Abstract

Axelsson, A-L. 2001. Forest Landscape Change in Boreal Sweden 1850–2000 – a multi-scale approach. Doctoral dissertation. ISSN 1401-6230, ISBN 91-576-6067-0.

In the project described in this thesis, structural changes that have occurred in the boreal Swedish forest during the last 150 years were studied through analysis of historical records. Historical perspectives on forest landscapes provide a better understanding of natural disturbance dynamics as well as anthropogenic changes and a frame of reference for assessing current ecological patterns and processes. The studies were performed at various spatial scales, and were conducted in two different forest regions in boreal Sweden. In the district of Lycksele, Västerbotten county, changes were studied from stand to regional scale within the same geographic context. In the county of Dalarna changes in the age distribution of large diameter trees were studied at county and landscape scales.

Different types of spatially explicit historical data were used, including delineation and forest surveys, early timber counts and data from the first Swedish National Forest Inventory. Quantitative data on changes in logging and forest management were also included, and Geographic Information Systems (GIS) were used to integrate various types of historical records and to perform spatial analysis at different scales.

During the last 100 years a sharp reduction in complexity of the forest structure has occurred at all spatial levels. A multi-aged forest matrix has been replaced by a patchwork of forest stands of various ages. Most stands are younger than 100 years and dominated by even-aged forest. The current landscape structure created by forest management differs radically from the earlier landscape structure created by fire disturbance. At the end of the 19th century, deciduous patches were large and occurred at recently burned areas at higher altitudes. Today deciduous stands are distributed more evenly in the landscape and are connected to logging disturbance. Deciduous trees have been systematically removed during the 20th century and today most deciduous trees occur in young stands. Both mean tree age and age variation of large diameter trees has decreased and nowadays large trees older than 400 years are rare in the boreal forest.

Historical records provide unique spatially explicit information on forest structure at various spatial levels that could not be gathered in any other way. Forest surveys are useful for describing historical landscape structure and structural changes from larger stand (>100 hectares) up to regional levels. At smaller spatial scales the resolution of the forest survey maps are too coarse and analysis should be complemented with other types of historical records or other historical methods.

A systematic approach to increase our knowledge of previous landscape patterns and regional variation in disturbance dynamics is presented. ”*Retrospective gap analysis*” involves local analysis of historical records and integration of historical data in ecological landscape planning. In intensively managed landscapes the method can provide a framework for multi-objective forest management and restoration efforts at regional level. The method can also be used to develop regional goals for strategic conservation planning, or to refine goal-setting in forest certification.

Key-words: Boreal forest, landscape history, historical records, forest history, multi-scale analysis, fragmentation, *Pinus silvestris,* age structure*,* deciduous stands, timber-frontier.

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Trädet kan leva utan människor.
Människosläktet kan inte leva utan träd.

Rolf Edberg

Contents

Appendix

Papers I-IV

This thesis is based on the following papers, which will be referred to in the text by their respective Roman numerals.

I. Östlund, L., Zackrisson, O., Axelsson, A-L. (1997). The history and transformation of a Scandinavian boreal forest landscape since the 19th century. Canadian Journal of Forest Research, Vol. 27, No 8, pp 1198-1206.

II. Axelsson, A-L. & Östlund, L. (2001). Retrospective gap analysis in a Swedish boreal forest landscape using historical data. Forest Ecology and Management. In press.

III. Axelsson, A-L, Östlund, L & Hellberg, E. Use of retrospective analysis of historical records to assess changes in deciduous forests of boreal Sweden 1870s–1999. Submitted to Landscape Ecology.

IV. Axelsson, A-L. Old Trees in Northern Sweden – an historical analysis. Manuscript.

Sammanfattning

I denna avhandling har olika typer av historiska källmaterial och kartor använts för att studera förändringar i det norrländska skogslandskapet under de senaste 150 åren. Ett historiskt perspektiv ger en bättre förståelse för såväl naturliga variationer som mänskligt betingade förändringar i skogslandskapet. Historisk information är också värdefull som referens för ett mer ekologiskt skogsbruk, där man strävar efter att efterlikna naturliga strukturer.

