method described by Mäkelä (1996; 1999) and Mäkelä and Hyverinen (2000). Pollen grain size might be affected by the preparation method, geographical factors and hybridization (Mäkelä, 1996; Caseldine, 2001). So, to facilitate the interpretation of the fossil pollen size distributions, modern pollen from local populations of *B. pubenscens* ssp. *czerepanovii* and *B. nana* were also measured and used to generate reference data (Paper II).

Pollen accumulation rates

Pollen accumulation rates (PARs) have been suggested to provide more reliable evidence of the presence or absence of local trees than pollen percentage values, since they provide measures of absolute pollen concentrations per unit time, usually as pollen cm^{-2} $year^{-1}$ (Davis, 2000). This makes it possible to compare fossil PARs between sites, and with modern pollen loading from different vegetation zones (Hicks and Hyvärinen, 1999; Hicks, 2001). PAR limits for inferring the local presence of *Betula* and *Pinus* can be set empirically from data obtained, for instance, from modern pollen traps situated in the *Betula* and *Pinus* tree- and forest-limit ecotone (Hicks, 2001, Seppä and Hicks, 2006; Jensen *et al*., 2007). Hence, PARs have often been used in tree-line studies (e.g. Barnekow, 1999; Barnekow and Sandgren, 2001; Bjune *et al*., 2004).

Macrofossil analysis

It has been suggested that macrofossil analysis is an essential complement to pollen analysis for detecting local tree cover (Birks and Birks, 2000; Eide *et al*., 2006). Plant macrofossils such as seeds, fruits and leaves are deposited at much lower frequencies than pollen, but they can often be readily identified to a lower taxonomic level than pollen. For instance, it is readily possible to differentiate between seeds and bud scales from tree *Betula* and *B. nana* (see e.g. van Dinter and Birks, 1996). Furthermore, due to their limited dispersal from the source plant, macrofossils generally represent the local vegetation at the site (Birks, 1980).

The reference area approach

In order to distinguish between vegetation changes driven by anthropogenic influence from changes due to climatic effects, the following reference area approach was used. The vegetation histories at four settlement sites were contrasted to the vegetation histories in three forested reference areas within the same region, at the same altitude as the settlement sites but lacking documented human presence. Vegetation changes caused by human disturbance were only expected to occur at the settlement sites and to be contemporaneous with the archaeological remains. In contrast, vegetation changes driven by climate were expected to be regionally synchronous and hence occur at all sites, especially if they coincided with historically documented climate changes.

The multiple scenario approach to modelling

A fairly recently introduced method for studying vegetation dynamics is to reconstruct past vegetation composition in a quantitative manner by modelling based on pollen data, using software that has been developed for this purpose, notably POLLSCAPE (Sugita, 1994, 1998; Sugita *et al*., 1999) or HUMPOL (Middleton and Bunting, 2004, Bunting and Middleton, 2005). These software packages are based on the Prentice-Sugita model of pollen dispersal and deposition, and the relationship between pollen percentage data and distance-weighted plant abundance (Prentice, 1985, 1988; Sugita, 1993, 1994). In recent years these models have been used to explore (*inter alia*) mountain area tree-line dynamics (von Stedingk and Fyfe 2006), vegetation composition and structure characteristics related to the decline of elms (Caseldine and Fyfe, 2006), the expansion of agriculture (Fyfe, 2006) and early Neolithic landscapes (Caseldine *et al*., 2007).

The multiple scenario approach (MSA) is a simulation method that is used to create possible landscape scenarios from fossil pollen data. In the first step a large number of simulated landscapes are constructed from a set of defined rules/assumptions governing vegetation composition and the distributions of the taxa of interest, e.g. altitudinal control, soils and geological variables and/or archaeological data (cf. Bunting *et al*., 2007). Pollen loading is then calculated at a fixed location (the location of the actual pollen record) in all of the created landscapes, and compared to real pollen data for the time period of interest. Landscapes that produce simulated pollen loading patterns that closely resemble the real pollen loading patterns are deemed to be scenarios that may reflect the actual vegetation in the "historical landscape" that is to be reconstructed. To define landscapes that produce pollen assemblages that resemble observed assemblages sufficiently closely to represent possible scenarios, dissimilarity coefficients, such as squared chord distances (SCDs), can be used (Bunting *et al*., 2007).

Micro-and macro-scopic charred particles

Microscopic (25 – 100 µm) and macroscopic (> 100 µm) charred particles can provide information on the frequency, extent and dates of fires in the study area. Hörnberg *et al*. (1999) suggest that Sámi people might have used fire to modify the vegetation to provide grazing grounds for wild and domestic animals. However, charred particles may also originate from wood burning in the huts.

Outline and summary of papers

Paper I – Long-term vegetation changes in the northern Scandinavian forest limit: a human impact – climate synergy?

The aim of the first study was to compare changes in the vegetation and forest limit altitude during the last 5000 years at a currently treeless archaeological site (Adamvalta) situated below the regional forest limit and a forested reference area with similar geological features but without archaeological evidence of human presence (Ajdevaratj). The study included analyses of pollen, microscopic charcoal, pollen accumulation rates (PARs), macrofossils and organic matter contents (loss-on-ignition). The results indicated that the vegetation changed at ca. 1850 BC and ca. 1450 – 1550 AD in both areas, probably due to climate changes, and at Adamvalta at about 1150 AD. At Adamvalta, Stállo settlements were established close to the mountain birch (*Betula pubescens* ssp. *czerepanovi*) forest limit between ca. 800 to 1150 AD. At about 1150 AD, the birch forest cover at Adamvalta decreased due to human-induced deforestation, and the vegetation developed into an alpine heath. The following "Little Ice Age" in combination with the effects of human activities from the 16th century onwards prevented forest recovery, and the site still remains treeless. Such vegetation changes were not recorded at Ajdevaratj. It was deduced that the present position of the forest limit at Adamvalta reflects the effects of a combination of factors, and that previous human activities and climate have been the major forces driving long-term changes in the vegetation. Hence, a thorough knowledge of the site history is important when forest limits are used as proxy indicators of climate change.

