Pristine Forest Landscapes as Ecological References

Human Land use and Ecosystem Change in Boreal Fennoscandia

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Cover: Old Scots pine tree with a bark-peeling scar. Photo taken in the northern part of Tjeggelvas nature reserve.
(photo: Torbjörn Josefsson)

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Abstract

Northern boreal forests that display no signs of forestry or agriculture in the past are often regarded as intact, pristine forests. Yet, humans have inhabited these environments for millennia and developed a variety of economic strategies for their subsistence. Generally, these forms of land use have been regarded as minor disturbances, and have thus frequently been neglected in ecological studies. Despite the increased recognition of the importance of past land use in other forest landscapes, the land use effects in northerly remote forests remain unclear.

In this thesis the influence of human land use on forest structure, composition and biodiversity (dead wood and wood-inhabiting fungi) during the last 1 000 years was studied in three Scots pine forests in northern Sweden. For this purpose I used an interdisciplinary approach, combining field studies on present forest characteristics with long-term records such as archaeological remains and biological archives, and short-term records such as historical documents.

My results show that long-term, low-intensity land use can substantially influence forest structure and composition and that land use legacies can reverberate through the ecosystem for many centuries. This implies that forests in remote and inaccessible areas with no recent management cannot be indiscriminately used to represent 'pristine' reference conditions. The results also show that to understand the overall magnitude and complexity of the relationship between humans and the land, all forms of human activities that may have occurred within the studied space should be considered. Furthermore, different patterns and gradients of past land use; varying in space, time and intensity across landscapes, create 'layers' of land use. The result is a matrix in which some areas have been heavily used for extensive periods of time whereas other parts may have practically escaped human exploitation.

To detect and interpret anthropogenic disturbance in northern forest ecosystems a clear strategy for choosing relevant methods and applying them in the right order should be adopted. Then, possibly pristine forests can be evaluated as reference areas for addressing scientific research questions and conservation management.

Keywords: forest history, interdisciplinary research, indigenous people, Sami, disturbance, dead wood, wood-inhabiting fungi, reference areas, conservation

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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 Josefsson, T., Hörnberg, G. & Östlund, L. (2009). Long-term human impact and vegetation changes in a boreal forest reserve: implications for the use of protected areas as ecological references. *Ecosystems* 12(6):1017-1036.

II Josefsson, T., Östlund, L., Gunnarson, B., Bergman, I. & Liedgren, L. Historical human influence on forest composition and structure in boreal Fennoscandia: indigenous peoples' land-use legacies in protected forest landscapes (Submitted manuscript).

III Josefsson, T., Bergman, I. & Östlund, L. (2009). Quantifying Saami Settlement and Movement Patterns in Northern Sweden, 1700–1900. Accepted for publication in *Arctic* (In press).

IV Josefsson, T., Olsson, J. & Östlund, L. Linking forest history and conservation efforts: effects of logging on forest structure and diversity of wood-inhabiting fungi (Submitted manuscript).

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1 Introduction

What is a pristine forest landscape? To most people the concept 'pristine forest' evokes an image of wilderness – an untouched environment devoid of human imprints, for example the impressive forest of the Pacific Northwest with colossal trees and deep layers of foliage, or the barren forests of the northernmost Taiga with very old and rugged trees scattered over vast, roadless landscapes. Highly valued by the general public and nature conservation authorities for their "unspoiled" appearance and richness in plants and wildlife, such forests were among the first types of ecosystems to be preserved in National Parks and nature reserves in North America and northern Europe (Steen, 1992; Peterken, 1996; Lundholm, 2008), and as Zapovedniks in western Russia (Shtil'mark, 2003). The idea of pristine forest as undamaged nature runs deep in society as well as in the scientific community (Pollan, 1991; Cronon, 1995; Povilitis, 2002), and is far from new (Thoreau, 1854). In recent times, deforestation, forest fragmentation and transformation of forests (Bryant *et al.*, 1997; Aksenov *et al.*, 1999; Potapov *et al.*, 2008) have heavily reduced the extent of remaining "pristine" forests, providing an important reason why people strongly care about them. However, another reason that is just as important is their supposedly natural appearance. Since many people today are distanced from nature, forests considered as pristine are often believed to resemble the natural environment in a near-ideal state, as it was before human interference.

To ecologists and foresters interested in the functions, structure and composition of forest ecosystems, pristine forests often represent a natural state and have long been studied in Europe (Schenck, 1924; Jones, 1945; Peterken & Jones, 1987; Linder *et al.*, 1997), Russia (Iwaschkewitsch, 1929; Bobkova *et al.*, 2007; Shorohova *et al.*, 2009) and North America (Cline & Spurr, 1942; Lorimer, 1980; Runkle, 1982). Traditionally, this research has focused on structural components, ecosystem dynamics and processes within these forests, and much of what we know about them has been obtained from such descriptive studies. However, the study of forests believed to be pristine has also become a fundamental component of comparative studies of the effects of anthropogenic disturbance on forest structure, composition and biodiversity for various applications. Notably, they have been widely used as models for near-natural management in forestry (Angelstam & Majewski, 1996; Çolak *et al.*, 2003; Frelich *et al.*, 2005; Kuuluvainen, 2009) and for obtaining ecological baselines for biodiversity (Lesica *et al.*, 1991; Dettki & Esseen, 1998; Willis *et al.*, 2005; Junninen *et al.*, 2006).

By its very nature, the study of 'seemingly pristine' forest ecosystems also incorporates a historical dimension, and the roles of both natural and anthropogenic events in the past in shaping the environment have become increasingly apparent to ecologists. As pointed out by various authors, for example Foster *et al.* (2003) and Rhemtulla and Mladenoff (2007), the legacy of past land use may reverberate through ecosystems for many centuries. For this reason, studying the past has become an important element of attempts to interpret the structure and function of contemporary ecosystems (Östlund *et al.*, 1997; Foster *et al.*, 1998; Motzkin *et al.*, 1999; Storaunet *et al.*, 2000; Bürgi & Gimmi, 2007; Jönsson *et al.*, 2009) and to guide restoration and conservation efforts (White & Walker, 1997; Swetnam *et al.*, 1999; Honney *et al.*, 2004; Lilja, 2006). Furthermore, the incorporation of a historical approach into ecological research has generated increasing awareness that all of the world's ecosystems have been immensely affected by humans (Turner II, 1990; Vitousek, 1994; Birks *et al.*, 1998; Delcourt & Delcourt, 2004), and the degree to which 'seemingly pristine' forests have been affected by human activities is becoming increasingly evident.

In fact, many of the forests initially designated as pristine have been subsequently shown to be far from unaffected by human activities. For example, Fiby urskog (Fig. 1) in south-eastern Sweden was long considered to be a pristine forest (hence, its name, which means 'the pristine forest of Fiby') (Sernander, 1918). However, long-term reconstructions of the forest's history by Hesselman (1935) and Bradshaw & Hannon (1992) showed that it had been disturbed by humans using fire and grazing to keep the forest open until about 200 years ago. Another example is the well-known Białowieża forest in eastern Poland, once preserved as a hunting forest for the Russian Tsars but later considered to be one of very few remnants of pristine temperate forests in Europe (Jones, 1945). Further information regarding the history of this forest obtained in more recent studies, notably pollen analyses by Mitchell & Cole (1998), have shown that anthropogenic impact on the forest has been substantial during at least the last 250 years.

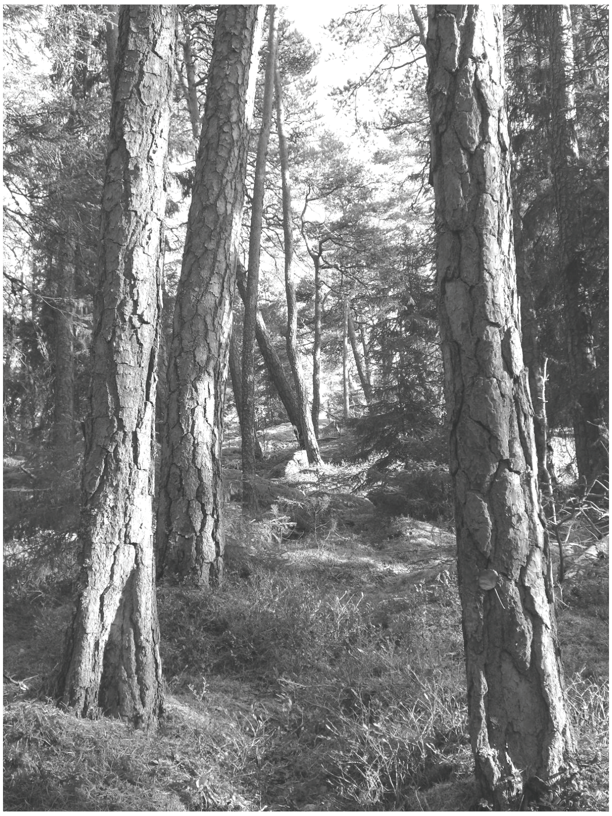

Figure 1. Old Scots pine forest in a late succession stage in the nature reserve Fiby urskog, central Sweden. (Photo by Mari Jönsson)

To date, most evidence that many supposedly 'pristine' forests may still bear the imprint of past human activities has been acquired from studies of remnant forests in densely populated regions and landscapes that have been heavily influenced by humans over extensive periods of time (predominately forests within the temperate region). However, throughout the boreal parts of Eurasia and North America large forested landscapes that have not been affected by modern forestry still exist, and many of these forests are still widely considered to be pristine (Norton, 1996; Aksenov *et al.*, 1999; Yaroshenko *et al.*, 2001).

1.1 Long-term human land use in boreal forests

The boreal forest forms a circumpolar belt in the northern hemisphere. In North America it covers the area between Newfoundland and Alaska, bordering the Great Lakes in the south and the tundra in the north. Known in Russia as the Taiga, it constitutes one of the largest biomes in the world, extending from the Kamchatka peninsula to Fennoscandia (Norway, Sweden, Finland, Karelia and the Kola Peninsula). While extensive parts of these vast forests have been heavily utilised by large-scale industries such as mining, hydroelectric development and forestry, some large areas of unexploited forest still remain, predominately in the Russian North but other areas are also present in northern Canada and interior Alaska (Bryant *et al.*, 1997; Aksenov *et al.*, 1999). Western Europe's last tracts of such forest are in northern Fennoscandia. However, nowhere has the overall transformation of the boreal forest been as dramatic and nearly comprehensive as here (Östlund *et al.*, 1997; Kouki *et al.*, 2001; Löfman & Kouki, 2001). Once covered by vast areas of multi-aged and structurally diverse forest, both Finland and Sweden now encompass highly homogenous forests managed for timber and pulp production. Pristine forests are believed to exist only in a few northerly national parks and nature reserves. However, according to recent forest surveys, areas of pristine forest also exist outside these parks and reserves (Anon, 2006a; Anon, 2006b; Anon, 2008).

Throughout human history, northerly boreal and subarctic forest landscapes have been very sparsely populated, often by less than one person per km^2. Consequently, these ecosystems have been exposed to very low direct anthropogenic influence via human land use activities, compared to forests in more southerly regions. However, other, indirect anthropogenic effects, via processes such as global warming and nitrogen deposition, may well be strong at northerly latitudes as well as in more southerly regions (Vitousek, 1994; Vitousek *et al.*, 1997). Furthermore, people have inhabited these environments for thousands of years, primarily relying for their subsistence on hunting, fishing and gathering natural resources at optimal times, and storing their harvests to sustain them during the long seasonal periods when resources were scarce (Nelson, 1980; Östlund & Bergman, 2006). Generally, these varied forms of land use have been regarded as minor disturbances, restricted in spatial scale and magnitude, and have thus frequently been neglected in ecological studies of northern boreal forests.

This is quite remarkable since, as pointed out earlier, past disturbances, even very far back in time can continue to influence ecosystem structure and processes for extensive periods of time, especially in northern boreal forests where tree growth and decomposition are slow (Wardle *et al.*, 2004). Furthermore, there is an increasing body of evidence suggesting that pre-industrial human activities have had (and continue to have) profound, widespread effects on ecological processes and the structure and composition of boreal ecosystems (Hicks, 1995; Hörnberg *et al.*, 1999; Karlsson *et al.*, 2007). In the light of the long history of human subsistence in boreal environments there are reasons to believe that land use legacies of people, i.e. their effects on contemporary boreal ecosystems, may have been underestimated both in North America and Europe (cf. Denevan, 1992; Östlund *et al.*, 2003; Delcourt & Delcourt, 2004).