Studierna har utförts i olika rumsliga skalor, och arbetet har varit koncentrerat till två olika talldominerade områden; 1) Lycksele kommun, Västerbottens län, där tre olika studier har genomförts från beståndsnivå upp till regional nivå inom samma större geografiska område. 2) Dalarnas län, där variation i ålderstruktur i tid och rum för grova barrträd har undersökts på regional nivå. Inom samma region har den naturliga ålderstrukturen rekonstruerats inom ett enskilt landskap genom en kombination av olika typer av källmaterial.

De främsta informationskällorna har varit avvittringskartor, äldre skogsindelningar, timmerräkningar och data från den första Riksskogstaxeringen. För att kunna ta fram regionala tidsserier över avverkad virkesvolym och skogskötselåtgärder har även olika typer av rapporter från Domänverket använts. Geografiska informationssystem (GIS) har använts för att integrera olika typer av källmaterial med rumslig information och för att utföra analyser av olika rumsliga skalor. Olika aspekter kring tolkning, analys och användning av historiska källmaterial diskuteras och flera exempel som visar på vikten av källkritik presenteras.

Under de senaste 100 åren har skogens struktur förändrats kraftigt både på bestånds- och landskapsnivå. Under 1900-talets början dominerades landskapet av stora sammanhängande områden med olikåldrig tallskog. Idag finns endast små uppsplittrade områden med äldre skog kvar och landskapet domineras av likåldrig skog; oftast helt utan träd äldre än 100 år. Den nuvarande landskapsstrukturen, som har skapats av intensivt skogsbruk under 1900-talet, skiljer sig kraftigt från den tidigare naturliga landskaps-strukturen, som främst skapades av återkommande lågintensiva skogsbränder. Lövträden har systematiskt missgynnats under 1900-talet och idag finns ytterst få äldre lövträd kvar i landskapet. I början av 1900-talet var lövbestånden relativt stora och koncentrerade till tidigare bränd mark i högre liggande områden. Idag är lövbestånden mer jämnt spridda i landskapet och främst knutna till tidigare avverkningar. Intensivt skogsbruk under 1900-talet har också gjort att äldre träd är mycket sällsynta i dagens skogar. För barrträd har medelåldern för grova träd (dvs 30 cm och grövre i brösthöjd) minskat kraftigt under 1900-talet. Under slutet av 1800-talet var 6 % av de grova tallarna äldre än 400 år. Idag är grova barrträd äldre än 400 år mycket sällsynta.

Äldre, systematiskt genomförda inventeringar erbjuder unik rumslig information om det förindustriella skogslandskapet som inte kan samlas in på annat sätt. Äldre skogsindelningar är mest användbara för studier på landskapsnivå och regional nivå. För detaljerade studier på beståndsnivå bör analyser kompletteras med mer detaljerade inventeringar, t. ex. data från den första Riksskogstaxeringen, eller andra skogshistoriska metoder, t. ex. årsringstudier eller pollenanalys. En ny metod – kallad *historisk bristanalys* – som på ett systematiskt sätt kan öka kunskapen om tidigare störningsregimer och landskapstruktur har utarbetats. Metoden innefattar lokala skogshistoriska analyser på landskapsnivå och kan användas för att ta fram information som kan ligga till grund för ekologisk landskapsplanering och restaureringsarbeten. Metoden kan också användas för att ta fram referenser för arbetet med regionala bevarandeplaner eller för revision av kriterier i olika typer av skogliga certifieringsystem.

Introduction

Historical perspectives increase our understanding of the dynamic nature of forests and provide a frame of reference for assessing current ecological patterns and processes (Swetnam et al. 1999). Consequently, an historic perspective must form an inherent part of ecological science and natural resource management (Foster et al. 1996). In recent years a large number of studies have addressed the ways in which natural and managed forest ecosystems differ from each other (Mladenoff et al. 1993, Martikainen et al. 1996, Foster et al. 1998). Integration of different types of data (Foster et al. 1996, Landres et al. 1999, Swetnam et al. 1999) and analysis at multiple scales (Landres et al. 1999) have been cited as important tools for obtaining a better understanding of these differences.

