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The Transformation of a Norway Spruce Dominated Landscape Since Pre-Industrial Times in Northern Sweden: the Influence of Modern Forest Management on Forest Structure

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Logging history and the study of reference conditions in Scandinavian boreal forests has tended to focus on Scots pine dominated ecosystems. This paper presents a regional study of pre-industrial forest conditions and examines the effects of the industrial exploitation of ecosystems dominated by Norway spruce in northern Sweden. Historical records covering a period which preceded industrial logging in the study area (1917–1927) were used to obtain quantitative data on forest structure and influence of forest fires. These data were compared with a modern data set (2003) to analyse changes due to the industrial transformation of the forest. The early 20th century landscape was dominated by old, multi-cohorted spruce forests and mixed coniferous forests. It was found that fire affected both the structure and composition of the landscape. In post-burnt areas, even-aged forests dominated by deciduous species were the principal forest type. Between the early and modern data sets, profound changes in tree-species composition and age structure were documented. While the total volume of deciduous species increased substantially, the coverage of forests dominated by deciduous species decreased. There was also a significant increase in pine-dominated forests and in the total volume of pine. The industrial transformation of the studied landscapes has had profound effects on the structure of spruce forests, but much less so on deciduous forests. The study concludes that the present forest structure is a function of past management regimes, and that future transformations of the landscape will continue, thus affecting the natural variability and biodiversity of the forests.

Keywords forest history, disturbance dynamics, deciduous forest, fire, birch
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1 Introduction

Forest systems dominated by Norway spruce (*Picea abies* (L.) Karst.) constitute an essential part of the Fennoscandian boreal forest and harbour a variety of habitats that are important for many rare and threatened species (Esseen et al. 1997, Siitonen 2001). The stand dynamics of spruce forests are believed to be characterised by gap-phase dynamics, where the death of dominant trees and consequent regeneration occur continuously at local spatial scales (Sernander 1936, Hofgaard 1993, Kuuluvainen et al. 1998). Fires are also important in forest dynamics, having longer term impacts in spruce dominated landscapes than in those characterised by Scots pine (*Pinus sylvestris* L.) (Gromtsev 2002, Pitkänen et al. 2003, Wallenius et al. 2005). To date, historical analysis of the impact of fires on forest structure in northern Sweden has focussed on ecosystems dominated by Scots pine (cf. Östlund et al. 1997, Axelsson and Östlund 2001). The role of fire as a driving force for change within a forest ecosystem, together with the effects of early logging undertaken in Norway spruce dominated ecosystems in northern Sweden, are both important issues about which relatively little is known. Such knowledge is critical for the effective implementation of forest management strategies based on the natural variability of forest ecosystems (Seymore and Hunter 1999, Kuuluvainen 2002). A further interesting aspect revealed when analysing pre-industrial forest conditions is the distribution and abundance of deciduous trees in landscapes dominated by Norway spruce. In Scots pine dominated areas, deciduous trees occur as a minor component of multi-aged coniferous forests, and deciduous forests constitute only a limited part of the pre-industrial landscape (Linder and Östlund 1998, Axelsson and Östlund 2001). However, Axelsson and Östlund (2001) have shown that deciduous forests were more common in high altitude areas where spruce was more abundant.

Throughout the 20th century forestry was a very intensive industry. Typically, only relatively small areas of forest (< 1000 ha) are protected in nature reserves or national parks. Due to the small size of these protected areas, and because natural disturbance regimes within them have been interrupted, such areas are not suitable for the study of natural forest dynamics at a landscape and regional level. Consequently, the study of forest dynamics at a landscape scale requires retrospective methods of assessment to be used. Historical records, e.g., forest inventories and forest management plans, provide data and information to allow tree species composition and the age-distribution of forests to be studied in detail at specific points in time (Axelsson et al. 2002, Mladenoff et al. 2002). Furthermore, the analysis of records from specific time periods provides an efficient method for studying landscape change (Bürgi 1999, Rhemtulla et al. 2007). The time frame for such studies, however, is limited by the availability of data. In northern Sweden, the first available forest surveys date from the second half of the 19th century. The data in these forest surveys are generally of a very high standard, with detailed spatial resolution covering entire landscapes (Östlund et al. 1997).

Reconstructions of pre-industrial forests are often interpreted as representing natural forest conditions (Linder et al. 1997, Bollinger et al. 2004). However, it is argued in this study that anthropogenic activities that occurred in pre-industrial forests could have substantially affected disturbance regimes (Lehtonen 1998, Niklasson and Granström 2000), forest structure (Lehtonen and Huttunen 1997, Hörnberg et al. 1999, Ericsson et al. 2000), vegetative composition and forest dynamics (Segerström and Emanuelsson 2001, Hellberg et al. 2003). Consequently, in order to assess the degree of naturalness, the reconstructed landscapes have to be interpreted in their specific historical context, and the factors that have shaped the forest landscape need to be thoroughly investigated. By adopting such an approach, knowledge about the effects of disturbance on forest structure and composition at a specific point in time can be gained and this can lead to an improved overall understanding of the dynamics of the boreal landscape.