1.2 Conceptual problems with 'pristine forest'

During the last decade increased use of different terms related to the concept of pristine forest has generated much confusion. For example, wilderness, primeval, virgin, frontier, old-growth, primary, and ancient forest/woodland (in Swedish 'urskog' and in German 'urwald') are often used more or less synonymously. Some of these terms have been strongly criticised (Satterfield, 1997; Innes & Er, 2002; Kimmins, 2003) and there are several problems related to all of them. Generally, when such concepts are applied they are poorly defined, which causes confusion and leads to misconception. Frequently, they are used to refer to environments devoid of humans, and in other cases they are used synonymously with late successional stages. Another problem is that they are used in inappropriate contexts and often in a value-laden manner. Alarmed by the reduction and fragmentation of previously unmanaged forest – with attendant reductions in biodiversity – ecologists and foresters have called for a conceptual clarification, and although serious attempts have been made to distinguish and define some of these concepts, they still cause confusion regarding exactly what is meant (Peterken, 1996; Er & Innes, 2003; Helms, 2004; Rouvinen & Kouki, 2008).

The extent to which forests have been considered as pristine is closely related to its level of structural and compositional heterogeneity. Such heterogeneity is gradually created and maintained by diverse processes, principally disturbance and succession, operating over a wide range of temporal and spatial scales (Sprugel, 1991; Spies & Turner, 1999; Kuuluvainen, 2002). Commonly, forests denoted pristine are thought to be in late succession stages, highly heterogeneous in age and structure, and only affected by natural disturbances. This, however, might be too simplistic. Is it essential for pristine forests to be heterogeneous and in late successional stages? If so, then the even-aged, homogenous post-fire deciduous forests of northern Fennoscandia (Fig. 2), those studied by Hellberg et al. (2009) for example, should not presumably be regarded as pristine, nor the Ponderosa pine (Pinus ponderosa P. & C. Lawson) and lodgepole pine (P. contorta Dougl. ex Loud.) ecosystems in North America, which are frequently affected by natural disturbances (cf. Veblen, 1986; Covington & Moore, 1994).

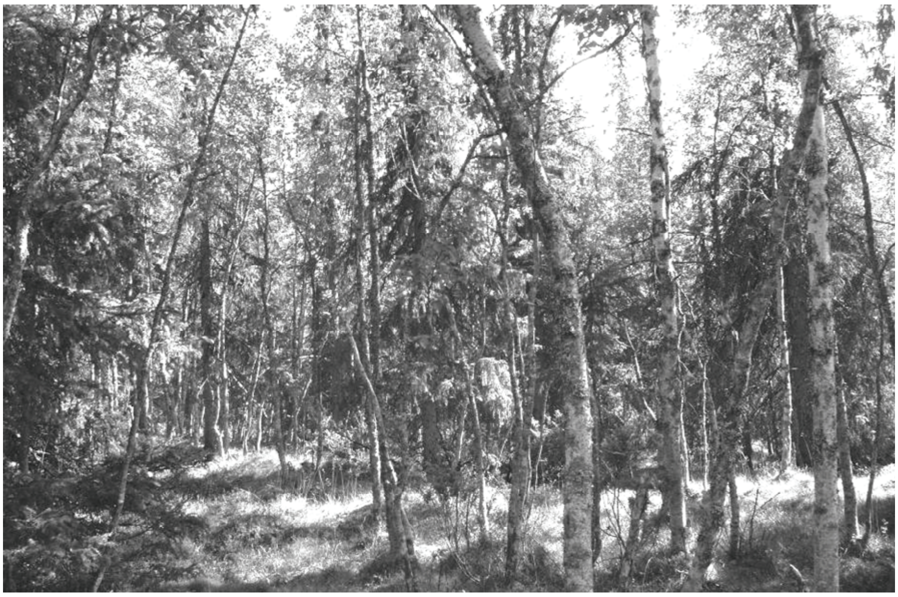

Figure 2. Post-fire deciduous forests, about 100 years old, at Måkkavara, northern Sweden. (Photo by Torbjörn Josefsson)

An important aspect in this context concerns the difference between natural disturbances and those caused by humans. The level of anthropogenic disturbance in forests has commonly been linked to activities that are radically different from natural disturbances, e.g. agriculture or logging (Mladenoff et al., 1993; Linder et al., 1997; Fuller et al., 1998; Bürgi & Turner, 2002; Rouvinen et al., 2002; Okland et al., 2003). However, pre-industrial anthropogenic disturbances can resemble natural disturbances in that they may continue to influence whole forest ecosystems and their functions up to the present day (Foster et al., 2003). In northern boreal forests, long-term and low-intensity land use by indigenous people, for example reindeer herding (Vitebsky, 2005) and the use of fire (Ray, 1996), may be of great importance, but their effects are rarely considered. The reasons for this are not simply unawareness of their importance, or unwillingness among researchers and managers to consider them; it is because we lack appropriate analytical instruments for identifying and interpreting the effects of other forms of land use in these ecosystems.

1.3 Objectives

The fundamental research questions addressed in this thesis are centred on the concept of 'pristine forest' and the characteristics and history of boreal forest landscapes. The studied forest type is dominated by Scots pine (*Pinus sylvestris* L.) and the kind of landscapes under consideration include gradients of forests, from those with indiscernible anthropogenic impact, as interpreted by archaeological investigations and historical analyses, to forests with highly visible influence of past human land use. Particular emphasis is on the subtle and less intensively studied human impact of indigenous people and how they may have contributed to the present structure and composition of the ecosystem. The timeframe for this thesis encompasses the period AD 1000 to 2000, with a particular focus on the period AD 1600 to 1900. More specifically, my aims in this thesis are to: 1) analyze and describe how humans have utilised northern boreal forests and how their activities may have affected forest structure, composition and biodiversity during the studied period, 2) discuss human impact in terms of environmental patterns and gradients in the present landscape, 3) present a set of tools that can be used to study past human land use in northern boreal forests, and 4) discuss and evaluate northern boreal forests' status in terms of pristine forest, core areas for biodiversity and their potential utility as ecological references. The thesis is based on studies described in four appended papers addressing long-term local vegetation changes (Paper I), structural and compositional differences within seemingly homogenous forest landscapes (Paper II), movement patterns and resource utilisation by reindeer herders (Paper III), and the impact of early selective logging on biodiversity in possibly pristine forests (IV). The information obtained in these studies provides the foundations for a broad discussion regarding ecological research and conservation strategies in northern forests.

2 Study areas

The fieldwork reported in Papers I – IV was conducted in the western part of Norrbotten County, in the northern boreal zone of Sweden (Ahti *et al.*, 1968) (Fig. 3). The study areas were selected to cover a range of sites with differing degrees of past human impact. The studied ecosystem is characterised by late successional, generally semi-open forests dominated by

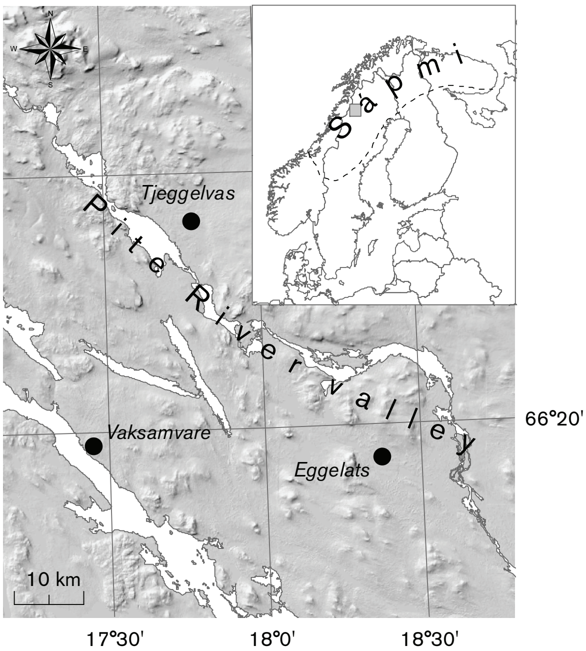

Figure 3. Location and detailed map of the upper part of the Pite River valley, showing the locations of the three study areas Eggelats, Vaksamvare and Tjeggelvas. © Lantmäteriverket 1998, dnr 507-98-4720

Scots pine with scattered downy birch trees (*Betula pubescens* Ehrh.) on dry and nutrient-poor soils (Fig. 4). Other deciduous trees, mainly goat willow (*Salix caprea* L.) and grey alder (*Alnus incana* (L.) Moench), occur at moister sites while mountain birch (*B. pubescens* Ehrh. ssp. *czerepanovii*) features at higher elevations. Norway spruce (*Picea abies* (L.) Karst.) occurs infrequently throughout the landscape. The topography is characterised by an undulating terrain, interspersed with small wetlands, lakes and streams.

Figure 4. Close-up of the late-successional Scots pine forest in Tjeggelvas. The rugged old pines adopt many forms, adapting to the harsh environment. (Photo by Torbjörn Josefsson)

The first study area, called Tjeggelvas, is the least human-influenced forest and is situated on the Arctic Circle within the Tjeggelvas nature reserve, which lies in the vicinity of the continuous mountain range called the Caledonians. The Pite River divides the reserve into a northern part with large, roadless forest landscapes, in which the study site is situated, and a southern part. Due to its remoteness and inaccessibility, these forests have neither been cleared for agriculture, nor affected by forestry. The second (Eggelats) and third (Vaksamvare) study areas are situated further down the Pite River valley and constitute two of the forest remnants that were recently identified in a national inventory of unprotected forests with high conservation value (Anon, 2006b). Scattered stumps testify that both areas have been selectively cut around a hundred years ago, but only to a minor extent.

All three of these areas are located within a region called Sápmi (i.e. the Sami land) covering the northern part of Fennoscandia (Fig. 3). People have inhabited the region encompassing the three study areas since shortly after the last ice-age, finding sustenance in resources located throughout these vast forest and mountainous landscapes (Bergman *et al.*, 2003). During the last few thousand years Sami ethnicity is believed to have developed, and in the course of time the Sami developed a variety of economic strategies to exploit many natural resources, including reindeer (*Rangifer tarandus* L.) (Ruong, 1969; Hansen & Olsen, 2006). Initially, wild reindeer were hunted, but later reindeer pastoralism developed. Due to the seasonally shifting availability of recourses and the intensive nature of reindeer herding (i.e. migrating with the herd, keeping close watch over it and using the animals mainly for transport and milk production) they moved over large areas. Each reindeer herding family had several camp sites with specific resources and temporary or more stationary huts that were used during different times of the year (Fig. 5). Until the beginning of the 20^{th} century the subsistence of many of the Sami in northern Sweden was based on reindeer pastoralism complemented with hunting, fishing and gathering edible plants (cf. Ruong, 1969; Fjellström, 1985). Extraction of specific plant resources was crucial in Sami subsistence, for example the collection of inner bark from pine for food was particularly important (cf. Zackrisson *et al.*, 2000; Bergman *et al.*, 2004). Today, tending much larger herds of reindeer, primarily for meat production, has replaced the intensive form of reindeer pastoralism.

Figure 5. Moving with the reindeers. Early 20^{th} century, Arjeplog (Photo by Lars Rensund, Source: The Silver museum)

In the late 17th century the interior parts of northern Sweden began to be colonised by farmers. For several reasons, including geopolitical and religious factors, in addition to the rapidly increasing agrarian population in the south and central parts of Sweden, the Swedish state took measures to encourage farmers to move north (Arell, 1979). However, the pioneer settlers faced enormous difficulties in cultivating crops, due to the poor soil conditions and extremely short growing seasons. Consequently, a new form

Figure 6. The agrarian settlement Akkapakte, situated just outside the Tjeggelvas nature reserve. The people who utilised this settlement were Sami and descended from reindeer herders who had inhabited the area for several centuries. (Photo by Torbjörn Josefsson)

of farming developed, based on the creation of pastures for domesticated animals and making hay from vegetation gathered from sedge bogs (cf. Campbell, 1948). This colonisation wave reached the upper parts of the Pite River valley in the mid 19th century (Bylund, 1956). In this region many of the new settlements were established by Sami people who had given up reindeer herding, and one such abandoned settlement, named Akkapakte, is adjacent to the Tjeggelvas nature reserve (Fig. 6). In the late 19th century, more attention was also paid to the economic values of the extensive forest in the area. Consequently, increasing utilisation of the forest followed the colonisation process. As described in Andersson *et al.* (2005) the initial forest exploitation by the sawmill industries, was focused on the largest trees. At the turn of the 20th century the logging activities intensified, but it was not until the 1950s that large-scale cutting for timber and pulpwood was introduced in this region (Andersson *et al.*, 2005).