Paper II - Vegetation development at a mountain settlement site in the Swedish Scandes during the late Holocene - palaeoecological evidence of human-induced deforestation

In order to see if the deforestation apparently caused by human activities in the Stállo settlement areas was part of a general pattern, a second study was carried out to assess the degree to which human disturbance has affected the vegetation at the Stállo settlement site of Hiednikvalta in the northern part of the Swedish Scandes. In order to separate the effects of humans and climate on the vegetation, a reference area approach was adopted, in which the vegetation history at the Hiednikvalta settlement site was compared to the vegetation history in the forest reference area Avvuhatjåhkkå, in which there are no archaeological traces of human presence during the Stállo settlement period. Pollen, microscopic charcoal, organic matter contents (loss-on-ignition, LOI), pollen accumulation rates (PARs), macrofossils and *Betula* pollen size distributions were all examined.

The results indicated that Hiednikvalta was forested with *Betula* trees prior to the Stállo settlement period, between ca. 700 and 1200 AD. Human activities resulted in a reduction in tree cover at the site, as previously found at the Stállo settlement site Adamvalta (Paper I). However, the magnitude of vegetation change, and the post-Stállo vegetation development was different in Hiednikvalta compared to Adamvalta, suggesting that site-specific factors were also important.

Paper III – A millennium of human disturbance in the northern Scandinavian mountain range: Long-lasting effects on forest lines, vegetation and ecological processes.

The third study was carried out in a Stállo settlement area further south than those examined in the previous two studies (Papers I-II). The vegetation histories at two Stállo settlement sites, Gieddeålge and Varenodjukke, and one forested “reference area” with no settlement remains in the Vindelvagge area were studied. The aim was to examine the effects of human presence on the local vegetation during the settlement phase, and to elucidate possible effects of human activities on ecological processes in both short and long term perspectives. The methods used were analyses of pollen, microscopic charcoal, pollen accumulation rates (PARs) and macroscopic charcoal.

The results indicated that the settlement site Gieddeålge was established above the forest limit and the settlement site Varenodjukke probably in the *Betula* forest. At Gieddeålge there were apparent increases in herbs and graminoids at ca. AD 1350, suggesting that the vegetation was altered due to nutrient addition, most likely related to human activities around the settlement. At Varenodjukke, the *Betula* trees in the area around the settlement were cut down and the site developed into a *B. nana*-dominated alpine heath, which still characterizes the site today. In the reference area there were no signs of vegetation changes caused by human activities. It was concluded that the current vegetation in Gieddeålge and Varenodjukke has resulted from previous human activities, which can thus potentially have both short and long term effects on the vegetation and ecosystem properties in these areas.

Paper IV - Quantitative estimation of pre-settlement forest cover using the multiple scenario approach at a Stállo settlement site in the Swedish Scandes.

In the fourth study an attempt was made to obtain quantitative estimates of the forest cover from the pollen record, at the Stállo settlement site Adamvalta (examined in the study reported in Paper I) at ca. AD 500, just before the settlements were established. The possibility that *Betula* may have been the sole major tree species in the tree-line ecotone at this time was also examined. The study method used was multiple scenario approach (MSA) modeling, with HUMPOL software. A total of 4320 different landscape scenarios were created by adding patches of forest to the modern vegetation map of the site, varying the rules regarding the patch size of forest, percentage of forest cover, forest-limit altitudinal elevation and the vegetation communities to which forest was added. Pollen loading was simulated at the sampling point used to collect actual pollen records, in each of the different landscape scenarios.

Comparisons between real and simulated pollen data, using squared chord distance (SCD) values, revealed that the proportion of *Pinus* in the mountains was most likely higher at 500 AD than today. However, the results also indicated that a similar pollen composition could have originated from different landscape scenarios, most likely due to the high potential contribution of pollen dispersed over long-distances. Hence, it was not possible to identify the most plausible landscapes in terms of *Betula* forest cover percentages and forest limit elevation.

Discussion

Were trees present during the pre-settlement period?

In order to determine the effects of human presence on the vegetation at the settlement sites it is important to establish the baseline conditions, i.e. the kind of vegetation that prevailed in the settlement areas prior to settlement, especially whether or not the settlement areas were forested. In the presented studies (Papers I-IV), it is argued that *Betula* trees were growing locally in these areas when the Stállo settlements were established.

Although it may be difficult to determine changes in the tree layer from the pollen percentage values (see above), a similar change in local ground cover vegetation appears to have occurred at all of the examined Stállo settlement sites apart from Gieddeålge following the establishment of the settlements (Paper III); an increase in *B. nana* shrubs suggesting that the site conditions had changed (see below). It is argued that this change was due to the removal of tree cover, and hence trees must have been present before it occurred. The Gieddeålge settlement was most likely established just above the forest limit (Paper III). The presence of trees is also supported by macrofossil evidence (fig. 4) and macroscopic charcoal from the hearths at Adamvalta (Paper I; Hellberg, 2004; Liedgren *et al.*, 2007), and the finding that *Betula* was used in the construction of the Stállo huts at all settlement sites, suggesting that *Betula* was locally present (Lars Liedgren, pers. comm.).

Pollen accumulation rates in forested areas

Comparisons of the estimates of *Betula* PAR obtained for the settlement sites and the reference areas also suggest that the settlement sites were forested with *Betula* stands before the settlements were established. Summaries of the pre-settlement *total Betula* (including both tree *Betula* and *B. nana*) and *Pinus* PARs obtained for the settlement sites and reference areas are presented in table 1 and figure 4. Tree *Betula* pollen appears to have made high contributions to the total *Betula* PARs during the pre-settlement period (table 1). For details of sampling and sample preparation see Papers I-III. It should be noted that he reliability of the PAR data from the Vindelvágge reference area is negatively affected by the few dates available. No PAR data are available from the settlement site Varenodjukke due to dating problems (Paper III).