This paper presents a regional study of forest composition and structure in landscapes dominated by Norway spruce in northern Sweden, with special emphasis on deciduous trees and deciduous forest types during the 20th century. The study was undertaken by collating data from forest management plans covering the period 1917–1927, and from the year 2003. To better understand the reasons behind the characteristics of the 1917–1927 landscape, and to validate the historical data in the forest management plans some forest fire events were interpreted by cross-dating fire scars on living trees.

2 Material and Methods

2.1 Study Area and Historical Sources

The study area is located in Västerbotten County, in boreal Sweden (Fig. 1). The region belongs to the northern boreal vegetation zone (Ahti et al. 1968). The study area is characterised by an undulating terrain at fairly high altitudes, ranging from 250 to 640 m above sea level (Table 1). The average July temperature is between 12 °C and 14 °C, the length of the growing season extends to between 130 and 140 days, and the annual precipitation rate is approximately 600–700 mm/year (Raab and Vedin 1995). The underlying bedrock of the region mainly comprises younger granites and quartzite, covered by moraine deposits rich in clay (often >8%) (Fredén, 1995). Along the river systems, coarser fluvial material represents the dominant deposit. Large areas of peat land are found throughout the study area. The forest tree layer is dominated by two main coniferous species, Norway spruce and Scots pine, with small numbers of deciduous trees (mainly *Betula pubescens* Ehrh., *Betula pendula* Roth., *Salix caprea* L., *Populus tremula* L. and *Sorbus aucuparia* L.). Dwarf shrubs (*Calluna vulgaris* (L.) Hull., *Vaccinium vitis-idea* L., *V. myrtillus* L., *Empetrum hermaphroditum* Hagerup) and herbs dominate the lower vegetation, their distribution being dependant on individual site conditions and altitude. Reindeer lichens (*Cladina* spp.) and feather mosses (*Pleurozium schreberi* (Bird.) Mitt., *Hylocomium splendens* (Hedw.) BSG., and *Dicranum* spp.) tend to dominate the ground vegetation.

Within the study area, the delineation of state forest and private land occurred during the late 19th century. The areas of state forest land formed practical management units, called State Forest Parks (Sw. "Kronoparker", hereafter referred to as SFP). All state forest land was managed by the Swedish Forest Service (Sw. "Domänverket"). In

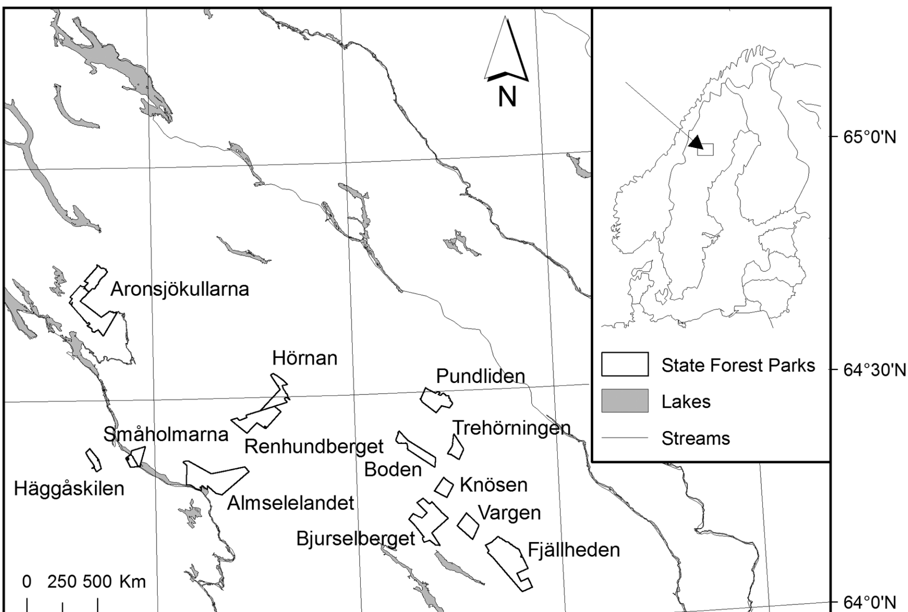

Fig. 1. Map of study area with location of the State Forest Parks studied.

Table 1. Date of the first inventory, forest area (1917–27 and 2003) and altitude (in m above sea level) for all study sites.