Historical records contain an immense amount of valuable ecological information (Peterken 1979, Östlund and Zackrisson 2000) and provide opportunities to increase our understanding of natural variability and changes in forest ecosystems at various spatial scales. In England historical maps and descriptions have been used to study changes in woodlands since the 14th century (Peterken 1979). In USA, data from the General Land Survey Office (GLO) have been used to create general maps of pre-settlement vegetation at a landscape level (White and Mladenoff 1994, Whitney 1994, Delcourt and Delcourt 1996, Radeloff et al. 1999). Aerial photos have been used to study changes in forest landscapes from the 1930s onwards (Mast et al. 1997, Hessburg et al. 1999), while satellite images have been used during the last 30 years (Spies et al. 1994, Lambin and Ehrlich 1997, Zheng et al. 1997, Sachs 1998, Radeloff et al. 2000). Recently historical records have been used to model the impact of hurricanes in New England (Boose et al. 2001). In some studies, analysis of historical records has been combined with other historical methods, for example dendroecology (Östlund and Linderson 1995, Lehtonen 1998) or pollen analysis (Foster et al. 1998, Hörnberg et al. 1999). At a smaller scale, forest structure in remaining old-growth forests has been used as a reference (Hofgaard et al. 1991, Frelich and Reich 1995, Kuuluvainen et al. 1998a, Kuuluvainen et al. 1998b, Linder 1998b, Mast et al. 1999, Wallenius et al. 2001). However, in many landscapes in Fennoscandia extensive logging and other activities have taken place during the 20th century. In these areas analysis of historical records and old maps is the only way to study past forest structure at larger scales (Lehtonen 1997).

The spatial arrangement of different forest types cannot usually be identified with confidence from traditional historical records, resulting in a general lack of information about the spatial variation of past forest conditions. However, historical forest surveys (i.e. maps and stand data) provide spatially explicit data of various forest components (Peterken 1979). So far these records have not been used to study changes in Swedish forest ecosystems to a large extent, despite the enormous amount of historical records available with spatial information on forests (Östlund and Zackrisson 2000). Furthermore, using this type of data facilitates the compilation of complete historical data sets over large areas, which makes it possible to improve the basic understanding of disturbance and spatial structure over broader spatial scales. In Sweden old cadastral maps have been used to analyse and model change in agricultural landscapes (Skånes 1996, Cousins 2001). Geographic Information Systems (GIS) have become an invaluable tool for the analysis of spatially explicit data at a variety of scales (Stow 1993). In a GIS, historical maps can easily be spatially integrated with other types of historical data or modern surveys. The use of GIS in retrospective studies facilitates analysis of relationships between historical and modern landscapes and can be used to illustrate different types of landscape transitions (Kienast 1993).

The natural variability approach

In recent years several different conceptual approaches to ecological forestry have been used in Sweden. Today the ”natural variability” approach (Landres et al. 1999) or ”natural landscape” model (Fries et al. 1998) is the most widely recognised in Scandinavia (Angelstam 1998, Fries et al. 1998). This approach suggests that if natural processes and structures are maintained, the biodiversity and ecosystem integrity will be preserved. Manipulation of a forest ecosystem should work within the limits established by natural disturbance patterns (Seymour and Hunter 1999). Today, the main problem when adapting forest management to mimic natural processes and structures is the lack of detailed knowledge about natural forest conditions. The development and use of general models in practical conservation planning are important, but the knowledge required to achieve conservation goals for a particular landscape must also come from an empirical knowledge of local environmental patterns, disturbance regimes and processes (Spies and Turner 1999, Kuuluvainen 2001). Using the wrong temporal and spatial scale can also produce erroneous conclusions about spatial structures and the processes shaping the forest landscape. Conclusions about parts of the landscape are often not applicable to the broader landscape (Baker 1989), but it would be difficult to ascertain this from studies restricted to smaller scales (cf. Lertzman and Fall 1998). Today it is difficult to study natural large-scale phenomena at a landscape level in Fennoscandia. Conclusions about natural disturbance regimes at larger scales are therefore often based on data collected at smaller scales. Today the general ASIO model (Rülcker et al. 1994) is frequently used to model earlier fire disturbance. In this model stand-level information on vegetation type together with fire frequency is used to extrapolate characteristics of the fire regime at landscape scale (Angelstam 1998).