Table 1. *Summary of pre-settlement (prior to 600 AD) pollen accumulation rates (PAR).*

Site	**Time AD/BC**	**Tot. *Betula* pollen cm^{-2} year^{-1}**	**Estimated % Tree *Betula** of total PAR**	**Pinus pollen cm^{-2} year^{-1}**
Adamvalta SS (Paper I)	AD 100 – 2200 BC	40 – 250	> 85 %	100-230
Ajdevaratj Ref (Paper I)	AD 520 – 2000 BC	85 - 900	> 85 %	90-380
Hiednikvalta SS (Paper II)	AD 400 - 1500 BC	205 – 1010	> 80 %	130 – 700
Avvuhatjåhkkå Ref (Paper II)	AD 600- 1700 BC	160 – 720	> 70 %	70 – 210
Gieddeålge SS (Paper III)	AD 300- 1700 BC	5		5 – 10
Vindelvagge Ref (Paper III)	AD 200 - 2700 BC	200 – 1400	> 50 %	60 – 320

* Based on ratio of pollen ≥25/<25 microns for all sites except the Hiednikvalta settlement site and the Avvuhatjåhkkå reference area (Paper II) where proportions are based on estimations from *Betula* stat.

The *Betula* PAR from Hiednikvalta, Avvuhatjåhkkå and Vindelkroken reference area suggest that *Betula* forest during the pre-settlement period was characterized by a minimum PAR of ca. 150-200 tree *Betula* pollen cm^{-2} year^{-1} (paper II-III). The total *Betula* PARs from Adamvalta and the nearby reference area Ajdeveratj from ca. 100 to 500 AD were very low, ca. 40 to 100 *Betula* pollen cm^{-2} year^{-1} (fig. 4) (Paper I). However,

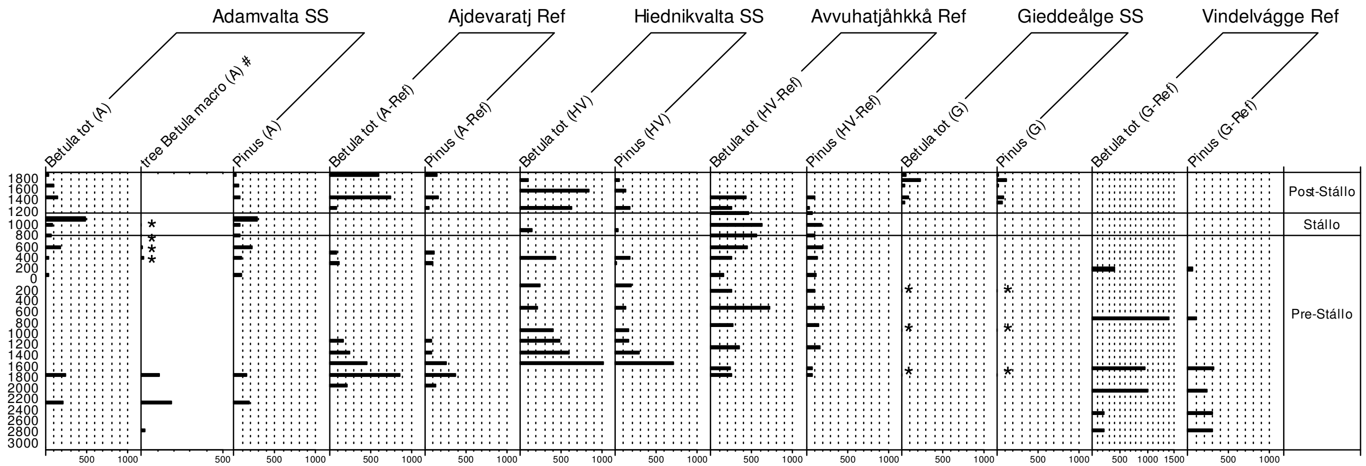


Figure 4. Fig 3. Total *Betula* (tree and *B. nana*) and *Pinus* pollen accumulation rates (PAR) as pollen cm^{-2} $year^{-1}$ for the Stállo settlement sites (SS) and reference areas (Ref). # tree *Betula* macrofossils from Adamvalta, per 100 ml peat. *macrofossils too few or PAR too low to be readily visible in the diagram.

the presence of trees in the Adamvalta locality is supported by findings of tree *Betula* macrofossils.

The estimates of PAR obtained for both the Stállo settlement sites and reference areas in the studies this thesis is based upon (Papers I-III) are low compared to measured rates of modern pollen loading in the *Betula* forest limit ecotone of northern Scandinavia. Based on 13- to 18-year average pollen trap data from the tree-and forest limit ecotone in Finland, Hicks (2001) suggest that that a typical PAR for *Betula* forest is ca. 1000 tree *Betula* pollen cm^{-2} $year^{-1}$, and Seppä and Hicks (2006) suggest that the presence/absence threshold for such forest should be ca. 350 to 500 tree *Betula* pollen cm^{-2} $year^{-1}$. However these data were obtained from an area with a relatively flat landscape that is part of a vast region covered in *Betula* trees. Hence, the background component of tree *Betula* pollen is most likely larger than in the current study area in north-western Sweden where the *Betula* forest is fragmented by tree-less mountains.

Jensen *et al*. (2007) suggests that the modern *Betula* forest-limit ecotone in the mountain areas of northern Norway is characterised by a PAR of ca. 2000 tree *Betula* pollen cm^{-2} $year^{-1}$, based on 8 years of measurements, while open *Betula* woodland at the coast in northern Norway is characterised by ca. 80 – 350 tree *Betula* pollen cm^{-2} $year^{-1}$. This difference in *Betula* PAR between the inland mountain ecotone and the coast may be due to the regional component of *Betula* trees being higher in the inland mountain areas, and the *Betula* tree cover being lower by the coast.

The cited studies in Finland and Norway show that it is important to consider the regional pollen component when attempting to determine PAR threshold values that accurately reflect the local abundance, or absence, of *Betula* trees (Hicks, 2001; Seppä and Hicks, 2006; Jensen *et al*., 2007). Hence, the relatively low *Betula* PARs found in the studies underlying this thesis (Papers I-III) in areas suggested to be covered in trees may be due to a lower regional *Betula* component compared to northern Finland and the mountain areas in Norway in the western part of the Scandinavian mountain range. It is also possible that the studied sites were characterized by open forests and hence tree cover densities were low during the pre-settlement period (Papers I-III).