State Forest Park	Year of first inventory	1917–27		2003		Altitude (m.a.s.l.)
		Total area (ha)	Productive forest (ha)	Total area (ha)	Productive forest (ha)	
Almselelandet	1924	12 219	9828	5816	4466	340–540
Aronsjökullarna	1917	5692	4116	5621	3901	360–510
Bjurselsberget	1927	4374	3521	4667	3702	270–570
Boden	1927	2061	1352	2013	1373	420–560
Fjällheden	1923	5496	4164	6236	4624	260–580
Häggåskilen	1925	848	585	807	593	340–480
Hörnan	1917	5700	3199	2050	1281	340–480
Knösen	1923	995	663	1106	875	390–560
Pundliden	1927	2701	2071	2461	1852	250–440
Renhundberget	1926	2751	2262	4059	2118	390–640
Småholmarna	1917	2752	1044	1033	865	330–610
Trehörningen	1927	1013	864	1108	983	280–400
Vargen	1921	1675	1234	1658	1142	390–540
Total		48 277	34 903	38 635	27 775	

some SFPs, timber counts of all pine and spruce trees with a diameter at breast height greater than 20 cm were conducted in the 1880s and 1890s. Later, forests were surveyed in more detail and forest management plans were produced. During the 1910s, the first standardised surveys of the area were undertaken. These forest surveys were undertaken as a combination of a superficial survey and delineation of each stand and data from transects. The density of sample plots varied somewhat between the SFPs but on average approximately five percent of the forest stands were sampled. However, timber volume estimates were only calculated for coniferous trees. Timber volume estimates for deciduous trees were compiled at a later date, from 1917 onwards, in some areas. The dates of the first forest surveys vary between different SFPs, with some not having been surveyed until the 1920s. Today, all SFPs are owned and managed by Sveaskog AB, a state owned company.

A total of thirteen SFPs were selected for the present study, based on the following criteria: 1) data on the volume of deciduous trees were available from surveys conducted before 1930; 2) at least 70% of the total coniferous volume was comprised by spruce; and 3) data were available in a modern format, i.e. the forest was still owned by the state. All the SFPs in the study area that met these criteria were included in the study. The earliest management plans that fulfilled the above criteria were produced in 1917 and the end of the study period was set to 1927. In several areas, the inventories used were the first to be conducted in the parks. During this period (1917–1927), the areas of the parks studied ranged from 848 ha to 12 219 ha (Table 1). The total investigated area was 48 277 ha, of which 34 889 ha was productive forest land, with an annual increase in volume of more than 1 m^3 per hectare per year. Over time, parts of some SFPs have been sold off to other land owners. Thus, the total investigated area in 2003 of 38 635 ha was less than that of the earlier period (1917–1927). However, the percentage of land in productive forest use remained the same over the entire study period (72%), from the early 20th century until 2003 (Table 1).

2.2 General History of the Study Area

The study area is as sparsely populated today as it has been historically. A significant rise in population took place during the mid 18th century, when farmers began to settle in the area. The agricultural colonisation of the region intensified over the 19th century (Rudberg 1957, Lindgren 1995). People's use of the forest in the 18th and 19th centuries was primarily to exploit its agricultural resources, such as grazing in the forest and the harvesting of hay from mires (Tirén 1937, Ericsson 2000). Even during the 20th century such activities continued to be documented in forest management plans for almost all areas. In addition, deliberate burning of the forests was undertaken to improve their grazing potential. An exhaustive historical analysis of forest fires conducted in a region close to the study area revealed that both the number of fires and total area burnt increased after farmers settled in an area (Niklasson and Granström 2000). However, after 1870, the documented influence of fire on forest structure and composition has been sparse due to fire suppression (Zackrisson 1977, Niklasson and Granström 2000). In addition, grazing by livestock could have affected the forest ecosystem (Ronge 1940, Tirén 1948, Frödin 1952). Prior to the industrial period, trees were mainly felled for construction purposes, for fuel, or for small-scale forest utilisation activities, such as the production of potash. Potash was produced in the region during the late 18th century until 1860 (Tirén 1937, Östlund et al. 1998). This practice necessitated the selective cutting of deciduous trees, but it is uncertain whether potash production was actually undertaken in the study area. The industrial exploitation of forest resources in the region began towards the end of the 19th century. At first, logging primarily comprised high-grading and strip cutting (Sw: "kulisshuggning"), but the industry rapidly expanded, and by the turn of the 20th century included the logging of smaller timber trees as well as pulp-wood production. Today, almost all productive forest land in the study area is affected by intensive forestry practices.

2.3 Analysis of Forest Composition and Structure

From the earliest forest management plans (1917–1927) detailed information was compiled for each stand. The following data were recorded: tree species composition (proportion of pine, spruce and deciduous trees), structure (openness, age structure and volume of conifers) and logging history (clear cutting or selective cutting). Table 2 presents the definitions and criteria used to delineate different forest types. Indices were developed for different forest types in order to allow comparisons with modern forest data. At the start of the study period multi-aged forests covered large areas of the investigated area, and between 1917 and 1927 the percentage coverage of each age class within each individual stand was recorded. This approach makes it difficult to calculate an average age for each stand. However, since the area covered by each age class was recorded, this information was summarised for each SFP instead of for each stand. This approach will result in an underestimate of the area covered by old forest stands since the area

Table 2. Classification criteria for forest type and stand structure.