3 Methods

Forest history studies, especially long-term studies, benefit from using a combination of methods since all retrospective methods have both advantages and limitations (Foster *et al.*, 1996; Briggs *et al.*, 2006). Methods available for retrospective studies include analysis of long-term records such as archaeological remains and biological archives, and short-term records such as historical documents, oral histories, aerial photographs and remote sensing data (cf. Agnoletti & Andersen, 2000). In the studies underlying this thesis the following retrospective methods that have been developed for applications in both natural sciences and the humanities were used.

3.1 Archaeological field surveys and historical records

For the studies described in Papers I – III, superficial land-based archaeological field surveys were carried out to locate old, abandoned and naturally reforested settlements and related resource areas. Remains such as hearths, i.e. fireplaces made of stone and cooking pits (cf. Bergman, 1995), degraded dwelling huts (Liedgren *et al.*, 2009) and other wooden constructions provide good, although incomplete, insights into the spatial distribution of past human activity (Fig 7a-c). While archaeological data provide temporal and spatial context, historical documents offer information regarding individuals, pre-industrial forest utilisation and geographical features within specific areas (cf. Östlund & Zackrisson, 2000). In Fennoscandia, particularly in Sweden and Finland, the historical records are uniquely comprehensive (for the boreal region) and for the most part available and well preserved, hence they have been used in several studies on Sami history and subsistence (Hultblad, 1968; Kvist & Wheelersburg, 1997; Helle & Helama, 2007; Bergman *et al.*, 2008). For the study described in

Paper III archival sources in the forms of cameral and judicial documents and church records from the 17th century onwards were used.

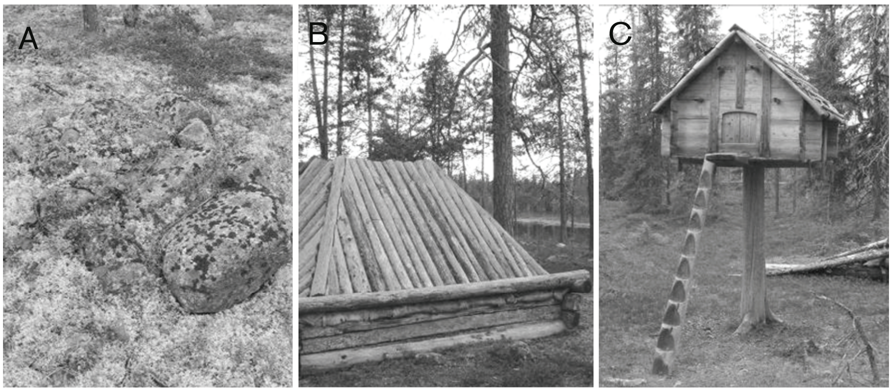

Figure 7. Archaeological remains near Sami settlements: a) unexcavated hearth of árran type, Eggelats, b) dwelling hut, Njaltaheden, northern Sweden, and c) reconstruction of a small storage house – njalla, Nilas nature reserve, northern Sweden. (All photos by Torbjörn Josefsson)

3.2 Biological archives

For the assessments of long-term vegetation changes reported in paper I a palaeoecological approach was applied – including fine resolution analyses of pollen, organic matter contents and charcoal fragments in peat cores – to elucidate possible imprints of pre-industrial human activities on past vegetational composition and their temporal extent. Indications of past human activity in pollen diagrams may include abrupt changes in the proportions of arboreal pollen, i.e. pollen produced mainly from tree taxa, or the presence of anthropogenic indicators, (pollen taxa indicating various kinds of human activity), referred to as apophytes and anthropocores (cf. Behre, 1981; Vorren, 1986). For the studies reported in Papers II and IV dendrochronology, i.e. the analysis of tree-ring growth patterns (cf. Schweingruber, 1988), was used. Cross-dating, i.e. matching patterns of variations in the widths of sequences of rings in cores taken from trees enables human-induced scars caused by past resource utilisation to be dated (cf. Östlund *et al.*, 2002; Andersson, 2005).

3.3 Ecological field studies on forest structure and biodiversity

In the studies described in Papers II and IV extensive field data were collected on past traces of forest utilisation, current forest structure and composition (including living and dead trees). In Paper II this information was used to study the impact of human land use activities, and in Paper IV it was used to examine the effects of the first commercial loggings in the area (around 1900). One of the most serious threats to the continued presence of many forest-dwelling species is the loss of dead wood, since it provide essential habitats for a wide range of species, including certain fungal species (cf. Harmon *et al.*, 1986; Siitonen, 2001). Consequently, the field data reported in Paper IV also included records of wood-inhabiting fungi. The fungal flora of dead pine trees, mainly polypore and corticioid fungi, were studied by recording sporocarps. This approach – assessing the presence/absence of fruiting bodies – is well established in studies on wood-inhabiting fungi (Bader *et al.*, 1995; Renvall, 1995; Rolstad *et al.*, 2004). To allow reliable species identification large numbers of samples were collected and their microscopic characters were subsequently checked in the laboratory.

4 Results and discussion

In general, northern boreal forest landscapes that have escaped modern forestry are large tracts of late successional and multi-aged coniferous forests with large amounts of dead and dying trees, including deciduous trees and a comparatively species-poor field layer. In northern Fennoscandia, these forests are generally dominated by Scots pine, Norway spruce (*Picea abies* (L) Karst.) or, at higher elevations and in the subarctic regions, birch (*Betula* spp.) (Sjörs, 1965). In the pine forests included in this study, ages of trees commonly exceed 400 years (the oldest trees are almost 700 years old) and the proportion of dead wood is very high – occasionally representing almost half of the total timber volume, i.e. the summed volume of living and dead trees (II, IV). These general characteristics are consistent with those of late successional pine forests in northern Fennoscandia observed by various other authors, for example Sippola *et al.* (1998) and Lilja & Kuuluvainen (2005). However, at a finer spatial resolution these forest landscapes encompass areas with distinct variations in forest structure and vegetation composition. Such disparities are partly due to variations in edaphic conditions, i.e. conditions influenced by physical and biological properties of the soils rather than climate, and partly the result of past disturbances such as fire, wind and pathogen attacks. Some of these differences, however, also result from various forms of human land use in the past.

4.1 Pre-industrial land use

In northern boreal ecosystems, the harsh climate and short vegetation growth periods have shaped unique subsistence strategies and settlement patterns among the people inhabiting the region. Here, the land use was heavily dictated by the temporal patterns of abundance and scarcity of resources, across vast areas. In forests that have escaped logging and agriculture, signs of this type of land use may still be found. This is in sharp contrast to forest ecosystems further south, i.e. in southern boreal and temperate forests, where the landscapes have been affected by many superimposed layers of cultural activities over time (Östlund & Bergman, 2006).

Hearths are often the most distinctive structures at very old and otherwise degraded pre-industrial settlement sites (Fig. 7a) (Hedman, 2003). In the interior parts of northern Fennoscandia hearths can be found along the shores of the larger lakes, and many mark locations that were used for quite short periods of time, while people were gathering specific resources (Bergman, 1995). During the field investigations in Tjeggelvas, remains of more than 100 hearths used for occasional activities were detected (I). However, hearths can also pinpoint the locations of dwellings that were used seasonally or during a substantial part of the year (Fig. 7b). In northern Fennoscandia such sites often included two or three dwelling huts in addition to storage buildings and other wooden constructions utilised by the Sami (Fig. 7c). Two such settlement sites were found in Tjeggelvas – situated on the shores of two of the larger lakes (I). Datings of different wooden parts of one of the disintegrated dwelling huts indicate that that this settlement was established in the late 18th century (Liedgren *et al.*, 2009).

4.1.1 Utilisation of natural resources

Near the settlements a range of activities were carried out. Like many northern people, the Sami hunted using extensive systems of trap-lines (Nelson, 1983; Brody, 1988; Ray, 1996). The only remaining signs of these are blazed trees and stones, or piles of stones, placed at regular intervals, marking systems of trap lines, starting from a settlement or shoreline and extending through the sparse forest in an oval pattern, returning to the starting point (Fig. 8a). It probably took the hunter a day or two to inspect and empty the traps along such trap lines. Animals that were commonly hunted included red squirrel (*Sciurus vulgaris* L.), ermine (also known as stoat, *Mustela erminea* L.) and wolverine (*Gulo gulo* L.). The Sami also fished for northern pike (*Esox lucius* L.) and arctic char (*Salvelinus alpinus* L.), primarily in larger lakes, sometimes using a small log raft (Fig. 8b) (III). The importance of good fishing lakes is apparent from old historical documents regarding land use rights in which lakes suitable for fishing were carefully noted (III). Decayed stumps originating from the collection of firewood, blazes on trees indicating the locations of important resources or walking trails, and remains of storage platforms carefully positioned at strategic places constitute other traces of past land use (Fig. 8c).

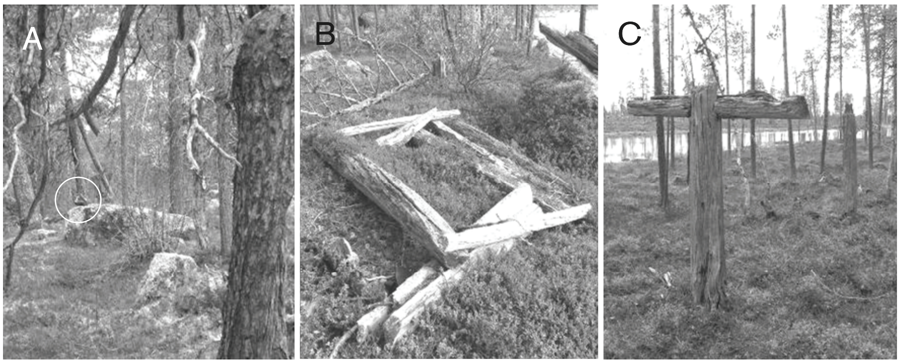

Figure 8. Archaeological remains of Sami land use: a) a small stone placed on top of a boulder (encircled) marking a trail, Tjeggelvas, b) the degraded remains of a fishing raft, Tjeggelvas, and c) foundation of a wooden storage platform, Paulavuobme, northern Sweden. (All photos Torbjörn Josefsson)

Some of the most conspicuous signs of past resource utilisation in coniferous forests across the northern hemisphere are trees with large rectangular or triangular scars, namely bark-peeled trees (Fig. 9a-c). Long confused with natural damage to the tree, e.g. from forest fire, we now know that these scars derive from harvesting of tree inner bark (Östlund *et al.*, 2009). The use of this resource extends far back in time; evidence of collection of inner-bark almost 3 000 years back in time in northern Fennoscandia has been provided by Östlund *et al.* (2004). Throughout the northern hemisphere bark has been used for a number of purposes, including as building material, for producing ropes and storage utensils, as medicine and as a source of food and nutrients (Martorano, 1981; Swetnam, 1984; Mobley & Eldridge, 1992; Zackrisson *et al.*, 2000; Prince, 2001; Marshall, 2002). The Sami primarily used inner-bark from Scots pine for food (as a complementary source of nutrients, carbohydrates and vitamin C) and for making containers for storing sinews (Bergman *et al.*, 2004).

In Tjeggelvas, bark-peelings were found throughout the whole forest landscape, covering thousands of hectares, indicating that people covered large distances to harvest this resource. Close to the lake shores, there are large concentrations of bark-peelings and near settlement sites almost every other tree bear signs of this ancient form of resource utilisation. Many of the bark-peelings near the Sami settlements in Tjeggelvas were dated to the 18th century, corroborating the dating of one of the dwelling huts. However, the oldest bark-peeling that was recorded was found on a living tree and dated to 1636 (II). Presumably, older, undetected bark-peelings on lying dead trees are also present in the area. In Vaksamvare and Eggelats only a few trees with bark-peelings were recorded (IV), almost certainly due to the early selective cuttings carried out at the turn of the 20th century, when the bark-peeled trees were cut, rather than to a reduction in Sami activity in the area (IV).