There are no *Pinus* trees today, at either the settlement sites or reference areas. Instead, *Pinus* forests are generally found at lower altitudes, below ca. 600 m a.s.l. Although it is possible that scattered *Pinus* trees were present, interspersed within the *Betula* forest, *Pinus* was not the main tree- and forest-limit forming species in the area when the settlements were established (Papers I-III).

Pollen trap experiments

To investigate the current pollen loading in the study region, Tauber pollen traps (Tauber, 1974) were placed at ground level at the sampling mire in the open Stállo settlement site Hiednikvalta (66°46'430"N, 15°58'931"E) and the forested reference areas Ajdevaratj (66º57'529"N, 16º26'019"E) and Avvuhatjåhkkå (66°41'574"N, 16°05'406"E). To avoid trapping small animals, the openings of the pollen traps (5 cm diameter) were covered with a mesh. The trapping period was from September to September. After collecting the pollen traps from the sampling sites, in the lab five *Lycopodium clavatum* tablets were added to each trap to enable pollen concentrations to be calculated (Stockmarr, 1971). Each sample was filtered through a paper filter that was then subjected to acetolysis (Moore *et al*. 1991) to retain the pollen. *Betula* pollen grains were separated according to size, and *Betula* pollen grains < 25 microns and ≥ 25 microns were assumed to be mainly *B. nana* and tree-*Betula* pollen, respectively. A minimum of 300 pollen and 300 *Lycopodium* spores were counted from each trap.

The average pollen loading estimates obtained from data acquired in three measurement years for Ajdevaratj (2004 to 2007) and two measurement years for all other sites (2005 to 2007), are presented in figure 5. The two- or three-year average pollen loading rates amounted to 1050-1300 tree *Betula* cm^{-2} $year^{-1}$ at all sites, although the local tree cover in Hiednikvalta is much lower than in the reference areas. The data series is too short for useful comparisons to the fossil PARs from the region. However, the data confirm that the regional tree *Betula* component in the region is substantial, and hence an important factor to consider when attempting to establish threshold values for tree density (Hicks, 2001; Seppä and Hicks, 2006; Jensen *et al*., 2007).

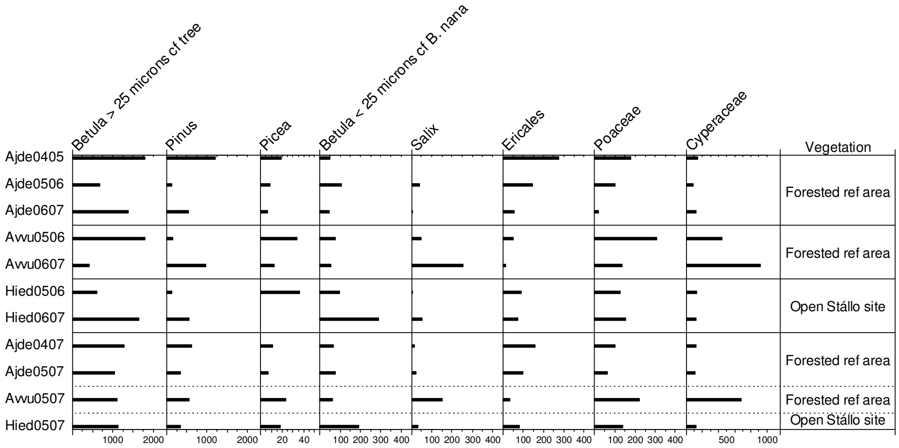


Figure 5. Average pollen loading in the pollen traps from the Ajdevaratj reference area (3-year average, 2004-2007; 2-year average, 2005-2007); Avvuhtjåhkkå reference area (2-year average, 2005-2007) and Hiednikvalta Stállo settlement site (2-year average, 2005-2007). Note that the scale differs between pollen types.

IV). It was estimated that between 10% and 90% of the areas within ca. 10 km of the Adamvalta sampling point that are currently characterized by dry/fresh heath or meadow and situated below ca. 705 – 765 m a.s.l. may have been covered in forest. It is suggested that an important factor hindering the acquisition of more precise estimates of forest cover is the large contribution of tree pollen dispersed over long distances to the total pollen loading at the site. The main tree genus in the forest limit ecotone at Adamvalta was *Betula*. However, the results also indicate that more *Pinus* trees were present in the landscape at 500 AD than today, and that *Pinus* trees might have prevailed locally at Adamvalta at that time.

Human impact on vegetation in the Stállo settlement areas during the last ca. 1500 years – general patterns

The human settlers during the Stállo period affected the vegetation in the settlement areas in two ways: through deforestation at Adamvalta (Paper I), Hiednikvalta (Paper II) and probably Varenodjukke (Paper III); and through nutrient addition at the site Gieddeålge, situated above the forest limit (Paper III). A summary of the vegetation changes is shown in table 2.

The studies reported in Papers I-III revealed that the most pronounced effect of the human activities at the Stállo settlement sites was on the tree layer (tab 2); *Betula* trees were used for firewood in the hearths (Hellberg

Table 2. *Inferred vegetation changes during the Stállo settlement period. Italics indicate Stállo settlement sites. Ref=Reference areas.*

Site	Time	Type of change	Cause
Adamvalta (A)	ca. 1150 AD	Decrease in tree *Betula* – increases in *B. nana, Salix*	Human induced deforestation
Ajdevaratj (A-Ref)	No vegetation change		
Hiednikvalta (H)	ca. 900 – 1300 AD	Decrease in tree *Betula* – increase in *B. nana*	Human induced deforestation
Avvuhatjåhkkå (H-Ref)	ca. 800 – 1000 AD	Increase in *B. nana* on the mire	Mire development
Varenodjukke (V)	Before 1450 AD	Decrease in tree *Betula*	Human induced deforestation
Gieddeålge (G)	ca. 1350 AD	Increases in herbs and graminoids.	Nutrient addition due to human impact
Vindelkroken Reference area (V- , G- Ref)	No vegetation change		

2004, Liedgren *et al*., 2007) and as building material for the Stállo huts (Lars Liedgren, pers. comm.). It is also likely that *Betula* twigs were used as bedding material in the Stállo huts (Ingela Bergman, pers. comm.). This exploitation of *Betula* trees resulted in reductions in tree cover at the sites, although scattered trees probably remained. The clearances caused a rather subtle change in the percentage tree pollen composition, presumably due to the relatively open character of the landscape, and hence large contribution of non-local tree pollen to the pollen assemblage (see Schofield *et al*., 2007).