	Criteria
Forest types	
Pine	Pine ≥70%, deciduous <10%
Spruce	Spruce ≥70%, deciduous <10%
Pine, deciduous rich	Pine ≥50%, deciduous 10–49%
Spruce, deciduous rich	Spruce ≥50%, deciduous 10–49%
Mixed coniferous	Conifers ≥90%, pine or spruce <70, deciduous <10%
Mixed coniferous deciduous rich	Conifers ≥50%, pine or spruce <50, deciduous 10–49%
Deciduous dominated	Deciduous 50–90%
Deciduous	Deciduous ≥90%
No record (clear cut)	No species recorded (clear cuts or recent burns)
Vertical structure	
Single-storied	One age class ≥90% of area
Two-storied	Two age classes, both ≥20%
Multi-storied	Three or more age classes, at least two >20%

covered by younger cohorts in a stand dominated by old cohorts will be categorised as younger forest even though they are a part of the older stand. Stands classified as deciduous forests or forests dominated by deciduous species (Table 2) were more uniform in age and allowed the classification of stand age. Hence, the age of the dominant deciduous cohort was considered to be equal to the stand age. When the forest management plans were created, age class intervals were determined by the average rotation time for stands in each SFP. For average rotation times exceeding 140 years, 50-year age class intervals were used (SFP Aronsjökullarna, Hörnan and Småholmarna); otherwise 20-year age class intervals were used. However, these were regularly combined, forming 40-year age-classes. In the old surveys, the method employed to estimate timber volume was achieved by undertaking line transect inventories in each stand (with 200 m between each transect). Approximately 5% of the forest area was surveyed in this manner and the diameter at breast height (DBH) of all trees more than 10 cm was recorded in 10 cm diameter classes. Local volume functions were presented with the inventory data. When processing the data, this information was used to calculate volume estimates for pine, spruce and deciduous trees in each diameter class (10 cm intervals). Volume estimates for deciduous species were only recorded for the entire SFPs, and not for each stand. Consequently, all the volume estimates for specific forest types presented in this study relate only to coniferous trees.

Modern day forest inventory data were collated for each SFP. Here the areas of different forest types and age classes were calculated, together with volume estimates for tree species and age classes. Volume estimates were made for trees greater than 5 cm (DBH) in young stands and for those over 10 cm (DBH) that will be subject to commercial thinning. The data did not include useful information on stand openness and age structure at the individual stand level. In the modern data set, forest age was considered to be equal to the average age of the stand.

2.4 Investigation of Forest Fire History and Post Fire Succession

In the earliest forest surveys, all stands exhibiting obvious signs of previous fire incidents were classified as "burns" (Swedish: "brännor"). Occasionally, an estimated time since the last fire was noted by a surveyor in the forest management plans. Research was undertaken to ascertain if a more precise and long-term fire history record of the area could be compiled. The study areas were carefully surveyed for any trees and stumps showing fire scars. Despite extensive survey work, scars from only the most recent fires were observed and at relatively few locations. Therefore, long term fire reconstructions based on dendroecological methods could not be reliably established. Instead, historical records with information on earlier fire instances were analysed. To validate the recorded information in the forest management plans, 25 stands which had documented accounts of fire influence were selected for thorough investigation. The stands were visited and trees and stumps surveyed for fire scars. Fire scars from the most recent fire incidents were only found in seven out of the twenty five stands (covering three different fires). Furthermore, fire scars were only found from the latest fire to occur in the stands. Complete or partial cross sections of scarred wood were sampled with a chainsaw (sensu Arno and Sneck 1977), then dried and sanded. All samples were cross-dated with methods described by Schweingruber (1988). The fires were dated to 1837, 1838, and 1861 (these occurring 60, 90 and 83 years respectively before the surveys were conducted). The dates of the fire scars were then compared with the information on tree ages for each stand in the forest surveys, together with any estimates of the time of the last fire recorded by forest surveyors. The fire scar dates correlated well with the age class information and the estimate made by the surveyor. Accordingly, the forest management plans were considered to provide a useful and reliable source of information for reconstructing past fire influences on forests. The time frame was, however, limited to an extent by the oldest age classes of the cohorts regenerated after fires, which were recorded to be either 81–120 or 101–150 years (dependant on which age classes were used in the inventories by surveyors).