Until recently forest management prescriptions also have focused mainly on the stand scale. To some extent the naturalness concept is used in multi-objective forest planning at larger scales, but the goals used are mainly quantitative and have not been well defined (Lämås 1996, Kangas et al. 2000). Efficient consideration of ecological values and natural variability in practical forest management requires that both a coarse filter and fine filter approach are applied (Lämås 1996). Larger scale patterns of logging and forest management have generally been the unplanned consequences of smaller scale decisions and actions. Recently, attempts have been made to perform multi-objective spatial planning at landscape scale using the core area concept (Öhman and Eriksson 1998, Öhman 2000). This concept is based on areas with high conservation values in the landscape and may help achieve certain conservation goals by lowering the edge effect. Efforts to include dead wood dynamics in multi-objective planning models have also been made recently (Kruys 2001).

History of the boreal forest

This thesis focuses on stand and landscape structure and changes in the Swedish boreal forest (Sjörs 1965, Ahti et al. 1968). Land-use history varies considerably within this area, but two major types of land-use can be discerned. In the larger mining district in the southern part of the boreal forest the forest resources have been used intensively, but basically sustainably, for mining and smelting for a long time (Nordquist 1959). In more remote and sparsely populated areas in the western and northern parts of the boreal region the intensity of early forest use was low and the forests were mainly used for agricultural purposes like grazing (Paper I, Ericsson et al. 2000). Only during the last 150 years have human activities severely altered the forest structure and function in these areas through logging. This process started when a so-called "timber frontier" advanced to these areas during the 1800s (Gaunitz 1980, Bunte et al. 1982, Björklund 1984). In the beginning large trees were selectively logged (Östlund 1993), but after the turn of the century logging changed with the development of the pulp industry and smaller trees were also logged. This facilitated the introduction of more intensive silvicultural measures (Mattsson and Stridsberg 1980) and clear-cutting. In 1950 selective logging was forbidden on state forests and clear-cutting started on a large scale (Ebeling 1959).

Many different types of land use activities have affected the boreal forest during the last 150 years. These activities have modified existing ecological boundaries and patterns and resulted in the creation of new patterns and boundaries in the landscape. Some of these new boundaries are clearly visible and occur at smaller scales in today's landscape, for example sharp boundaries between old growth forest and young plantations created by clear-cutting. Other boundaries are more diffuse, occur over larger scales and cannot be discerned as easily, like the landscape changes caused by fire suppression. Ecological boundaries like natural ranges for different tree species have been relatively stable for a long time, but recently they have shifted due to the introduction of plantation forestry, where Scots pine or Lodgepole pine have replaced Norway spruce over large areas. Some boundaries are dynamic and have swept through the landscape, like the timber frontier movement during the 19th and 20th centuries (Björklund 1984). This frontier was driven by the dramatic increase in demand for wood products in Europe during the 19th century.

Spatial and temporal context

Multi-scale research on historical landscapes and disturbance dynamics is likely to provide more useful results than research performed at only one spatial scale (Lertzman and Fall 1998, Landres et al. 1999). Another general guideline, originally recommended for monitoring of biodiversity, is to proceed from the top down, beginning with a coarse-scale inventory of landscape patterns, vegetation and habitat structure (Noss 1990, Poiani et al. 2000). These two general approaches were combined and formed the basis of the work described in this thesis. Five different spatial scales were used and the studies were conducted in two different regions in boreal Sweden (Figure 1). Papers I, II and III form a hierarchical multi-scale analysis, where changes were studied at four different spatial scales within the same large geographical area in the district of Lycksele, Västerbotten county (Figure 2). Changes and variation at district/parish, region, landscape and stand level were investigated. In contrast, in the county of Dalarna (Figure 1) various aspects of age of large diameter trees were studied at county and landscape scales (Paper IV).