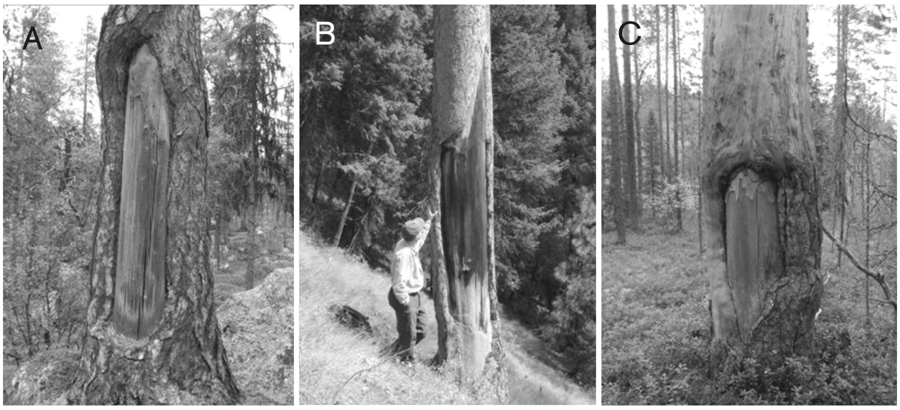

Figure 9. Trees with typical bark-peeling scars: a) Scots pine tree in Tjeggelvas, b) Ponderosa tree in Fales Flat, southwest Montana, USA, and c) Scots pine tree in Kostomukshsky Zapovednik in western Karelia, Russia. (All photos Torbjörn Josefsson)

4.1.2 Effects of low-intensity land use near settlements

Considering the temporal extent and variety of traces of past land use at and close to the Sami settlements in Tjeggelvas, it is conceivable that this occupancy may have had extensive effects on the local environment. The two settlement sites, easily distinguishable in the field, were abandoned about a century ago and have subsequently been reforested. Both settlements formerly encompassed about 3 – 4 ha, in accordance with dimensions of settled areas published by Hicks (1995) and Östlund *et al.* (2003), who also studied past Sami land use patterns (II). At present, numerous birches and a few large, very old pines cover the dwelling sites (Fig. 10). The settlement sites differ substantially from the surrounding forest in several ways. In general, the forest at the settlement sites is dominated by birch and is much younger (mean age c. 140 – 190 years) than in the surrounding landscape, where the mean age often exceeds 300 years (II). In addition, the volumes of dead wood, in particular standing dead trees, are much lower in the forest at and close to the former settlement (II). The difference in dead wood characteristics is also illustrated by the lower volumes of dead wood in later decay stages near the settlements (II). These disparities suggest that the settlement site used to be much more open – a result of cutting both living and dead trees for firewood and wooden constructions.

Figure 10. Forest structure at a Sami settlement site, Tjeggelvas. The settlement was used for approximately 300 years until the beginning of the 20th century when it was abandoned and the area has since been reforested. (Photo by Torbjörn Josefsson)

Closer examination of the palaeoecological data provides additional information regarding the human impact on the vegetation near the settlements. According to the pollen records there was a pronounced increase in apophytes, i.e. taxa closely related to human activities, starting approximately 400 years ago at one of the Sami dwellings (Fig. 11a) (I). Noteworthy in this respect is the pronounced presence of grasses (Poaceae) and sorrel (*Rumex acetosa/acetosella*). According to Räsänen (2001), human activities close to settlements (physical disturbance and nutrient addition) promotes a greater variety of herbs, especially sorrel, but also *Achillea*, *Epilobium* and *Solidago* species. Interestingly, in Sami tradition common sorrel (*Rumex acetosa* L.) was a highly appreciated food source and therefore harvested in large amounts (Fjellström, 1985; Qvarnström, 2006). Today, sorrel species are very uncommon in this pine forest landscape. Another interesting find is the occurrence of cereal pollen at six levels in the lithostratigraphy, which strongly indicates intense land use, including small-scale cultivation at the settlement site (c. 100 – 350 years ago) (I). These findings are highly illuminating, since the extent and kind of cultivation the Sami may have practiced is largely unknown.

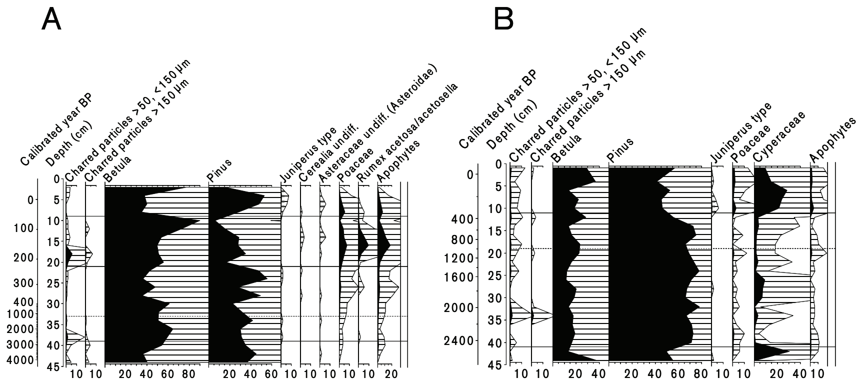

Figure 11. Percentage pollen diagrams obtained from sample sites from: a) a Sami semi-permanent settlement, and b) the agrarian settlement Akkapakte. Pollen types and microscopic charred particles in percentages (solid) and 10× magnification (lined). Only pollen types relevant for the discussion in this thesis are included. Redrawn from Paper I.

About 80 km northwest of this settlement lies the abandoned agrarian settlement Akkapakte, which was also included in the palaeoecological analysis. The pollen record from Akkapakte indicates that this settlement was established at about the same time as the Sami settlements described above, i.e. about 400 years ago when there was a change in forest structure to more open conditions (Fig. 11b) (I). However, here a different assemblage of species related to human activities appeared, including juniper, grasses, sedges and some other apophytes, indicative of farming of domesticated animals (I). Sedges were the preferred sources of fodder for domesticated animals in these harsh environments (Campbell, 1948; Segerström, 1990) and, according to Aronsson (1991), a strong increase in sedge is a possible indicator of hay-making at or near the sampled mire. Thus, there are strong indications of farming of domesticated animals long before the inhabitants acquired property rights in the mid 19th century.

Consequently, long-term, low-intensity land use at settlement sites and the surrounding forest has promoted an open forest characterised by scattered old Scots pine trees, younger birch trees and a ground vegetation with distinct elements of herbs and grasses that otherwise are very rare in this ecosystem. The repeated cutting for firewood and wooden construction also decreased the abundance of dead wood, which may in turn have caused cascade effects on the diversity of epiphytic invertebrates, bryophytes and wood-decaying fungi (cf. Siitonen, 2001). Furthermore, as shown by

Palviainen *et al.* (2008), decomposing dead wood retains nitrogen rather effectively in boreal forest ecosystems, thus forming a long-term, small but steady pool of nutrients with a slow release rate. As a consequence, the long-term loss of dead wood in these rather nutrient-poor forests may also have substantially affected the input of nutrients to the soil. It has also been shown that long-term absence of major disturbances results in reductions in plant biomass and tree basal area, probably due to increases in phosphorus limitation (Wardle *et al.*, 2004). It is possible that long-term human land use may have restrained or delayed the progression toward more nutrient-poor conditions at the settlement sites (I).

4.1.3 Environmental effects of reindeer herding

Small-scale reindeer herding was the main source of sustenance for many Sami families in the study region, as it was for many other groups of people throughout northern Eurasia. Among other people that have a long history of herding reindeer are the Nenets and the Chukchi in northern Siberia and the Dukha or Tsaatan people of northern Mongolia (Germeraad & Enebish, 1999; Vitebsky, 2005). Aronsson (1991), who studied possible indicator species of reindeer herding in northern Sweden, has suggested that both settlement and grazing/trampling in this kind of forest ecosystem favour grasses and some herbs, including sorrel and *Melampyrum* spp. The relatively high levels of Poaceae and *Rumex* pollen recorded close to one of the Sami settlements therefore point to reindeer activities in the area. Important artefacts indicative of past reindeer herding practices are tall, thin stumps (hereafter denoted lichen stumps) created by the herders cutting smaller trees on which arboreal lichens were abundant (Fig.12a), to allow their reindeer to feed on the lichens during periods when grazing was severely limited due to icy conditions (cf. Berg *et al.*, 2009). In Tjeggelvas, large quantities of lichen stumps were recorded, and the majority were situated close to settlements (II).

In the vicinity of one of the dwellings the degraded remains of a fence, mainly built of dead pine trees, revealed an old reindeer enclosure, originally enclosing more than 1 000 ha (Fig. 12b) (I). Dendrochronological dating of the enclosure and lichen stumps shows that it was used for at least two centuries (c. 1700 to 1900) (II). The area formerly encompassed by the enclosure is unusually large – much larger than reindeer pens described, for example, by Manker (1968) and Ruong (1954), and lichen stumps within it shows that it was probably used for fencing reindeers all year around or a substantial part of the year. Furthermore, the amount of lichen stumps inside the former enclosure was estimated at c. eight per ha, implying that several thousands of trees were cut in this area during a period covering at least two centuries (II). The repeated cutting of lichen stumps has caused differences in the current forest structure, including higher tree volumes

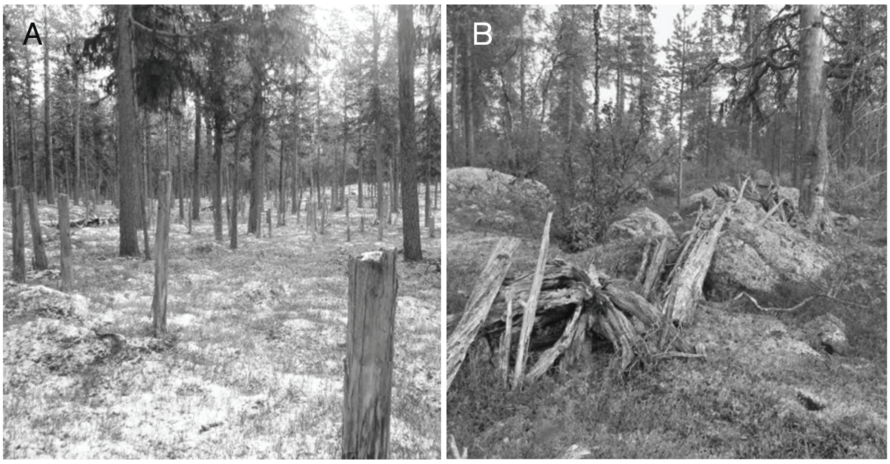

Figure 12. Remains of past reindeer herding practices: a) lichen stumps, Lulip Maida, northern Sweden, and b) much decayed parts of an old reindeer enclosure, Tjeggelvas. (Photos of the lichen stumps and the reindeer enclosure by Per-Erik Mukka and Torbjörn Josefsson, respectively)

inside the enclosure (c. 90 m^3 ha^{-1}) than in the surrounding landscape (c. 70 m^3 ha^{-1}) (II). Almost certainly, these cuttings generated a more open forest with increased light conditions, in addition to the positive effects of reindeer herding, i.e. grazing (Stark *et al.*, 2000) and manuring in combination with trampling (Aronsson, 1991). This may have encouraged the regeneration of trees, and this is mirrored in the higher number of small and medium-sized trees (Fig. 13) (II). The cuttings may thus have contributed to the low number of large trees inside the enclosure at present (Fig. 13) (II).

This form of land use apparently encompassed areas of several km^2 and covered time periods lasting many centuries. In areas where the reindeer were kept fenced for long time periods, such as the reindeer enclosure described above, or where the reindeers were present in high densities, the structural and compositional effects on the forest can be substantial. As discussed by Suominen & Olofsson (2000), grazing, trampling and fertilisation by the animals may strongly influence the ground vegetation. This is manifested in the paleoecological data (I). There is also abundant evidence that extensive trampling and grazing can indirectly affect soil process such as soil respiration, decomposition, nutrient mineralization and densities of soil-dwelling invertebrates (Stark *et al.*, 2000; Olofsson *et al.*, 2001; Suominen *et al.*, 2003).