Domesticated or semi-domesticated animal herding at the settlement sites

It has previously been suggested that one reason for the establishment of Stállo settlements might have been for the Sámi population to exploit the previously unused ecological niche in the tree-line ecotone as grazing grounds for semi-domesticated reindeer (Storli, 1993, 1994; Bergman *et al*., 2007). At the settlement sites Adamvalta (Paper I) and Hiednikvalta (Paper II) there are no indications in the pollen record of a vegetation change that can be solely related to animal herding. However, this cannot be interpreted as unambiguous evidence for the absence of grazing and trampling by animals, e.g. semi-domesticated reindeer, at these sites.

Generally, summer grazing and trampling by domesticated or semi-domesticated animals is indicated by increases in graminoid species and herbs like *Rumex acetosa/acetosella* that benefit from the disturbance caused by trampling and the fertilization effects of animal feces and urine (Aronsson, 1994; Räsänen, 2001; Olofsson *et al*., 2001). However, the presence of reindeer, or other domesticated animals, is only detectable in the palynological record if their impact on the vegetation is sufficient to cause substantial changes to the vegetation. If the animals are present at a low density, such an effect on the vegetation is only likely to occur if they are gathered together on unfrozen ground e.g. in a reindeer pen (Aronsson, 1991). In order to detect such an impact the sampling site probably has to be close to the activity area, like in Giedddeålge (Paper III).

Furthermore, if these areas were used as grazing grounds outside of the plant growing season, the effect of grazing may instead have been to decrease the graminoid abundance since the nutrient additions originating from animal waste products would have occurred at a time when the plants could not benefit from them through increased growth (Grellmann, 2002; Stark and Grellmann, 2002). Although feces and urine are deposited also during the winter, they would have been diluted in the spring flush (Stark and Grellmann, 2002). Since graminoids are preferred for grazing, this might favor Ericales and *B. nana* dwarf shrubs. Due to the low pollen productivity of Ericales shrubs in alpine areas (von Stedingk *et al*., 2008), this might be difficult to detect in the pollen record, especially since the impact was probably low and the change subtle. The main reindeer winter food, lichens such as *Cladina* spp., leaves no trace in the palynological record, so changes in lichen abundance cannot be used to detect the presence of reindeer at the sites (see Hicks, 1985).

In Gieddeålge (Paper III) the detected increases in graminoids and *Rumex acetosa/acetosella* that occurred at ca. 1350 AD could be interpreted as effects of grazing and trampling. However, as pointed out by Räsänen (2001), it can be difficult to separate the effects on vegetation due to the aggregation of domesticated animals from the fertilization effects due to other activities related to a settlement. It is interesting to note that these vegetation changes in Gieddeålge appear to have occurred later than the settlement phases in Adamvalta and Hiednikvalta, where the construction dates are clustered in the period ca. 800 to 1050 AD (Liedgren *et al*., 2007; Ingela Bergman pers. comm.). The constructions in Gieddeålge have not been dated. However, provided that the dating of the vegetation change in Gieddeålge is correct this suggests two possible scenarios. Firstly, the Stállo settlement in Gieddeålge may have been used for a prolonged period but the initial occupation phase did not cause changes to the vegetation that are detectable in the palynological record, and the vegetation change may indicate a change in subsistence strategy. Alternatively, the Stállo settlement in Gieddeålge may have been established considerably later than the settlements at Adamvalta and Hiednikvalta, and the vegetation change may indicate the initial occupation phase. Large proportions of graminoid and herb pollen were found in the pollen records at Gieddeålge, even for times after the presumed abandonment of the settlement, suggesting that the site was utilized as grazing grounds for a prolonged period of time, by either domesticated or wild animals (Paper III).

Post-Stállo settlement period

The Stállo settlements at Adamvalta and Hiednikvalta were abandoned in around the 13th to 14th century, possibly due to a change in the community structure of the Sámi society (Bergman *et al*., 2008). However, there is extensive evidence of human presence in the mountain areas during the post-Stállo period, e.g. free-lying hearths. At Adamvalta most of these hearths have been dated from 1500 AD to the present time, although some are older (Hellberg, 2004) and in the Hiednikvalta area the datings range from the Viking age (800 – 1050 AD) up to the present time (Lars Liedgren, pers. comm.).

Despite the archaeological and historical evidence of firewood exploitation and reindeer herding during the Post-Stállo period (Hellberg, 2004; Manker, 1953; Hultblad, 1968; Djupedal, 1987; von Düben, 1989), these activities are not reflected in the pollen record from Adamvalta during the post-Stállo period (Paper I). In Hiednikvalta, however, the increase in graminoids at the site that apparently occurred at ca. 1600 AD could reflect a vegetation response to increased nutrient addition due to grazing by semi-domesticated reindeer, although a natural explanation cannot be excluded (Paper II).

Long-term effects of human presence and climatic changes

It is deduced that climate has not been the sole primary driving force causing vegetation change in the Stállo settlement areas during the last

1500 years. The decrease in tree cover that occurred during the settlement period was confined to the settlement areas and was contemporaneous with the available radiocarbon dates of the Stállo constructions. These findings suggest that human activities were largely responsible for this vegetation change. Although contemporaneous vegetation changes occurred in the Avvuhatjåhkkå reference area (Table 2; Paper II), it is argued that they were due to mire development following a succession that had already started by ca. 1000 BC (Paper II), rather than to adverse changes in the regional climate. However, although climate has not been the primary cause, it might have reinforced the long-term effects of human activities.