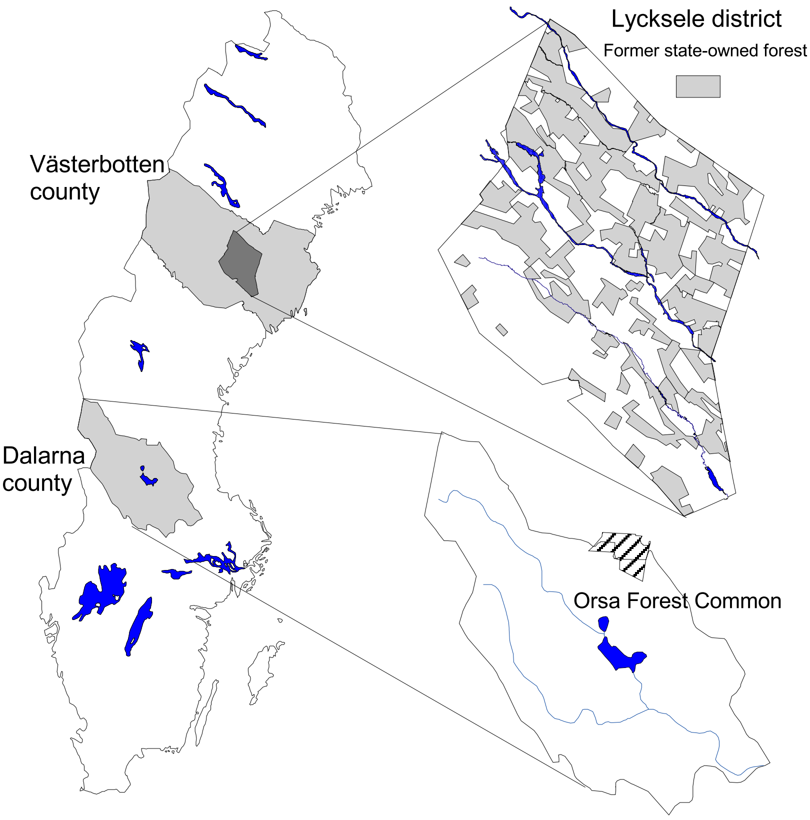

Figure 1. The locations of the two studied areas.

The pre-industrial boreal landscape during the late 19th and early 20th century is used as an example of natural landscape structure in the boreal forest. Landscapes, like other ecological units of study, are dynamic in structure, function and spatial pattern (Dunn et al. 1991). However, the current forest and landscape structure in boreal Sweden is far beyond the historic range of variability, and the changes that have occurred during the last 150 years have been very large compared with natural landscape variability. Anthropogenic landscape transitions usually occur over a relatively short time period (cf. Skånes 1996, Sachs 1998, Hessburg et al. 1999) while climate related vegetation changes generally occur gradually over longer time periods (Kullman 1996, Hofgaard 1997). During the last 150 years climate changes have occurred, but their impact on overall landscape patterns during this time period is open to speculation. However, if climate related changes occurred they were small in relation to the changes caused by logging during the same time period.