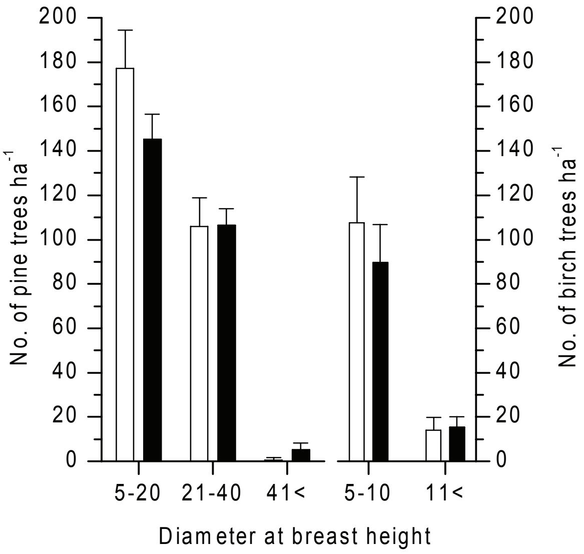

Figure 13. Diameter distribution of pine (left) and birch (right) trees in the decayed reindeer enclosure (open bars) and the surrounding forest (solid bars) (mean and S.E.), Tjeggelvas. From Paper II.

4.1.4 Movements across the landscape

Similarly to other pastoralists inhabiting boreal forests in Eurasia, Sami reindeer herders followed their reindeer closely all year around, moving from place to place within a well-defined area (Vorren, 1978; Vainshtein, 1980; Arundale & Jones, 1989; Vitebsky, 2005). Generally, they utilised the same areas year after year. Historical records of the region encompassing Tjeggelvas demonstrate that the area used by a reindeer herding family, consisting of two to four households according to Hultblad (1968), could cover several hundred km^2, and that this land use seems to have been confined to certain land units – at least until the 17^{th} century or early 18^{th} century in some areas (III). In addition, it appears that these land units were utilised by few people and featured several different vegetation types (III).

The demographic data show that the mean size of a reindeer herding family ranged from 8 – 16 persons, hence the population density during the 18^{th} and 19^{th} centuries was very low – approximately 0.08 persons per km^2 (III). These estimates are higher than the upper limits (c. 0.04 persons per km^2) obtained for hunter-gatherer societies in sparsely populated areas in several previous studies on group sizes and hierarchic structure (cf. Johnson & Earle, 1987; Kosse, 1990). However, they are substantially lower than the characteristic densities (up to five persons per km^2) of societies relying on hunting, fishing and gathering supplemented with pastoralism or farming.

This is not surprising, since northerly forest areas have extremely low productivity and the conditions are very poor for farming, thus population densities exceeding one person per km^2 would have been very unlikely. The historical records also indicate that there were fluctuations in population size over time, probably reflecting climatic fluctuations, epidemics and instability in subsistence, for example unfavorable conditions for reindeer herding, as suggested by Hultblad (1968) and Kvist (1987).

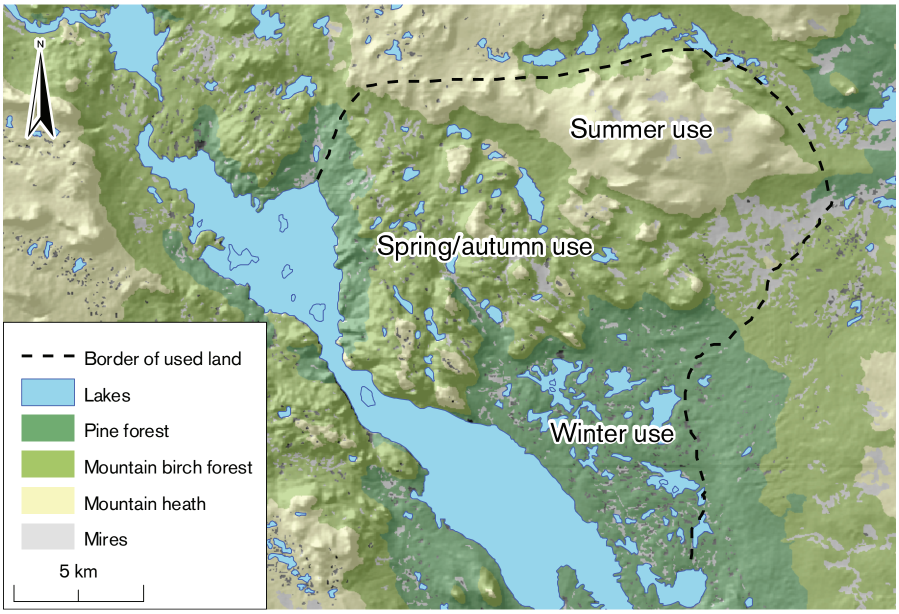

Figure 14. Spatial configuration of areas of different vegetation types and lakes in a land area used by one reindeer herding family, Tjeggelvas. The seasonal use of the areas is indicated on the map. © Lantmäteriverket 1998, dnr 507-98-4720. Modified from Paper III.

A closer examination of the spatial configuration of the land used by the reindeer herders shows that the landscape encompasses a variety of environmental features, including pine and mountain birch forests, mires, lakes and mountain heath (Fig. 14) (III). It also appears that the land was covered by distinct proportions of different vegetation types. While only a small proportion of the land was covered by lakes and mires (about a tenth), pine and mountain birch forest covered approximately three fifths of the land and mountain heath nearly a third (III). This environmental variety provided the people with summer and winter pastures as well as suitable areas for hunting and good fishing lakes, utilised in different parts of the year (Table 1) (III). However, during the late 18^{th} and 19^{th} century increases in numbers of people and sizes of herds eventually led to shortages of high quality pastures (especially summer grazing areas) and increasing pressure on natural resources such as good fishing lakes. Consequently, settlement patterns changed and even larger areas were covered in the seasonal movements.

Table 1. *Sami seasonal land use activities in different environmental settings. From Paper III.*

Vegetation type	Season	Main land-use activities
Pine forest	Winter/spring	Reindeer herding, hunting, collection of pine inner bark
Mountain birch forest	Spring/autumn	Reindeer herding, hunting, collection of birch wood and bark, collection of edible plants
Mountain heath	Summer	Reindeer herding
Mire	Spring/autumn	Collection of berries and sedges
Lake	All seasons – occasionally	Fishing

Thus, land use and movement patterns up to the late 19th century reflect intricate relationships between demographic changes, reindeer herding practices and the spatial and environmental configuration of the utilised land (III). The seasonal movements over vast areas with local variations in land use, characteristic for the Sami reindeer herders in northern Sweden, are not exceptional. On the contrary, they are typical of many pastoralist and hunter-gatherer societies, for example the Nenets and Komi reindeer herders (Dwyer & Istomin, 2008) in Siberia and the Koyukon people (now sedentary) in Alaska (Nelson, 1983), who have inhabited northerly forest areas in Eurasia and North America for long periods of time.

4.2 Early commercial logging

In contrast to the long history of land use by indigenous people, northerly boreal and subarctic forest landscapes have generally had only a brief history of logging. Early commercial loggings were mainly concentrated in areas close to waterways and forest roads (Hoppe, 1945; Arpi, 1959). The relationships between logging, forest structure and both the frequencies and relative proportions of fungal species may be very complex and require careful interpretation. In pine-dominated ecosystems these relationships have been previously studied by several authors, for example Junninen et al. (2006) and Sippola et al. (2002), but largely focusing on differences between production forests and forests with low levels of past logging (such as those at Eggelats and Vaksamvare). Comparisons between un-logged forests and forests with low levels of logging are very scarce. It is often assumed that the first commercial loggings, such as those carried out in northern Fennoscandia in the late 19th and early 20th centuries, are of minor importance for the structure and composition of contemporary boreal forests. In addition, the negative effects of logging are predominately believed to increase along a gradient of increasing logging intensity. However, these presumptions have not been previously tested. A comparison of the unprotected, selectively cut forests in Vaksamvare and Eggelats with the un-logged forest in Tjeggelvas nature reserve revealed interesting information regarding these relationships.

Figure 15. Signs of past logging events: logging blaze with a stamp on an old Scots pine tree, Jelka-Rimakåbbå, northern Sweden, and b) high grading stump, Jovan, northern Sweden. (Photos of logging blaze and high grading stump by Torbjörn Josefsson and Lars Östlund, respectively)

During the field inventories in Vaksamvare and Eggelats imprints of past logging activities were detected, of which logging stumps are the most evident (IV). Logging stumps can be divided into several categories depending on the methods used for felling the trees and the time since the cutting. In northern Fennoscandia, as in most other forest regions, the initial forest exploitation included high grading of the most valuable trees, i.e. the largest and straightest pines (cf. Östlund, 1995). Each tree intended for felling was marked using a special axe with a stamp on the reverse side (Fig. 15a). The trees, generally Scots pine, were then cut by axe leaving high, voluminous stumps that are still clearly discernible and easy to identify (Fig. 15b). Subsequent selective cuttings generally included felling of trees of various sizes with a manual handsaw. The recorded stumps provide evidence of several periods of early cuttings in both Vaksamvare and Eggelats.

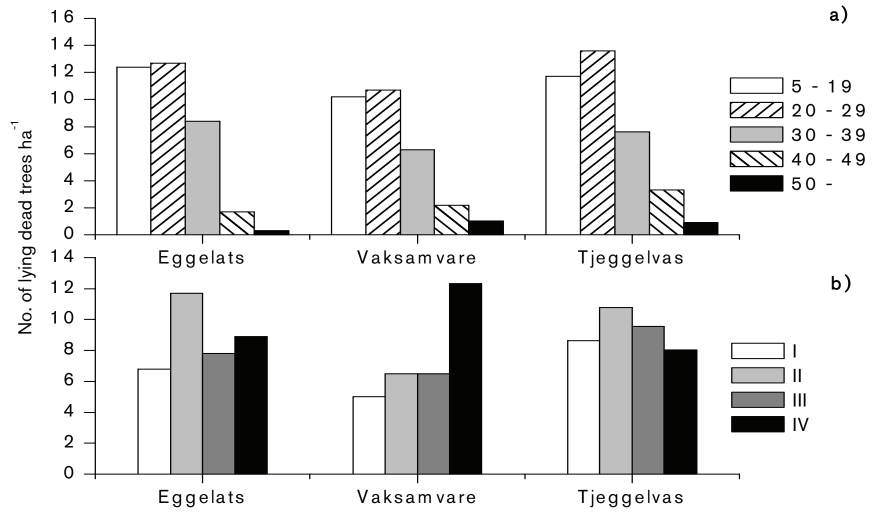

Figure 16. Distribution of lying dead trees (on which fruiting bodies of wood-inhabiting fungi were recorded) in different a) diameter-classes, and b) decay stages. From Paper IV.

Comparisons between the selectively cut forests and the un-logged forest of Tjeggelvas show that past loggings have resulted in lower tree volumes and tree ages, fewer standing dead trees and high stumps, and a slightly skewed tree diameter distribution with fewer large-diameter trees (≥ 50 cm in diameter) in Eggelats and Vaksamvare (IV). Since dead trees and stumps are key elements of biodiversity in Fennoscandian coniferous forests, the reductions in abundance of these elements may have been disadvantageous for a range of species (Linder & Östlund, 1998; Niemelä *et al.*, 2002). In both Vaksamvare and Eggelats the loggings have reduced not only the total volume of dead wood, but also (perhaps most importantly) numbers of medium-sized logs (20 – 39 cm in diameter) in early and intermediate stages of decomposition (Fig. 16a-b) (IV). Findings of many studies, including Bader et al. (1995) and Renvall (1995), indicate that these two variables are crucially important for the diversity of wood-inhabiting fungi.