Synergistic effects of human activities and climate

The mountain birch forest is adapted to recurrent disturbances, such as defoliation by the autumnal moth (*Epirrita autumnata*) and snow breakages (Kullman, 1981). If the damage is severe the trees usually respond by producing basal shots (Karlsson *et al*., 2004). Cutting trees also results in basal shoot production. However, the disturbance caused by cutting differs substantially from natural disturbances since entire trees are removed. Physical removal of the large trees, especially if a large proportion of the tree population is cut, changes the site conditions and affects the microclimate. Removal of the tree cover increases the site's exposure to wind, making the snow cover during winter less stable (Holtmeier and Broll, 2005, Vajda *et al*., 2006). This can be detrimental for mountain birch seedlings since reductions in snow cover reduce the winter soil temperatures, which may induce root injuries with adverse consequences for nutrient acquisition in the summer, growth and hence seedling survival (Weih and Karlsson, 2002). Moreover, the tree canopy has important feedback effects on the microclimate that tend to promote seedling performance since it may function as a solar energy trap during snowmelt, promoting earlier snowmelt in the forest than on alpine heaths and hence prolonging the vegetation season (Molau, 2003). In addition, during summer the seedlings in open areas are more prone to water stress than those in the forest due to the combined effects of increased radiation and wind. This has been found to be one of the main causes of summer mortality among *Betula* seedlings (Kullman, 1986). Hence, removal of the tree canopy, possibly in combination with grazing and trampling by domesticated or semi-domesticated animals, can have negative effects on seedling survival.

It is possible that trees managed to reestablish after being cut down during periods of favorable summer temperatures, such as the medieval warming period, from ca. 800 to 1200 AD (Briffa *et al.*, 1992; Korhola *et al.*, 2000; Gunnarsson and Linderholm, 2002; Grudd *et al.*, 2002; Moberg *et al.*, 2005; Osborn and Briffa, 2006). However, during periods of colder climate the positive feedback effects provided by the tree cover may be critical for seedling survival (Bekker, 2005). Hence, a climatic threshold may have been crossed during the Little Ice Age (LIA) from ca. 1350 to 1850 AD (Karlén, 1976; Campbell and McAndrews, 1993; Korhola *et al.*, 2000; Gunnarsson and Linderholm, 2002; Moberg *et al.*, 2005; Osborn and Briffa, 2006), during which re-establishment of trees was hampered.

Hence, the synergistic effects of changes in site conditions after removal of a large proportion of the *Betula* trees during the Stállo settlement period and the following period of colder climate during the LIA may have prevented reestablishment of mountain birch forest at the studied Stállo settlement sites. Scattered trees probably remained, at least at Adamvalta, where charcoal from free-laying hearths indicate that *Betula* trees were also used for firewood during subsequent periods (Paper I; Hellberg, 2004). This continuous utilization may have further hampered forest regeneration. At Hiednikvalta, the trees did not manage to reestablish in the flat area by the settlements due to the changed site conditions (Paper II). However, trees most likely reestablished on the surrounding slopes where their capacity to cope with the changes may have been greater due to a more favourable microclimate on the south- and west-facing slopes, and a higher availability of nutrients .

Synergistic effects between disturbance and climate have also been suggested to have affected forest structure and regeneration patterns in other areas. For instance, at a site in subarctic Canada the synergistic effects of fire and climate appear to have changed the black spruce (*Picea mariana* [Mill.] BSP) forest structure during the 16th century (Arseneault and Payette, 1997). Although a climatic threshold was suggested to have been passed during the early LIA, the sub-arctic black spruce forest maintained its structure through vegetative regeneration up to 1567-1568 AD, when a stand fire led to a change in site conditions, which in combination with the cold climate hindered successful post-fire regeneration. Similarly, the synergistic effects of human activities and climate may have hampered reestablishment of *Betula* forest in northern Finland (Kallio *et al*., 1983).

Possible effects on nutrient dynamics

It is suggested that the long-term absence of trees at the Stállo settlement sites might have changed the ecosystem properties of these areas since, in addition to differences in snow conditions and microclimate (Kullman, 1986; Holtmeier and Broll, 2005; Vajda *et al*., 2006), forested and alpine heath ecosystems differ in terms of nutrient dynamics. Generally sub-arctic forest and tundra ecosystems are considered to be nitrogen limited (Chapin and Shaver, 1986, 1996; Sveinbjörnsson *et al*., 1996). The symbiosis between nitrogen fixing cyanobacteria (*Nostoc, Stigonema, and Calothrix spp.)* and the feather mosses *Pleurozium schreberi* and *Hylocomium splendens* represent an important source of nitrogen in these alpine, artic tundra ecosystems (DeLuca *et al*., 2002; DeLuca and Zackrisson, 2007). The site conditions created by the removal of the tree cover may have had a negative impact on the abundance of the mosses, thereby decreasing nitrogen inputs to the system and adversely affecting the *Betula* seedlings, which require an adequate nitrogen supply for their growth and winter survival (Weih and Karlsson, 1999). Available phosphorous levels also tend to be lower in dry, alpine ericaceous heaths than in mountain birch forests (Berglund, 2004; Soudzilovskaia and Onipchenko, 2005), partly at least because *Betula* trees can act as ‘nutrient pumps’, drawing phosphorous into surface soils from deeper layers through their roots (Berglund, 2004). Hence, a transition from forest to alpine heath may shift the ecosystem from being primarily nitrogen limited to a limitation in both nitrogen and phosphorous.

Hence, the long term absence of tree-cover in Stallo settlement areas may have led to ecosystem degeneration by changing both the microclimate and nutrient dynamics, especially on coarse, sandy soils such as those at Adamvalta. This may have hindered the reestablishment of trees in these areas and had a long-lasting legacy on the landscape (see Foster, 2003; Briggs *et al*., 2006) that may be more widespread than previously thought since Stállo settlements are found on similar terrain throughout a large part of the Scandinavian mountain range. If so, the long-term degeneration may have made the ecosystems where Stállo settlements are found less suitable for studies of natural ecosystems responses’ to climate change.