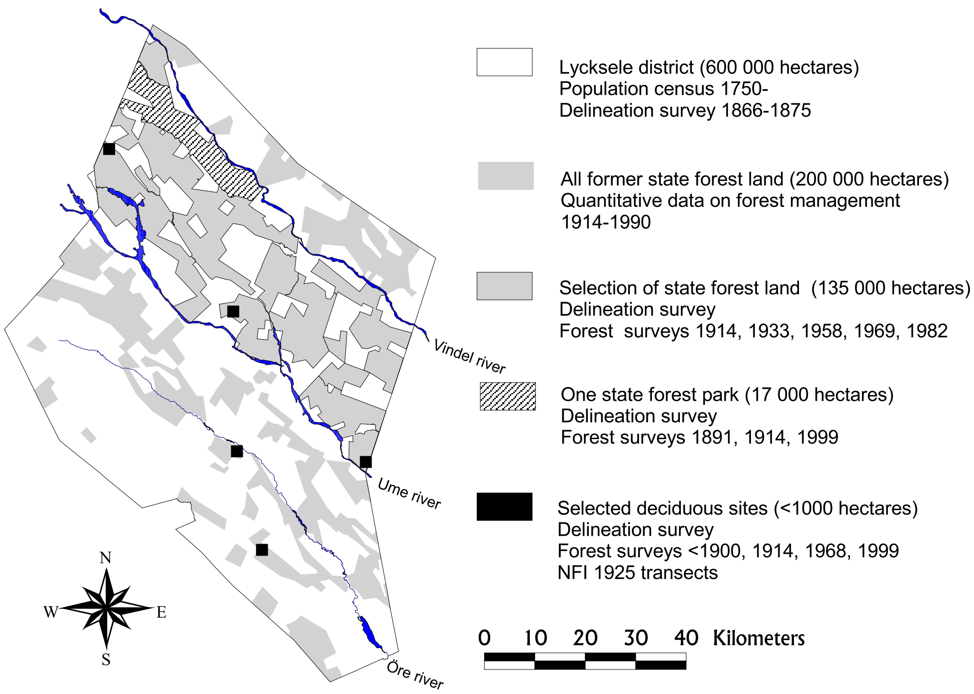

Figure 2. The multi-scale approach used in the analysis of changes in former state owned forest in Lycksele parish, Västerbotten county.

Objectives

The objectives of this thesis were to:

- Quantify and visualise variation in forest structure and landscape pattern in the pre-industrial forest landscape at a range of spatial scales.
- Assess the magnitude and trends of structural changes in vegetation patterns during the last century.
- Quantify forest management activities and link these to structural changes in vegetation patterns
- Outline a conceptual model on how to integrate historical data into practical forest management and nature conservation programmes.

Figure 3. Tree counting in unlogged forest during the early 20^{th} century. Photo: Anon. Photo archive at the Forest Museum, Lycksele.

Outline of the papers

I

In Paper I changes at larger scales were investigated. At district/parish levels general land-use trends and population development were described (Figure 2). A collection of delineation survey maps from the 1870s provided a mosaic of general information on earlier fire influence and land-use for the whole district, which covers approximately 5,920 km^2 (Figure 2). For all state forests within the district (around 2,490 km^2) forest management activities during the last century were quantified from yearly reports and annual accounts. At the regional level, a time series of five different forest surveys were sampled to study changes in tree species composition and forest structure on state forest land between the rivers Umeälven and Vindelälven during the last century. The area between the rivers amounts to 2,000 km^2, of which 1,320 km^2 was formerly within state forest boundaries.

II

In Paper II changes at landscape and stand scale were investigated. One state forest park that was included in the regional scale study (Paper I) was chosen for further investigations. This landscape covered 170 km^2 and around 80 % of the total area was forested. In this area information on stand boundaries from the two oldest forest surveys were digitized and compared with data from recent digital forest surveys in a GIS. Delineation surveys and dendroecological investigations provided additional information about earlier fire influence at the landscape level. At stand scale three different forest types within the studied landscape were selected for a more detailed analysis.

III

Paper III focused on changes at stand level, and five deciduous forests situated on former state forest land were studied. Spatially explicit data from the early delineation survey and forest surveys were analysed and compared with the current state of the forest in a historical map analysis. Transect data from the first Swedish National Forest Inventory in 1923 were used to provide a more detailed view of structural variation in each of the studied deciduous forests.