A closer look at the species assemblages of wood-inhabiting fungi shows that species abundance (defined as the number of logs on which each detected species was recorded in the sampled plots) and species composition radically differs in the three studied forests (Fig. 17). Apparently, relatively minor differences in past human land use and their persistent legacy are today visible in the form of differences in species composition. Thus,

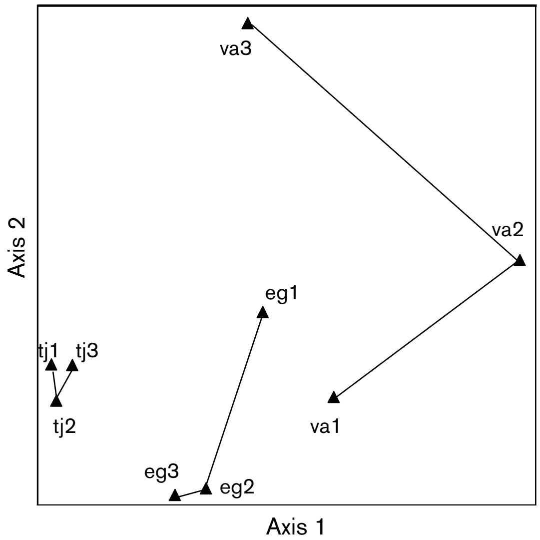

Figure 17. Two-dimensional solution for a non-metric multidimensional scaling (NMS) ordination of the species composition of wood-inhabiting fungi in Eggelats (eg), Vaksamvare (va) and Tjeggelvas (tj). Each study site is represented by three transects (▲). The NMS ordination clearly shows that the species composition differs among the three study sites and that the variation within sites is highest in Vaksamvare and lowest in Tjeggelvas. From Paper IV.

variations in the persisting legacy of past human land use, due to relatively minor differences in practices, can be still observed in differences in species composition. For example, the number of species per log was significantly lower in Vaksamvare than in both Eggelats and Tjeggelvas. However, the loggings do not seem to have affected the total number of species or the number of red-listed species present per unit area (Gärdenfors, 2005). Nevertheless, the total number of records and the abundance of red-listed species were much higher in Tjeggelvas, indicating that selective cuttings may have a negative impact on species at risk of extinction (Table 2) (IV). Similar results have been published by other authors, for example, Sippola *et al.* (2004).

Overall, the selective loggings carried out in the late 19th and early 20th centuries have affected both dead wood characteristics, including the quantity and quality of the lying dead trees, and the abundance of common and red-listed wood-inhabiting fungi (Fig. 18). Contrary to expectations, the impact of logging on forest structure and species composition was higher in Vaksamvare than in Eggelats, although the intensity was lower (22 cut stumps ha^{-1} compared to 26 cut stumps ha^{-1}). The higher impact of selective cuttings in Vaksamvare appears to have been due to a combination of the types of logging carried out (more high grading) and the numbers of trees removed, indicating that the relationships between past logging and present forest characteristics are very complex. This implies that estimations of logging effects cannot be based solely on logging intensity, and that the interpretation of logging gradients requires both quantitative and qualitative data on logging history and forest characteristics.

Table 2. *List of red-listed species of wood-inhabiting fungi recorded at the three study areas and in total. Status according to Gärdenfors (2005). From Paper IV.*

Species	Status[a]	Vaksamvare	Eggelats	Tjeggelvas	Total
Aleurodiscus lividocoeruleus	NT			2	2
Anomoporia kamtschatica	NT		4		4
Antrodia albobrunnea	VU	18	32	31	81
Antrodia primaeva	EN			2	2
Ceraceomerulius albostramineus	VU		1		1
Gloeophyllum protractum	VU		1	6	7
Hydnellum gracilipes	EN	1	2	3	6
Junghuhnia luteoalba	NT			1	1
Odonticium romellii	NT	25	30	63	118
Oligoporus hibernicus	NT		8	17	25
Oligoporus lateritus	VU	1	2	2	5
Phellinus nigrolimitatus	NT	5			5
Phlebia femsioeensis	DD	1			1
Physodontia lundellii	VU	2			2
Skeletocutis kuehneri	NT	1	1		2
Skeletocutis lenis	VU	4	12	16	32
Trichaptum laricinum	NT	1		4	5
Total		59	93	147	299

[a] NT = near threatened, VU = vulnerable, EN = endangered, DD = Data deficient

4.3 Cumulative effects of human impact

Focusing solely on a specific form of land use, during a limited period of time, may generate excellent information on a specific resource use, but will inevitably lead to failure to understand the overall magnitude and complexity of the relationship between humans and the land. All forms of human activities that may have occurred within the studied space should be considered. This adds considerable complexity to analyses covering larger spatial scales because of the difficulties of separating effects of natural disturbance from human-induced changes (Foster *et al.*, 1999; Urbieta *et al.*, 2008). Furthermore, the relative importance of natural and anthropogenic disturbance can shift over time due, for example, to the cessation of certain types of land use, or abrupt events such as large-scale windthrow or fire. This is accentuated in northerly boreal landscapes where many types of past human land use were subtle and often not well known in terms of their form, extent or effects on the forest ecosystem. The creation of lichen stumps by Sami reindeer herding activities mentioned in section 4.1.3 provides an example, since they are present in great numbers, indicating that their creation had a considerable impact on forest structure, yet they are rarely recognised today and thus have been previously overlooked.

Figure 18. Close up photo of *Antrodia primaeva* Renvall & Niemelä, a very rare polyporous fungus thriving on dead pine wood. Categorised as endangered according to the IUCN red-list criteria. (Photo by Wjatcheslav Spirin)

4.3.1 Gradients and patterns

Human land use takes place over a range of spatial and temporal scales, creating environmental gradients and complex patterns across landscapes (cf. Hammett, 1992; Mladenoff *et al.*, 1993; Foster *et al.*, 1999; Smith & McNees, 1999; Urbieta *et al.*, 2008). One important conclusion of this thesis is, therefore, that studies of past human impact require a complex, multidimensional blueprint for carefully considering these aspects. Otherwise, the risks of neglecting important disturbance events or misinterpreting present forest characteristics are substantial.

Furthermore, environmental gradients related to past land use can be explained by changes in land use intensity with distance from specific locations, such as settlements, and/or with increases in ecologically relevant variables, such as altitude and latitude (Hammett, 1992; Foster *et al.*, 1999). Marked differences in overall human impact can be expected between areas where people have lived for recurrent periods and areas that were visited only occasionally. In the Tjeggelvas area we can decipher certain detailed gradients in the forest that are related to past, low-intensity human land use.

In section 4.1.2 the immediate effects of such activities close to settlement sites are discussed. For example, trees may have been cut for firewood or building constructions far from the actual dwelling around a settlement site, and within this area dead trees and trees of certain species may have been successively removed, but the further from the settlement, the less intense the collection of wood is likely to have been. Similarly, collection of the inner bark of trees is likely to have been most intensive near settlements and temporary campsites. Thus, centuries of settlement and associated land uses can create explicit, and sometimes persistent, gradients around a specific locus (Fig. 19).

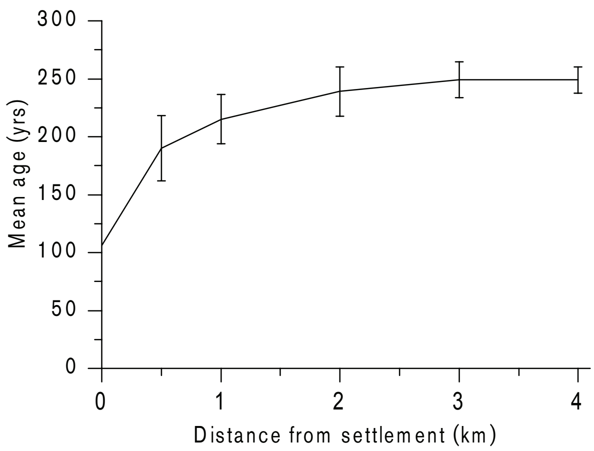

Figure 19. Age structure of the forest surrounding a Sami settlement (mean and S.E.). The forest is much younger at the settlement site than in the surrounding forest, but gradually increases in age with increasing distance from the dwelling site (up to two km from the location of the hut). Unpublished data, Tjeggelvas.

The formation of environmental patterns across a forest landscape may partly be explained as the result of specific land use activities that are, or were, quite restricted in space and time, for example Sami reindeer herding in areas where the animals are kept fenced at specific times during the year (cf. Ruong, 1945; Manker, 1968), and indigenous Americans' frequent burning of forest in certain areas to facilitate cultivation and aid hunting (cf. Cronon, 1983; Whitney, 1994; Delcourt & Delcourt, 2004). Such forms of land use, carried out regularly in certain places, may produce patches of forest that are substantially different from the surrounding landscape in terms of structure, composition and wildlife. Two illustrative examples of this are the Iroquois' deliberate use of fire, which altered tree species composition, both locally and at larger scales in Ontario, Canada (Clark & Royall, 1995), and the shifting cultivation practiced by the local Finnish population up to the early 20th century in northern Karelia, which caused specific, persistent patterns of tree species composition and age structure across whole landscapes (Lehtonen & Huttunen, 1997). Some land uses were also practiced along corridors running through the landscape, for example hunter/gatherers collecting resources along trails and Sami herders moving reindeer between regularly used campsites (as described in sections 4.1.1 and 4.1.4). Typically, such routes were tended, and marked by small piles of stone on the ground or blazes cut on trees that were regularly amended. In North America several indigenous people used fire to clear such routes (Lewis, 1985).

4.3.2 A matrix of different kinds of land use

When considered at larger temporal and spatial scales, the interpretation of land use gradients and patterns becomes more complex. Across landscapes, the signs and effects of several forms of land use, each with a specific spatial extension, time depth and intensity, may interact and overlap both in time and space, creating several 'layers' of land use that are discernible to varying degrees in varying places. The result is a matrix of diverse gradients and patterns, in which some areas have been heavily affected by an array of different land uses for extensive periods of time whereas other parts may have practically escaped human exploitation (cf. Zerbe, 2004; Östlund & Bergman, 2006).

Taking the upper part of the Pite River valley as an example, a mosaic of land use can be visualised. Throughout this valley Sami reindeer herders have utilised the forests and mountain heaths for many centuries (as described in sections 4.1.1-4). At settlement sites such as Munka and other locations in the landscape where specific resources are abundant, they erected several kinds of wooden constructions. Near these places various activities were carried out extensively, for example cutting of trees and small-scale cultivation. In the forest surrounding the settlement site the herders kept their reindeers, either roaming free or inside fences – depending on the time of the year. Over large areas they collected firewood and in the spring they harvested inner-bark. Extending outwards from these loci other forms of land use were performed, for example hunting along trap lines and gathering other specific resources (Fig. 20). These forms of land use were also repeated in various other parts of the landscape since the herders moved seasonally between different settlement sites.

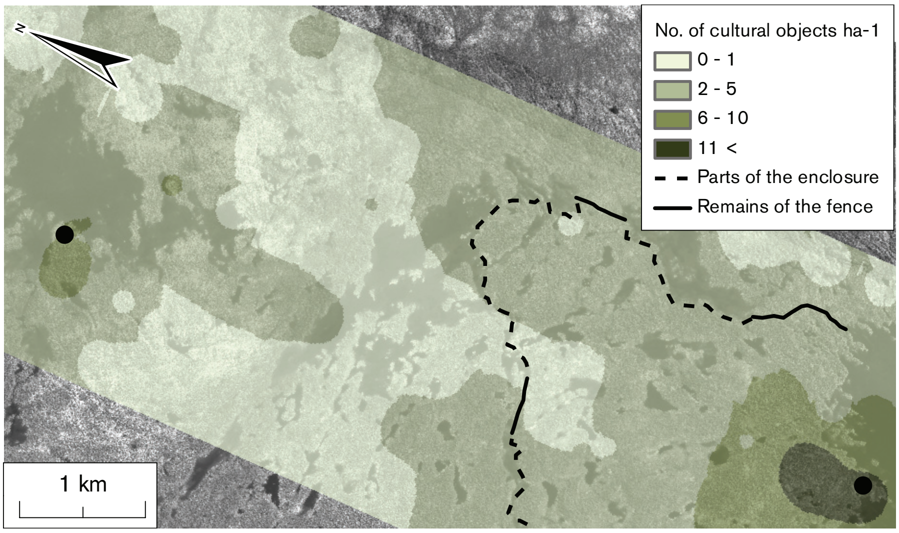

Figure 20. Map of the central parts of Tjeggelvas nature reserve showing interpolated data on numbers of cultural objects per hectare, the locations of two abandoned Sami settlements (•) and the area encompassed by the remains of an old reindeer enclosure. © Lantmäteriet 1998, dnr 507-98-4720

Furthermore, as the scale is increased other forms of land use add further layers to this mosaic. At certain places along the river valley small agricultural settlements were established during the 19th century. These permanent settlements required larger areas and introduced new types of land use, for example farming of domesticated animals and hay-making, which also formed gradients and patterns around the settlements. Moving forward in time and down the river valley the traditional forms of land use by Sami people are often overlain by more extensive agricultural land use and more recent forms of forest utilisation, logging in particular, which have masked (and sometimes obliterated) many of the signs of the previous uses. As demonstrated in section 4.2, these loggings were far from uniform in character; logging in different periods was directed towards different types of trees, resulting in clear dissimilarities in both the spatial extent and the intensity of the cuttings.