For all stands for which there were documented "burns" in the forest surveys, data and information on size (ha), topography (slope and aspect), and time since last fire (based on age class information or written information) were gathered. Information on stand structure (age class distribution, stand openness and volume) and species composition were also retrieved (except for those stands effected by forestry activities before the date of the inventory). In some cases, there were notes recording the time of the last fire, survival patterns of the pre-disturbance stands and occasionally the cause of the fire. This information was also noted and used for research purposes.

3 Results

3.1 Structure and Composition of the 1917–1927 Forests

Between 1917 and 1927 the study area was mainly dominated by old spruce forest (33% by forest type), followed by mixed coniferous woodland (26%) and occasionally deciduous forests (11% by forest type – see Table 3). Pine forests constituted a relatively minor part of the landscape (6% by forest type, Table 3) and deciduous forests and forests dominated by deciduous trees covered almost 14% of the study area (max 50%, min 0% per SFP). Approximately two thirds (66%) of the forest area had a two-tiered or multi-storied stand structure, while the remaining third (31%) was single-storied (including clear-cuts with residual trees). Parts of the study area were affected by forestry activities which preceded the first inventories used for the study; 8% of the total area was recently clear cut. There was large variation between different SFPs, one area had 28% clear-cuts (max) and one SFP had no clear-cuts at all. 19% of the total area was affected by various degrees of selective cutting (max 45%, min 0.7% for the different SFP).

The total standing volume for all tree species was calculated to be approximately 56 m^3/ha (Table 4). Of this, spruce constituted 68%, pine 18% and deciduous trees 14% (Table 4). The

Table 3. Proportion of different forest types and age classes on productive forest land in 1917–27 and 2003. Age data presented in 40-year (26 530 ha) and 50-year (8359 ha) classes.

	1917–27		2003
Forest types (%)			
Pine	6		20
Spruce	33		8
Pine, deciduous rich	2		7
Spruce, deciduous rich	10		25
Mixed coniferous	26		26
Mixed coniferous, deciduous rich	6		5
Deciduous dominated	11		5
Deciduous	3		0.1
No record (clear-cut)	3		4
Age-classes (%)			
Clear-cut	7		8
1–40	10		35
41–80	23		25
81–120	9		21
121–160	15		7
161+	36		4
Clear-cut	2	Clear-cut	12
1–50	17	1–39	33
50–100	36	40–79	15
101–150	9	80–119	21
150–200	13	120–159	14
200+	23	160+	4

Table 4. Volume estimates for tree-species and standing dead trees (total volume, volume per ha and percent) in 1917–27 and 2003.

Tree species	1917–27			2003		
	Total (1000 m^3)	m^3/ha	%	Total (1000 m^3)	m^3/ha	%
Pine	359	10	18	736	27	35
Spruce	1314	38	68	1041	38	49
Deciduous	280	8	14	317	11	15
Lodgepole pine	-	-	-	24	1	1
Total	1953	56		2118	77	
Standing dead trees	95	3		-	-	-

Age-classes	%	Age-classes	%
0–40	0	0–39	12
41–80	11	40–79	33
81–120	8	80–119	36
121–160	25	120–159	18
161+	56	160+	1
0–50	2	0–39	16
51–100	13	40–79	13
101–150	16	80–119	43
151–200	30	120+	28
200+	39		

highest proportion of the volume was found in the 20–29 cm diameter class for spruce and pine trees, and in the 10–19 cm class for deciduous trees (Fig. 2). The highest standing volume was found in spruce forests not previously subjected to forestry activities, yielding an average of 67 m^3/ha (only volume of coniferous trees included). Stand openness was recorded as being equal to or greater than 0.7 on more than 70% of the area of these forests (stand openness as recorded in the forest invent and defined on a scale from 0 which signifies a completely open canopy to 1 which represents a completely closed canopy). The mean volume of stands unaffected by forestry activities was 53 m^3/ha, and 40 m^3/ha for stands previously subjected to selective cutting (only volume of coniferous trees included).

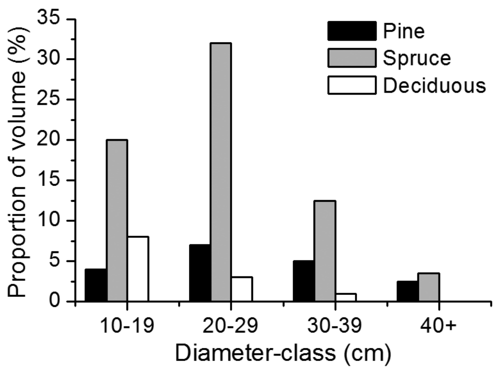

Fig. 2. Proportion of volume of pine, spruce and deciduous trees, in diameter classes, 1917–1927. Diameters for deciduous trees larger than 30 cm in diameter were not specified.