It has been suggested that *Juniperus communis* L. could be a key organism contributing to the recovery of these degenerated ecosystems (DeLuca and Zackrisson, 2007), since soils beneath *J. communis* plants have been found to be enriched in phosphorus compared to surrounding tundra, and appear to provide safe sites for nitrogen-fixing feather moss communities. The cited authors found feather moss cover to be more than 10-fold higher under *J. communis* plants than in open tundra (60% versus <5%). The presence of *J. communis* in open tundra may hence facilitate the return of *Betula* by providing fertile islands within the tundra and protecting small saplings from browsing reindeer. However, it is not known how long time such as process may take.

Methodological considerations

In the studies described in Papers I-IV several methods and approaches were used to elucidate the vegetation history in the Stállo settlement areas; including pollen analysis, separation of pollen from tree *Betula* and *B. nana* and PAR determinations (Papers I-III); macrofossil analysis (Papers I-II); analysis of macroscopic charcoal (Paper III); use of reference areas (Papers I-III) and pollen modelling (Paper IV).

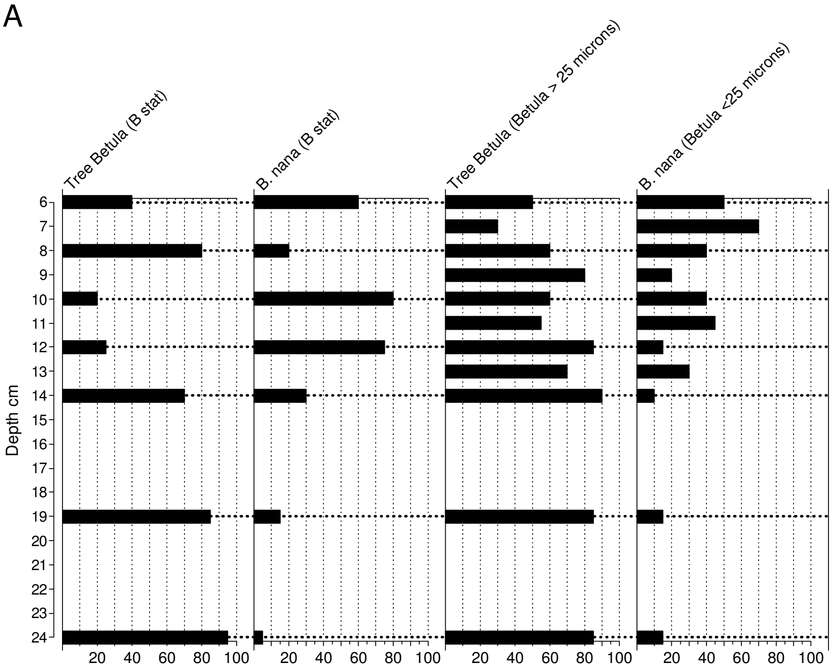
Pollen analysis is valuable for detecting changes in local ground cover vegetation. However, it may be difficult to infer local tree cover from such analysis due to the large contribution to the total pollen assemblage of non-local tree pollen from the high pollen-producing species *Betula* and *Pinus* (see discussion above). This also affected the outcome of the modelling exercise, since it proved to be difficult to separate vegetation scenarios in which 10% of the dry and fresh heath was covered by forest, from scenarios in which the forest cover was 90% (Paper IV).

Increases in pollen from indicator species that benefit from the disturbance and fertilization caused by human activities (i.e. graminoids and herbs) are often used to identify periods of human impact in the palynological record (Behre, 1981; Hicks, 1993; Aronsson, 1994; Räsänen, 2001; Schofield *et al*., 2007). The graminoid and herb pollen composition did not change significantly during the Stállo settlement period at any of the sites addressed in Papers I-III except Gieddeålge (paper III). However, the effect on the ground cover vegetation of people largely living as hunter-gatherers in these areas is likely to have been subtle. Furthermore, in contrast to other agricultural settlements in marginal ecosystems, such as Norse settlements in Greenland (see for example Schofield *et al*., 2007), no exotic species were introduced. Although the indicator species generally benefit from human impact, they also occur naturally in the mountains in more nutrient-rich and/or disturbed habitats. Hence, it may be difficult to separate the effect of human activities from the effect of natural sources of nutrients (see e.g. Varenodjukke, Paper III).

To separate pollen from tree *Betula* and *B. nana*, a “pragmatic” approach was adopted in which the *Betula* pollen grains were divided into two size classes: ≥ 25 microns (tree *Betula*) and < 25 microns (*B. nana*) (Papers I-III). Such an approach is approximate, but nevertheless is believed to indicate changes in the relative proportions of the *Betula* species. To validate this approach modern tree *Betula* and *B. nana* pollen from the study area were collected and the sizes of the grains were measured (Paper II). The mean pollen diameter was 25.94 (StD 0.69) µm for modern tree *Betula*, and 21.72 (StD 0.74) µm for *B. nana*. The data support the division into the two size classes, although suggest that 24 µm would have been more appropriate to separate tree *Betula* and *B. nana*. However, the modern *Betula* pollen was mounted in silicon, whereas the pollen samples for the traditional pollen analysis were mounted in glycerin (Paper II), which may cause swelling of the pollen grains (Anderson, 1960), and thus lead to an overestimation of the proportion of tree *Betula* in the pollen samples. Therefore, fossil *Betula* pollen collected from the Hiednikvalta and Avvuhatjåhkkå sites was mounted in silicon oil, measured, and the size distributions of the grains were analyzed statistically according to Bhattacarya (1967) using the method described by Mäkelä (1996, 1998, 1999) and Mäkelä and Hyvärinen (Paper II). Comparison between the estimated proportion of tree *Betula* and *B. nana* for Hiednikvalta and Avvuhatjåhkkå, using the statistical method and the division into two size classes reveals that the trends are similar (fig 6). However, in Hiednikvalta the proportion of tree *Betula* is overestimated at 10 and 12 cm when the pollen are mounted in glycerin and divided into two size classes.
This discrepancy between the methods is most likely due to swelling caused by the mounting medium glycerin and it is therefore suggested that silicon oil should be used as mounting medium when pollen size is important (see e.g. Andersen, 1960; Birks, 1968; Mäkelä, 1996, 1999; Caseldine, 2001).