Most importantly, although the immediate effect of a certain land use may seem insignificant, its cumulative effects may be extensive if carried out over long periods of time (Foster *et al.*, 2003; Briggs *et al.*, 2006; Willis & Birks, 2006). Accordingly, interpretation of the many different patterns and gradients of past land use, varying in strength and intensity, and the resulting mosaic of human disturbance, in contemporary forest landscapes is perhaps the most challenging task in historical ecology since so much detailed information is needed and so much complexity is involved. In northern boreal 'pristine forests' a characteristic feature is the presence, within very old forest ecosystems with few tree species, of subtle gradients and patterns, which might be related to factors other than those normally expected in temperate forests and regions that have been used for agriculture in the past.

4.4 Sources and strategies for studying land use in northerly forests

Linking ecology, history and archaeology to study past human land use and both its immediate and continuing effects on the environment is not an easy task, and I think there are several reasons for this. In general, studying past human land use is problematic, since the legacies of past anthropogenic activities, including low-intensity land use by indigenous people, may last for many centuries and interact with natural disturbance in ways that make their environmental effects very difficult to discern in the field (Foster *et al.*, 2003). Choosing the appropriate timeframe can be also problematic. Often a much too short time perspective is applied in ecological studies in analyses of processes that have shaped contemporary forest landscapes. For example, Willis & Birks (2006) found that timeframes of more than a few decades are rarely applied in modern biodiversity assessments. However, to understand ecosystem processes operating at landscape or larger scales, including those affecting long-lived organisms such as trees, timeframes encompassing centuries to millennia are more appropriate (Fuller *et al.*, 1998; Swetnam *et al.*, 1999; Willis & Birks, 2006). Furthermore, careful attention also has to be paid to the methods to be applied.

4.4.1 Methodological considerations

As noted by Briggs et al. (2006), deciphering the relationships between land use and the structure and function of ecosystems requires data spanning long time depths, which can be accessed through archaeological records. Some archaeological records tell of land use practices that may have had an impact on the forest ecosystem (for example cut stumps). Other traces, like bark-peeling scars and tree blazes, indicate land use that did not have any effect on either forest structure or vegetation composition. These traces form a vital part of the archaeological and biological record since they may aid the interpretation of past human activity in that they can tell of specific events that have taken place in the area and add context to the intensity of land use (Prince, 2001; Östlund *et al.*, 2002; Hageneder, 2003). Yet, no meaningful interpretations can be made about the type or magnitude of certain land use practices unless the archaeological record is correlated to the people who created and maintained the archaeological artefacts (Binford, 1980). Such correlations can be drawn using various archival sources. By combining demographic data and physical land descriptions with modern environmental information quantitative estimates of impacts of land use can eventually be obtained.

Furthermore, the great longevity of many tree species in boreal ecosystems provides good opportunities to analyse events related to human land use far back in time by using dendrochronology. To aid the analysis of tree ring patterns, a local chronology of specific years or series of years in which wood with distinctive properties was produced, for example very dense and dark late wood, can be initially established (Table 3). These so-called pointer years are very useful in the interpretation of past disturbance events, for example to see if they coincide with climatically extreme years (cf. Niklasson *et al.*, 1994). Furthermore, abrupt changes in ring patterns of mature trees are mainly caused by marked changes in tree growth rates. Such growth responses provide powerful indicators of past disturbance events, for example climatic changes, fires, storms or human activities (cf. Lorimer, 1980; Groven *et al.*, 2002; Josefsson *et al.*, 2005).

Analyses of pollen records provide even longer timeframes, and allow the interpretation of past changes in vegetation composition due to human activities. Traditionally, human impact on vegetation cover has been interpreted from reductions in arboreal pollen percentages (indicating forest clearance), increases in percentages of grass and herb pollen (signifying increases in open land), and the appearance of pollen from cereals and ruderal plants (Behre, 1988; Birks *et al.*, 1998). Even in northern Fennoscandia most previous research on past human activity has focused on regional vegetation history in relation to the introduction of agriculture, including farming of domesticated animals or slash and burn activities (Vorren, 1986; Hicks, 1988; Segerström, 1990). However, I believe that to identify and interpret other forms of human activity in northern boreal forests alternative approaches must be used. Because human activity are mostly restricted to certain localities in the landscape the peat samples should be collected from carefully selected forest hollows or small ombrotrophic peat mires (cf. Bradshaw, 1988; Calcote, 1998) (Fig. 21). These should be carefully examined and compared to samples from several other sites or reference areas (to distinguish regional climate signals from local patterns of changes). Especially important is the interpretation of taxa that are rare in the studied forest in the pollen records.

Table 3. *Pointer years obtained from cores of 35 very old Scots pine trees in the three study areas.*

Year	Type	Ring characteristics
1575	1	Wide ring with dark late wood
1601	3	Very thin ring, sometimes absent
1641	3	Thin ring, followed by several thin rings throughout the decade
1655	1	Ring with dark late wood
1671	1	Ring with dark late wood
1680	3	Very thin ring, sometimes absent
1688	3	Thin ring
1703	1	Very wide ring with dark late wood
1704	2	Ring with light late wood
1741	3	Thin ring
1744	1	Ring with dark late wood
1766	1	Wide ring with very dark late wood
1772	2	Ring with light late wood
1776	1	Wide ring with dark late wood
1801	1	Wide ring
1813	3	Thin ring
1821	3	Thin ring
1826	1	Very wide ring dark late wood
1831	1	Wide ring with dark late wood
1837	3	Very thin ring, sometimes absent
1844	3	Very thin ring, sometimes absent
1861	1	Wide ring with dark late wood
1868	1	Ring with dark late wood
1873	1	Ring with dark late wood
1881	3	Thin ring
1901	1	Very wide ring dark late wood
1902	2	Thin ring with light late wood
1934	1	Wide ring with very dark late wood
1937	1	Wide ring with very dark late wood
1959	1	Wide ring with dark late wood

(1) Ring with dense and dark late wood; (2) Ring with light late wood; (3) Narrow ring

However, all methods have limitations and problems associated with their application to particular ecosystems may be difficult to foresee. Specific problems encountered in the palaeoecological approach were difficulties in choosing appropriate pollen sampling sites in remote forests where no indicative data were available. Since past human land use is often difficult to distinguish in the field, the sample site had to be verified by archaeological information. Furthermore, the interpretation of different pollen taxa (anthropogenic indicators) and their relation to specific forms of past land uses was also problematic. Since the traditional interpretation of anthropogenic indicators is based on human land use in rather different contexts and ecosystems (cf. Vorren, 1986; Behre, 1988; Bos & Janssen, 1996), new such indicators have to be identified and alternative interpretations of the pollen record are required in studies of northern boreal ecosystems with historically low levels of human presence. In addition, in the dendrochronological analyses unexpectedly high degrees of heart-rot in old pine trees were encountered that hindered determination of the ages of the oldest trees. For the use of historical records other problems emerged. The historical records complement the biological archives in many ways, but they are limited in time and sometimes important records are incomplete or impossible to decipher. An unfortunate circumstance is the lack of very important data such as old reindeer counts and changes in reindeer numbers over time.

Figure 21. Collection of peat samples from a small ombrotrophic peat mire, Tjeggelvas. (Photo: Torbjörn Josefsson)

4.4.2 How to combine different methods

As mentioned above, one of my aims in this thesis is to present 'a set of tools' that can be used to decipher the ways northern boreal forests have been affected by anthropogenic land use. As pointed out by other authors, for example Östlund & Bergman (2006), the traditional methods and interpretations applied in landscape studies cannot necessarily be applied to more northern regions. By combining the different methodologies described in this thesis with new ways of interpreting and analysing data, human impact on northern boreal ecosystems can be better assessed (Fig. 22). Accordingly, each methodological approach underlying this thesis may be seen as a piece of a jigsaw puzzle, some pieces of which have been joined together, while other pieces remain to be linked and others are currently missing. To fit all the pieces together a careful strategy is needed. In my opinion an effective way to do this is to conduct the research in order of time-depth, starting with the long-term records. First, superficial archaeological field surveys and overviews of literature and other historical sources may identify places where more in-depth studies may be most fruitful. Secondly, palaeoecological analysis gives a long-term perspective on vegetational changes and helps to identify particularly interesting time periods. Thirdly, dendrochronological analysis provides high-resolution data on forest characteristics at local and landscape scales, including the precise dates of important historical events. Fourthly, historical records can put human *"…flesh on the carbon-based bones of forest history"* (Williams, 2000). Lastly, ecological field surveys of certain structural elements or species groups may generate information on effects of identified land uses on biodiversity. Based on the obtained knowledge, implications of past land use for conservation management and scientific research can finally be assessed.

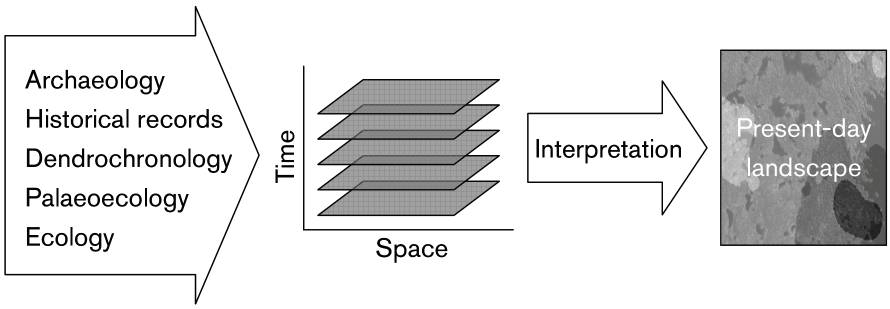

Figure 22. Conceptual model of the different methodologies applied in this thesis to analyse and interpret temporal and spatial gradients of human land use in northerly boreal forest ecosystems.

4.5 The value of studying pristine forest landscapes

Forest landscapes such as that of Tjeggelvas nature reserve constitute the remains of the vast expanses of forest that once blanketed large parts of the northern hemisphere. It is unique from a Fennoscandian (and European) perspective for a number of reasons. The forest in itself is captivating and impressive because of its remote setting adjacent to the Caledonian mountain range, its great age, structural heterogeneity and biological values. That large parts of this forest landscape have not been commercially logged is also remarkable. It has practically escaped exposure to agricultural activities, and there are no signs of common minor forest uses, such as production of tar or charcoal. Hence, it could be viewed as the archetypal pristine boreal pine forest of northern Europe. Nevertheless, forests are not pristine simply because they seem to be untouched and wild – the potential effect of pre-industrial land use should always be taken into consideration, since (as I have shown in this thesis) humans may have used forests like Tjeggelvas for centuries, or even millennia.

4.5.1 Approaching a definition of pristine forest

For generations, the northernmost part of Fennoscandia has been utilised by people with hunting- and fishing-based subsistence strategies and Sami reindeer herders. In North America, such forests have been the home to Koyukon people in the northwest, the Cree, Iroquois and Innu in the northeast (Nelson, 1980; Brody, 1988; Ray, 1996), and the Chukchi, Evenki, Koryak, Nenets and Yukagir (among others) in northern Russia and Siberia (Vainshtein, 1980; Golovnev & Osherenko, 1999; Vitebsky, 2005). Clearly, to these people the term pristine forest does not conjure up images of a forest untouched by humans, neither is it synonymous with areas of vast wilderness. Returning to the opening question about what a pristine forest really signifies, we realise that the answer largely depends on who we ask and how we define concepts such as pristine. Theoretically, a 'pristine forest' can be defined as an environment devoid of humans. In practice, however, no contemporary forests can be seen as pristine since human influence on the world's forests is all-pervasive (cf. Peterken, 1996; Rouvinen & Kouki, 2008).

One important realisation is that 'pristine' is intimately related to 'natural'. However, what is considered as natural depends on many ecological, historical, temporal and cultural factors (Sprugel, 1991; Hull *et al.*, 2001; Povilitis, 2002; Willis & Birks, 2006). Natural can, for example, be seen as the antithesis to artificial, or a state in which the features of an environment derive strictly from factors that are not attributed to people.

According to Martinez (2003), the dichotomy between 'natural' and 'presence of people' is a product of the Western idea of natural, i.e. that humans are separate from nature. To many indigenous people worldwide there is no such contradiction, since they view themselves as an integral part of nature. This is in part a result of an expression of their animistic religious belief, their affiliation to the land, but also partly due to the long times these cultures have been interacting with their environment (Hammett, 1992; Martinez, 2003; Bergman, 2006). Consequently, whether humans should be seen as a part of nature or not is, I believe, also a philosophical question.