3.2 Legacies of Past Fire Influence on Forest Composition and Structure in the 1917–1927 Landscapes

In total, 167 stands with a combined area of 6354 ha, equal to 13% of the productive forest land, were registered as burnt at the time of the first forest survey. The proportion of burnt areas within individual SFPs varied between 0% and 40% of the productive forest area. The most extensive burnt areas were recorded on flat and undulating terrain. Fires were also recorded as affect-

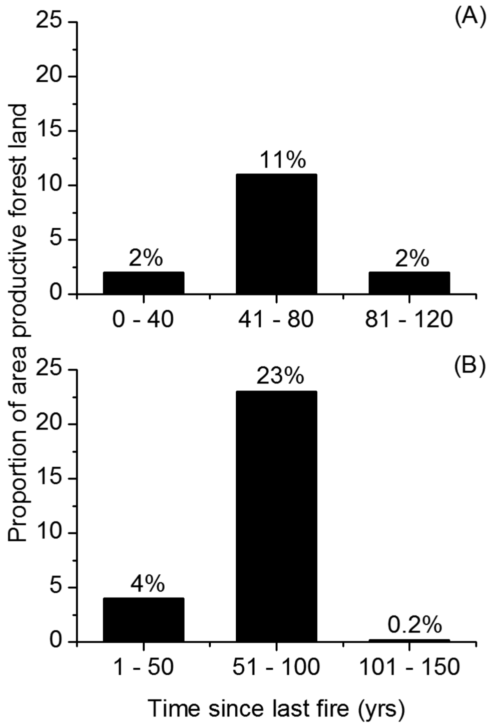

Fig. 3. Proportion of area burnt, in classes indicating time since last fire. A: SFPs with 40-year age classes (26 530 ha) and B: SFPs with 50-year age classes (8359 ha).

ing exposed terrain (at the apex of mountains) and land on northeast facing slopes. The size of individual fires was not calculated since many stands were present within the same fire area. In all, most parts of the study area had been burnt at some point between 40 and 100 years before the surveys were undertaken (Fig. 3).

Deciduous forests or forests dominated by deciduous trees were predominantly located on burnt areas. Together these two forest types constituted 60% of the burnt area (50% deciduous dominated forests and 10% deciduous forests). Deciduous rich pine or spruce forest types were also common, constituting 13% and 18% of the productive forest land, respectively. Almost all burnt areas contained residual trees that had survived the last fire. Most areas had low proportions of such trees, but areal coverage of up to 70% (i.e. tree coverage within stands) was recorded in some areas (Fig. 4). In the field notes from the surveys it was recorded that residual trees were either dispersed individually, growing in groups or dotted along the margins of a fire area. Usually such trees were in a poor state of health and showed evidence of fire scars.

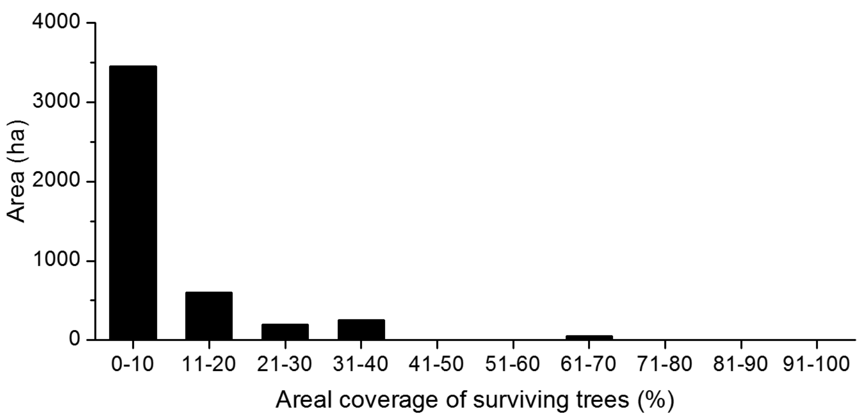

Fig. 4. Cover of surviving trees on burnt areas, including areas with more than 30% pine, with only pine as surviving trees and those with former logging influence are excluded. Note that these figures are not equal to the proportion of surviving trees since the original coverage was probably not 100%.

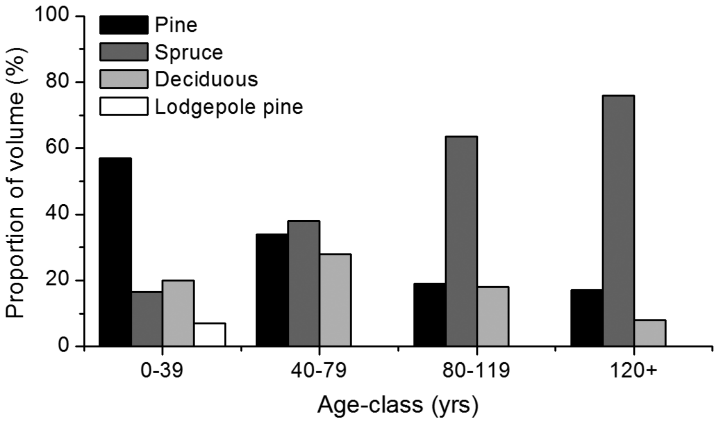

Fig. 5. Proportion of volume of pine, spruce, deciduous trees and lodgepole pine trees within each age class in 2003.