IV

In Paper IV variation and changes in tree age were studied at county level. Sample tree data from the county of Dalarna from 1923 and 1990 were used to analyse temporal and spatial changes in the age of larger (>30 cm DBH) coniferous trees. The age structure of large diameter trees in the Orsa Forest Common in 1885 was modelled by combining sample tree data from 1923 with historical diameter data from the first tree count.

Historical records

Delineation survey

The delineation survey ("avvittringen" in Swedish) was performed by the Land Survey Office ("Lantmäteriet") during the later part of the 19th century. This survey presents unique information about pre-industrial vegetation conditions, but it is important to note that the main purpose of the survey was not to sample vegetation. The main objectives were to delineate the boundaries between private and state forest land, and to favour new settlements (Almquist 1928). In Lycksele parish all land was surveyed between 1866 and 1875, but the border between private land holdings and state forests were not finally settled until the 1880s (Stenman 1983). Detailed maps were produced (scales 1:8,000 and 1:16,000) but the forest descriptions were very superficial and information on tree species composition was not collected in a systematic manner. Mires, which were important for hay production, were usually carefully mapped and the production capacity for individual mires was judged. The extent of open burned areas was carefully recorded, since they provided good grazing areas and were therefore of interest to the settlers. However, many of the maps that accompany these records only approximate the location of the fire perimeters (Figure 4), since only areas where stand replacement occurred were recorded (Axelsson, unpublished data).

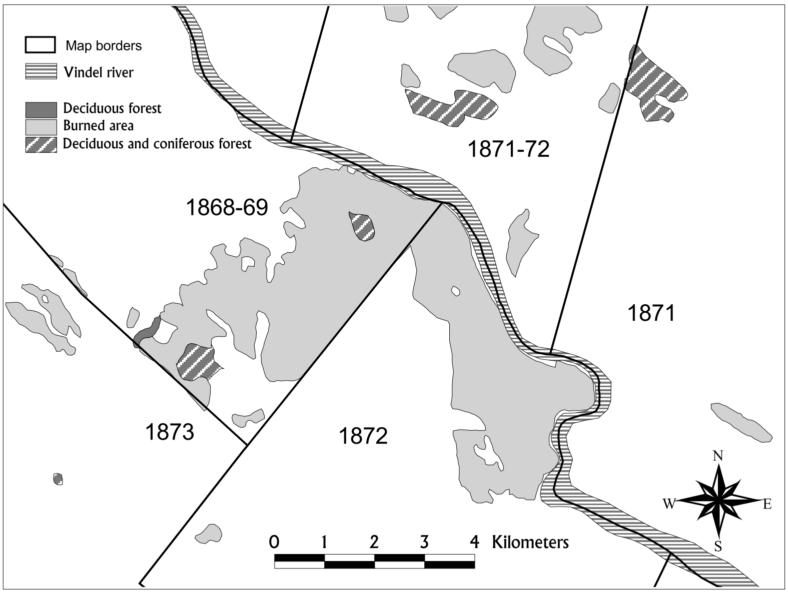

Figure 4. Information on fire influence and occurrence of deciduous trees provided by five separate maps from the delineation survey. Note the coincidence of the boundaries of the burnt area between the 1868-69 and 1872 maps, which were produced by different surveyors. Mount Doppmanoive, Bjurbäckslandet state forest.

Despite these limitations, delineation surveys can be used to get indications of earlier fire influence and tree species composition. One important advantage is that these surveys provide total landscape coverage, while their main disadvantage is the lack of information on forest age.