Regardless of the philosophical perspective, strict usage of 'pristine' would be useless in ecological research, as well as management for conservation and restoration, simply because no such forest exists. A certain degree of human impact may therefore be accepted in environments regarded as natural. However, if human influence is accepted, there are still large uncertainties regarding the extent and kind of land use that would be acceptable in a forest defined as natural. Since some forests are less affected by anthropogenic disturbance than others, they can also be said to display different degrees of 'naturalness'. This concept has a broader scope than 'natural' with implications that it incorporates not only the similarity to natural conditions, but also the extent of anthropogenic influence on the forest ecosystem. This makes the concept more useful, but one major disadvantage is that it is very difficult to quantify, since it is a continuous variable. For example, estimates such as high, medium or low levels of naturalness are difficult to interpret and compare with other data. Nevertheless, the concept of naturalness has been applied by some authors, for example, Uotila *et al.* (2002) using forest data and historical records to evaluate the extent to which past human influence has affected the current forest structure of protected forests in eastern Fennoscandia, and by Reif & Walentowski (2008) in assessments of its implications for nature conservation and forestry in central Europe.

How then may concepts such as 'pristine', 'old-growth' or 'natural' be defined? For a professional ecologist, forester or conservation manager, a wide-ranging definition of any of these terms is rarely feasible or desirable. In my opinion they are more useful when given a definition that is related to a particular place and time of interest. Furthermore, there are three important aspects that should be explicit components of any such definition, namely the forest characteristics and succession phase, spatial and temporal limits, and the historical impact by humans. In general, I believe that the concepts 'pristine', 'virgin' and 'primeval' can be used both in practice and in theory to describe the physical resemblance of a forest to a 'natural forest'.

On the other hand, 'natural' may often be better used in a theoretical sense, in accordance with assertions by Peterken (1996) that 'natural' is precise as a concept but imprecise as a descriptor of individual forests. Nevertheless, when referring to northern boreal pine forests in Fennoscandia I recommend that all concepts related to 'pristine' should be used with great caution since forests that may be appropriately termed pristine are extremely rare, and if they are used they should primarily be applied at the landscape level. Furthermore, many ecologists and foresters have used the concept 'old-growth forest' to describe a forest ecosystem with certain structural, compositional and functional attributes that may signify pristine conditions (Veblen *et al.*, 1980; Franklin *et al.*, 1981; Hofgaard, 1993; Sippola *et al.*, 2002). When regarded as a stage in forest development this term may be very useful. However, when old-growth is used to depict a pristine forest ecosystem I believe it is erroneous, because it fails to acknowledge the variations in successional stages and other ecosystem changes caused by natural (as well as anthropogenic) disturbances and ecological (e.g. climatic) changes. Most forest ecosystems are far from stable, and will never reach an equilibrium state (Sprugel, 1991; Kimmins, 2003).

4.5.2 Reference areas, conservation and cultural heritage

Using a combination of ecological and historical methods to study forest ecosystems, managed as well as unmanaged, serves many purposes. Studying forests that have escaped modern forest management is especially valuable. It increases our understanding of the complexity of past human activities and their interactions with the forest ecosystem. It also enhances our understanding of contemporary landscapes and their historical contexts, not only from an ecological perspective (Foster *et al.*, 1996), but also from a cultural point of view, i.e. that many 'pristine' forest landscapes are, in fact, cultural landscapes that have been shaped by human history (Foster *et al.*, 2004; Östlund & Bergman, 2006; Bürgi & Gimmi, 2007). Ultimately, it provides fundamental information for comparative, interdisciplinary studies and for conservation management (Gillson & Willis, 2004; Honney *et al.*, 2004).

An important lesson I have learned from the studies underlying this thesis is that forests in remote and inaccessible areas with no recent management cannot be indiscriminately used to represent 'natural' or 'pristine' reference conditions. Old secluded forests that give the impression of being undisturbed by human activities might be ecologically valuable in terms of intactness and biodiversity. Yet, as shown in this thesis, they may also have been utilised by humans for long periods of time, causing changes in forest characteristics. Hence, pristine forest should not be equated to 'untouchedness' or forests with high biodiversity. Likewise, there is no clear relationship between untouchedness and high biodiversity. Occasionally, high biological value may develop in quite short periods of time, for example after grazing (Ericsson *et al.*, 2000) and sometimes human impact may enhance rather than reduce biodiversity in forest ecosystems (Sprugel, 1991; Peterken, 1996).

Furthermore, periodic disturbances and successional processes operating over a wide range of temporal and spatial scales are the main forces shaping the forest landscape and sustaining ecosystem function and biodiversity (Spies & Turner, 1999; Kuuluvainen, 2002). This means that the effects of any process in a certain location at a certain time will depend on the status and responses of the surrounding ecosystem or landscape. A forest landscape is composed of patches, and thus may be structurally very complex, uneven-aged and affected by a multitude of disturbances (see discussion in section 4.3.2). Therefore, I suggest that forest areas such as Tjeggelvas may be regarded as pristine when a whole landscape is considered and may well be suitable sources of reference data on biodiversity and forest structure. Individual patches, however, may differ considerably from the overall landscape, and display marked variations in forest structure and composition. For example, some forest characters may have been altered locally where the land use has been more intense. Hence, designating a small patch as 'pristine forest' or using it to represent reference conditions is more problematic since it cannot be disconnected or detached from the surrounding landscape. In addition, using small sample sites to represent reference conditions requires very careful historical investigations, since ignoring the historical dimension may greatly increase the risk of misinterpreting ecological data acquired from the present forest ecosystem (Bürgi & Gimmi, 2007).

Another important aspect concerns the protection and management of the types of forest studied here. In traditional conservation management one of the most important aspects is sustaining biodiversity (Margules & Pressey, 2000; Angelstam & Andersson, 2001). However, northerly forests regarded as 'pristine' are often attributed higher conservation values than forests that have clearly been modified by human activities (cf. Pollan, 1991; Cronon, 1995; Proctor, 1996; Er & Innes, 2003). In northern Fennoscandia, conservation strategies are frequently guided by the results of field surveys on present ecosystem characteristics (Anon, 2005; Norén *et al.*, 2005), and the presence of structural elements and current diversity of species (Karström, 1992; Bredesen *et al.*, 1997; Nitare, 2005). This implies that conservation efforts mainly aim to preserve current biodiversity, primarily in forests believed to be pristine. This approach may be problematic for several reasons. To begin with, many of the forests that are assumed to be pristine do have a history of human activities. Furthermore, as discussed earlier in this section, ecosystems and their components change over time. Preventing ecosystem change, for example by fire suppression, can be seriously questioned in many ecosystems, and the assumption that the structure and composition of any current forests is the best descriptor of the forests' 'true' characteristics may be deceptive, since the forest we observe today may be more representative of past rather than current environments (Mladenoff *et al.*, 1993; Motzkin & Foster, 2004; Stevenson & Webb, 2004). This may be especially true for slow-growing northern forest ecosystems.

In my opinion, sound conservation management of forests that have not been subjected to industrial logging should be based on both present forest characteristics and past disturbance history – including human land use (Peterken, 1993; Gillson & Willis, 2004; Honney *et al.*, 2004). More precisely, choosing the right criteria for conservation is crucial for appropriate management of the forest, as well as broad agreement regarding conservation objectives among different stakeholders. For instance, conservation values of forests depend on their size and type, as well as their historical context (Norton, 1996; Berglund & Jonsson, 2003; Ericsson *et al.*, 2005). Too often the pristinity of a forest is referred to as the main criterion for forest protection. However, as discussed in this thesis and, for example, by Uotila et al. (2002) boreal forests in northern Fennoscandia with a pristine character are extremely rare features of today's forest landscapes. The Tjeggelvas forest is exceptional in this sense. I recommend that whenever concepts such as 'pristine forest' are applied in conservation efforts the reason for doing so should be well-founded. Taking Eggelats and Vaksamvare as examples, these two forests have been logged several times, with consequent effects on both dead wood characteristics and species composition of wood-inhabiting fungi, and they each cover less than five km^2, which makes them quite small from a landscape perspective. Accordingly, these forests should not be referred to as pristine forests. Nevertheless, they are ecologically very valuable and in great need of protection. In my view more appropriate criteria for conservation and management of forests such as Eggelats and Vaksamvare could be based on forest type and biodiversity.

While sustaining biodiversity and pristinity are two important goals of forest conservation, another reason to protect and manage forests has been substantiated in this thesis, namely to preserve cultural heritage. Most traces of past human activities have been practically erased by newer forms of land use, in particular industrial forestry. Pre-industrial settlement sites and trees that have been modified by humans for extraction of specific resources, marking trails and territories or for religious or ritual purposes (cf. Östlund *et al.*, 2002) are all rare features in today's boreal forests. I think that documenting and preserving such artefacts should be included in nature conservation efforts since they add unique qualities and make the protected forest more valuable (Östlund & Bergman, 2006; Bürgi & Gimmi, 2007). This would be in good accordance with the present social goals of environmental protection, preservation of the cultural heritage and provision of recreational opportunities (Koch & Kennedy, 1991).

5 Concluding remarks

The relationship between people and the environment has been shaped by many factors throughout history. The means of subsistence, social context and land affinity are all important determinants of how humans have chosen to use and shape the specific environment in which they live (Kosse, 1990; Haberl *et al.*, 2001; Sejersen, 2004; Östlund & Bergman, 2006). Several approaches can be applied to unravel this relationship and interpret the environmental effects of different forms of land use, for example combining pollen stratigraphies and historical records (old literature on vegetation and land use history) with archaeological findings, like Zerbe (2004) or with tree-ring chronologies like McLachan *et al.* (2000). The two cited studies emphasize the importance of an interdisciplinary approach to facilitate elucidation and understanding of the complex interplay of ecological, historical and geopolitical circumstances. As affirmed by Foster & Aber (2004), *"…the challenge for ecologists is to integrate biology and environmental sciences with an understanding of the complexities of landscape history in order to forge meaningful interpretations of the present"*. This strategy has also been adopted in the studies underlying this thesis. They also argue that widespread pervasiveness of human land use requires human activity to be acknowledged as an ecological process, and that ecosystem changes, resulting from natural and anthropogenic disturbances, may be quite imperceptible to the human eye, making analysis and interpretations of these changes very difficult.

These are all relevant considerations when studying northern boreal forest landscapes. However, taking this reasoning a step further I argue that for these kinds of forest ecosystems analyses of the relationship between humans and the environment should encompass broad spatial areas and timeframes, within which the possible environmental effects of indigenous peoples' land uses are considered. As I have shown in this thesis, there may be many different patterns and gradients of past land use, varying in strength and intensity, which have to be taken into account when interpreting human impact on contemporary forest landscapes. In addition, a clear strategy for choosing relevant methods and applying them in the right order should be adopted. Furthermore, a specific 'toolbox' should be used to detect and interpret anthropogenic disturbance in these forest ecosystems. Then, possibly pristine forests can be evaluated as reference areas for addressing scientific research questions and conservation management.

The methodological approaches used in the studies underlying this thesis are not only applicable to northern Fennoscandian boreal forests, but can also be applied to other northerly ecosystems. However, each forested region throughout the northern hemisphere has a unique human history and constellation of ecosystems. Thus, past and present environmental characteristics of each studied forest have to be considered in the light of their historical context. Furthermore, the methods used have generated interesting answers to the questions posed at the start of this thesis, but many questions remain unanswered. For example, can the cumulative imprint of human land use be seen as a set process, eventually leading to degenerated ecosystems with lowered productivity and biodiversity? Or, alternatively, can certain pre-industrial forms of land use maintain or even enhance productivity and biodiversity? Understanding low-productivity forest ecosystems' resilience, and thresholds for recovery, is crucial for conservation management as the world's climate is changing. Another fundamental research issue is the relationship between land use and forest fire in these ecosystems. For instance, why do large parts of the Tjeggelvas nature reserve show very few signs of past forest fire compared to the surrounding forest landscape and what are the ecological consequences of this?

In this thesis I show that the environmental impact of human subsistence and land use in northerly forest landscapes is far more complex and comprehensive than generally acknowledged. This gives reason to reconsider the allegedly pristine nature of these forests and perhaps to redefine the concept of pristinity. It also opens up new and exciting fields of research on the border between ecology and cultural history.

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