Table 5. Area of deciduous dominated and deciduous forest in 40- and 50-year age classes in 1917–27 and 2003.

	1917		2003	
	Deciduous dominated (ha)	Deciduous forest (ha)	Deciduous dominated (ha)	Deciduous forest (ha)
0–40	387	39	425	0
41–80	1587	461	293	22
81–120	329	0	158	2
0–50	384	49	449	8
50–100	1284	481	84	0
101–150	9	0	69	0

3.3 Changes in Species Composition and Age Class Distribution from 1917–27 to 2003

Comparison of the early forest surveys with the present data set revealed significant changes in species composition, forest types, age class distribution and total standing volume. The proportion of pure Norway spruce forest decreased markedly from 33% to 8% between the years 1917 and 2003, whereas Scots pine dominated forest types increased substantially, especially in younger forests (Table 3). Furthermore, a significant decrease in forests dominated by deciduous trees and deciduous forests (Table 3), together with a transition towards younger forests (Table 5) was also observed over the study period. By 2003, there were almost no older deciduous dominated forests remaining (Table 5).

The study shows that the total standing volume of timber has increased over time from 56 m^3/ha to 77 m^3/ha (Table 4). Due to a large decrease in the oldest age classes of trees and an increase in younger classes, the volume is more evenly distributed across age classes today than during the earlier study period (Table 4). The volume of spruce was almost the same in 1917–1927 as it is today (2003) despite the proportion of trees having decreased (Table 4). In 2003, most of the volume of spruce was found in the older forests (Fig. 5). The volume of pine has increased significantly from 10 m^3/ha for the period 1917–1927 to 27 m^3/ha in 2003. Most of this growth in pine originates from younger forests. The standing volume of Lodgepole pine constituted only 1% of the total volume of forest wood in 2003, with no recording for the earlier study period. However, Fig. 5 shows it to be a potentially important source of future timber, comprising 7% of the total forest volume in the youngest age class in 2003. Although the area of forests dominated by deciduous trees and deciduous forest has decreased (Table 5) there has been a considerable increase in the total standing volume of deciduous trees, from 8 m^3/ha in 1917–1927 to 11 m^3/ha in 2003 (Table 4).

4 Discussion

4.1 Characteristics of the Pre-Industrial Landscape

The pre-industrial spruce forest landscapes identified in the present study have many similarities (e.g. large areas of old mature forest, multi-cohorted stand structure and many large trees) with other studies of boreal Fennoscandia (e.g. Lehtonen 1998, Östlund et al. 1997, Linder and Östlund 1998). However, the spruce dominated stands in this study area tend to be denser compared to other studies. Our results show that fires have had a greater effect on the composition and structure of Norway spruce dominated stands at both the stand and landscape scale than previously acknowledged. For example, post-fire successions in forests dominated by deciduous trees were more common in the study area than in pine dominated landscapes nearby (i.e. Östlund et al. 1997, Axelsson and Östlund 2001), where stand structure and composition on recently burnt areas were similar to the rest of the landscape. Moreover, fire return intervals seem to be longer in this landscape compared to areas located nearby (Zackrisson 1977, Niklasson and Granström 2000), implying that they might have values similar to those suggested by Pitkänen et al. (2003) for a spruce dominated landscape in Finland.

Our results also indicate that the pre-industrial Norway spruce forests were characterised by large differences in the proportion of burnt areas, cover of different forest types, tree species composition and age class distribution. The degree of variation underlies the importance of studying large scale processes, such as fire, at an appropriate spatial level, in order to avoid erroneous conclusions about the characteristics of the fire regime. As discussed by Schulte et al. (2005) certain differences between areas are caused by environmental heterogeneity in physiography and climate, influencing local differences in fire frequency. Moreover, the date of the studied period in relation to the temporal dynamics of forest fire regimes is also significant. It is likely that the number of fires was higher and that the total area burnt was greater between the mid 1700s to late 1800s than prior to 1750, when settlement first started in the area. A number of the fires in the study area were considered to have been of human origin. The high proportion of land burnt within a limited time period could indicate increased human activity in the area (Fig. 3). Thus, the relatively high proportion of deciduous forest types (compared to pine dominated areas) could represent a legacy of earlier human interference with the forest fire regime. Also, different forms of past forest utilisation, for example production of potash, tar and charcoal may have generated long-lasting effects on forest structure and composition (Östlund et al. 1998, Granström and Niklasson 2008). This reinforces the need to conduct studies of the underlying causes of pre-industrial forest characteristics for assessments of naturalness (Uotila et al. 2002, Rouvinen and Kouki 2008) and interpretations of forest conditions in relation to disturbance regimes (Schulte et al. 2005, Wallenius et al. 2005). Due to deficiencies in the archive data and a lack of material for dendrochronological analysis, a more comprehensive assessment of the degree of anthropogenic influence on the forest fire regime could not be made in the present study.