Figure 6. Comparison of estimated proportions of tree *Betula* and *B. nana* pollen at Hiednikvalta (A) and Avvuhatjåhhkå (B), using the *Betula* size statistic method described in Paper II (pollen mounted in silicon oil), or > 25 and < 25 microns thresholds to delimit tree *Betula* and *B. nana* pollen, respectively, (mounted in glycerin). →

A


Tree Betula (B stat)
B. nana (B stat)
Tree Betula (Betula > 25 microns)
B. nana (Betula <25 microns)
Depth cm
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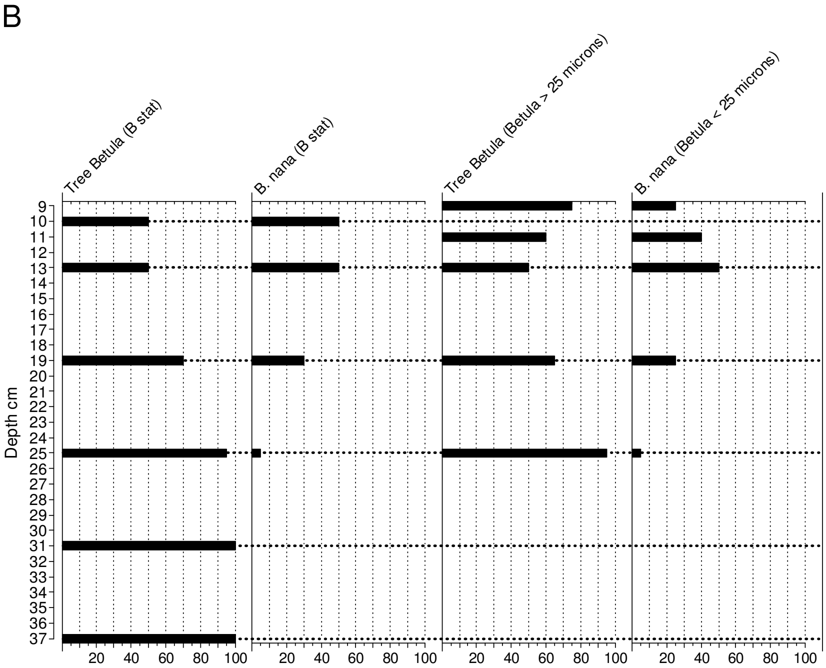
20 40 60 80 100

B


Tree Betula (B stat)
B. nana (B stat)
Tree Betula (Betula > 25 microns)
B. nana (Betula < 25 microns)
Depth cm
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13
14
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37
20 40 60 80 100

PARs can be used to infer local tree cover, but the PAR is dependent on the peat growth rate, which is estimated from calibrated ^{14}C-dates (Papers I-III). Thus, uncertainties associated with the dating and calibration to calendar years, in combination with the relatively few dates for each stratigraphy and the inherent uncertainties in the age-depth modelling lead to imprecision in the age estimates for the individual samples (Telford *et al*., 2004). Furthermore, the net rate of peat growth may vary irregularly and abruptly in peat sequences due to factors such as differences in rates of decomposition. Thus, there may be substantial differences between estimated and true peat growth rates (Hicks and Hyvärinen, 1999), which will inevitably affect the reliability of PAR estimates.

Macrofossil analysis has been proposed as an essential complementary method to pollen analysis (Birks and Birks, 2000; Eide *et al*., 2006). Unfortunately, however, very few macrofossils were found, presumably due catchment characteristics and poor preservation conditions (Papers I-II).

The use of reference areas can provide important information that can help to differentiate between vegetation changes caused by local human impact or regional climate change. Reference areas are also valuable for evaluating PAR threshold values to delimit local forests. However, the approach is complicated by several factors linked to the problem of finding two or more similar sites with suitable palynological records. The vegetation at each site may differ in robustness or sensitivity to disturbances (human, climatic or other), depending on site-specific factors such as soils, slope and aspect (Holtmeier and Broll, 2005), and vegetation history (Papers I-III), as well as species composition. The basin size differed between the Stállo sites and reference areas in Papers I and II. This will affect the relevant source area of pollen (RSAP), which is essentially the spatial scale within which local vegetation changes are visible in the palynological record (Jacobson and Bradshaw, 1981; Prentice, 1985; Calcote, 1995). However, the RSAP may also change over time due to changes in vegetation openness and structure (Bunting *et al*., 2004; Broström *et al*., 2005). A further complicating factor is differences in the vegetation between the settlement sites and reference areas. Especially the abundance of *B. nana* on the relatively large mires in the reference areas could diminish the pollen signal produced by an increased abundance of *B. nana* in the surrounding areas (Paper I).

Conclusions

It is concluded that *Betula* trees were present at the Stállo settlement sites when the settlements were established, although it is not possible to deduce the density of tree cover. The establishment of the Stállo settlements was accompanied by a reduction in *Betula* tree cover at the sites, since *Betula* trees were used for Stállo hut construction and firewood. It is difficult to detect any effect of the human presence on the ground cover vegetation, apart for an increase in *B. nana* shrubs, except at Gieddeålge where nutrient addition caused by activities at the settlement site, possibly due to domesticated animals, resulted in increases in graminoids and herbs.

Human activities have made major contributions to local vegetation changes in these areas during the last 1500 years. However, these areas are probably still treeless today because of synergistic effects of human activities and climatic changes. The deforestation during the Stállo settlement period was followed by a period of colder climate during the little ice age (ca. 1350 – 1850 AD), that together with continuing effects of human presence prevented reforestation of these areas. This long term absence of trees may have changed the ecosystem properties, hampering reestablishment of trees in these areas.

This thesis demonstrates that historical human impact in the northern part of the Scandinavian mountain range can have a substantial effect on the local vegetation, which is still visible in the landscape today, several centuries after the settlements were abandoned. This long-term legacy in the landscape suggests that these areas are not "pristine" ecosystems, and has profound implications for our understanding of the responses of the tree- and forest-limits in these areas to climate change.'

The thesis also shows the potential of integrated research for studying complex interactions between the effects of human activities and climate on ecosystems and their resilience. For example, the detected changes in vegetation patterns and forest cover can only be interpreted in the light of careful archaeological surveys and dated evidence of human presence such as the Stállo constructions.

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