4.2 Changes in Species Composition and Forest Structure

The increase in standing volume of deciduous trees follows the general pattern for the boreal part of Sweden documented by the National Forest Inventories (Statistical yearbook… 2003). It was not possible to analyse changes in diameter distributions of deciduous trees. However, the diameter distribution in 1917–1927 and the distribution of volume over age classes in 2003 imply that no significant changes have occurred. Furthermore, the stand structure in forests dominated by deciduous trees and deciduous forests during the two study periods appear similar. The substantial decrease in coverage of forests dominated by deciduous trees is most likely the result of silvicultural methods favouring coniferous species during the 20th century. However, as discussed by Niklasson and Granström (2000), fire suppression could also be an explanatory variable. To understand this change fully, spatially explicit data on logging and silvicultural activities need to be included. For pine dominated areas in northern Sweden, retrospective studies have documented profound changes in forest age and stand structure, but only small changes in species composition (Östlund et al. 1997, Linder and Östlund 1998, Axelsson and Östlund 2001). In the present study there was a significant increase in both the standing volume of pine and in the coverage of pine dominated forest types. Changes in stand structure could not be fully addressed due to data deficiencies on stand openness and vertical stand structure in the modern data set. However, over the last 80 years profound changes in age class distribution and timber volume have taken place. Stands in 2003 were typically denser and more even-aged (Tables 3 and 4).

A critical aspect when analyzing temporal data extracted from historical records such as forest surveys and forest maps, is the quality of the data of each survey and the comparability of the data between different surveys (cf. Östlund et al. 1997). The former problem causes unknown errors of precision for the different surveys and the latter problem may interfere with the desired comparisons over time. In this study there is a long time span between the early surveys and the modern ones and also methodological differences between the surveys. However, we do believe that the quality of data is generally very good and we base this assumption on the facts that large areas (up to five percent) were actually surveyed by transect inventories in the early surveys which yielded very precise and objective information on stand structure. Also, our investigation of a sample of the burnt areas (including the cross-dating of fire scars) verified the information in the historical records. Finally, many previous studies have used historical records (forest surveys and maps) from the state forest owner and these studies have invariably showed that the information is reliable and can be verified against independent records (cf. Axelsson et al. 2002).

The present study describes changes during the 20th century. Changes will continue to take place due to current forest management strategies and as a result of past activities. A further increase in the dominance of pine is likely to occur as older parts of the forest in the study area, which are predominantly spruce dominated, are logged. Furthermore, the volume of pine will increase as the existing pine forests mature and carry a higher standing stock. In the future, strategies for forest management e.g., stand treatment and regeneration practices, will act as driving forces for forest landscape change (Östlund et al. 1997, Bürgi and Schuler 2003). If similar practices are applied over large areas it will lead to homogenisation of forest landscapes at the region scale. For example, if practices that have prevailed in the study area continue, the resulting landscapes will show great similarities with the pine dominated landscapes studied by Östlund et al. (1997) that are located just north of the study area.

5 Conclusions

We conclude that the industrial transformation of spruce dominated forest landscapes has significantly affected the occurrence of large trees, stand age, species composition and stand structure of coniferous forests. Although, the spatial distribution of deciduous trees has changed, the structural effects of industrialisation on deciduous trees and forests have been limited. In comparison with pine dominated forests in the same region, spruce forests in the study area were denser, and larger areas were covered with deciduous forest types that regenerated after fire. This highlights the importance of considering infrequent disturbances to forest ecosystems (e.g. fire in spruce dominated forests) since they are likely to have profound and long-term effects on species composition and forest structure. Consequently, this important issue needs to be considered in the development of conservation strategies for boreal forest ecosystems. We also conclude that the analysis of past historical data pertaining to pre-industrial forest conditions, can contribute important information to estimations of the natural range of variability of spruce dominated forests, Nevertheless, any assessment of naturalness of these ecosystems must also take into account the underlying causes of past disturbance regimes and the long-term impacts arising from the use of forests by people in northern Scandinavia. The transformations of the studied landscapes are processes that will continue to change over time. The age structure of the present forest is created by past management activities and policies, and will subsequently leave an imprint on the processes of change that occur in the future. Therefore, a management approach which acknowledges knowledge of past processes and landscapes and integrates this into current management thinking is critical to preserve historical variability and prevent biodiversity loss.

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