Timber counts

The earliest forest surveys available for historical forest studies in northern Sweden are usually timber counts or timber surveys. They were performed in connection with logging and were used as the basis for selling timber contracts. Most often these surveys were performed after the first high-gradings (Östlund & Zackrisson 2000), which were usually unorganised and not well recorded, but in some rare cases the surveys were performed before logging started (cf. Gyllenhammar 1886). In these early surveys only trees planned to be logged were recorded and consequently only larger timber trees were included. The minimum recorded tree diameter varied between different geographic areas and decreased successively through time when large trees became more rare. In the tree count in Orsa Forest Common in 1885 only trees with larger diameters than 13 inches (>33.06 cm) at 1.52 m height were recorded, while trees larger than 26 cm DBH were recorded in 1888 in the state forest district of Nordanås in Västerbotten county. The forest was divided into operational logging areas (Linder and Östlund 1998) that could cover more than 1,000 hectares. Timber surveys were not performed in a consistent manner and therefore it is hard to compile information from this type of record at a regional scale. However, these records can be used to reconstruct the proportion of large diameter trees at landscape level and sometimes also at stand level, if spatially explicit data are available.

Records from the state forest administration

The state forest administration in Lycksele parish was formed in the 1860s (Holmgren 1959). It was a hierarchical organisation, which was centrally managed and has a well organised central archive. In the Lycksele district around 30 % of the area was covered by state-owned forest. The highest concentration of state forest parks (“kronoparker” in Swedish) was between the two main rivers, and the proportion of state owned forest decreased towards the south-west (Figure 2). The land ownership patterns have changed very little since the 1880s, when the borders for state forest parks were settled. These stable borders provide a unique opportunity for studying individual state forest parks over an extended period of time using various types of historical records. The size of state forest parks within Lycksele parish varies between a few hundred up to 20,000 hectares. The largest parks were always divided into several smaller areas, and these borders have shifted several times during the 20^{th} century.

Yearly reports from chief foresters/annual accounts

From the 1860s and until 1990, when the Swedish state-owned forests in Lycksele district were privatized, yearly reports and annual accounts for the state forest were produced at district level. In these reports general notes were made about fire, weather and hunting, as well as more quantitative records on logging and different silvicultural activities. The type of data that were recorded and the quality of the records vary between different periods. In the late 1800s the reports were primarily narrative, with little quantitative information, and in the late 1900s they mainly contained quantitative information on logging and silviculture. The same types of yearly reports can be found on all former state forests in Sweden, which covers approximately a quarter of the total Swedish forest area (Anon 2000). However, the administrative division has changed many times between the 1860s and 1990s. The temporal variations in descriptive quality and recurrent administrative changes have to be considered when longer time series of historical data are compiled. However, it is easier to follow the records collected after the 1910s, when a new territorial organisation was established in Lycksele district. This also coincided with more intensive silvicultural activities and the first uniform and recurrent forest surveys. Yearly reports can be used to compile time series of logging and forest management at regional or landscape scales. At stand scale it is more complicated to compile complete records of earlier management using only historical records, mainly because stand size has changed dramatically over time (Ekman 1997, Ericsson and Östlund 2001).

Forest surveys

Forest surveys were performed on a regular basis at state forest district level from the end of the 1800s until today (Figure 5). Trained foresters performed the surveys and consequently information on forest structure and species composition are more detailed and well structured than in earlier delineation surveys mentioned above. However, surveys conducted before 1910 were not performed in a consistent manner and the methods used varied between different state forest districts. The map scales also varied between 1:16,000 and 1:80,000. Until the early 20th century no increment corers were used in forest surveying and the stand age was subjectively estimated (cf. Lehtonen 1997). Forest surveys contain both quantitative and qualitative information but before the 1910s there were often relatively long narrative descriptions and less tabular data. These descriptions were highly subjective compared to the later, more quantitative forest estimations (Figure 5), and increased the variation among surveyors (cf. Manies and Mladenoff 2000). However, the early surveys give a good understanding of what the actual forest looked like. Notes about earlier logging operations or fire influence were often included and provide valuable additional information.

In the 1910s the first uniform forest inventory was performed in the Lycksele district. Tree species composition, age structure, soil moisture content, timber volume, canopy openness and many other stand variables were described for each stand. Tree species composition was given in proportion of standing volume for coniferous trees, while data on deciduous species were based on areal cover. Stand age was noted in 50-year classes (1–50, 50–100, 100–150, 150–200 and 200– years) and often two or three different age-classes occurred within the same

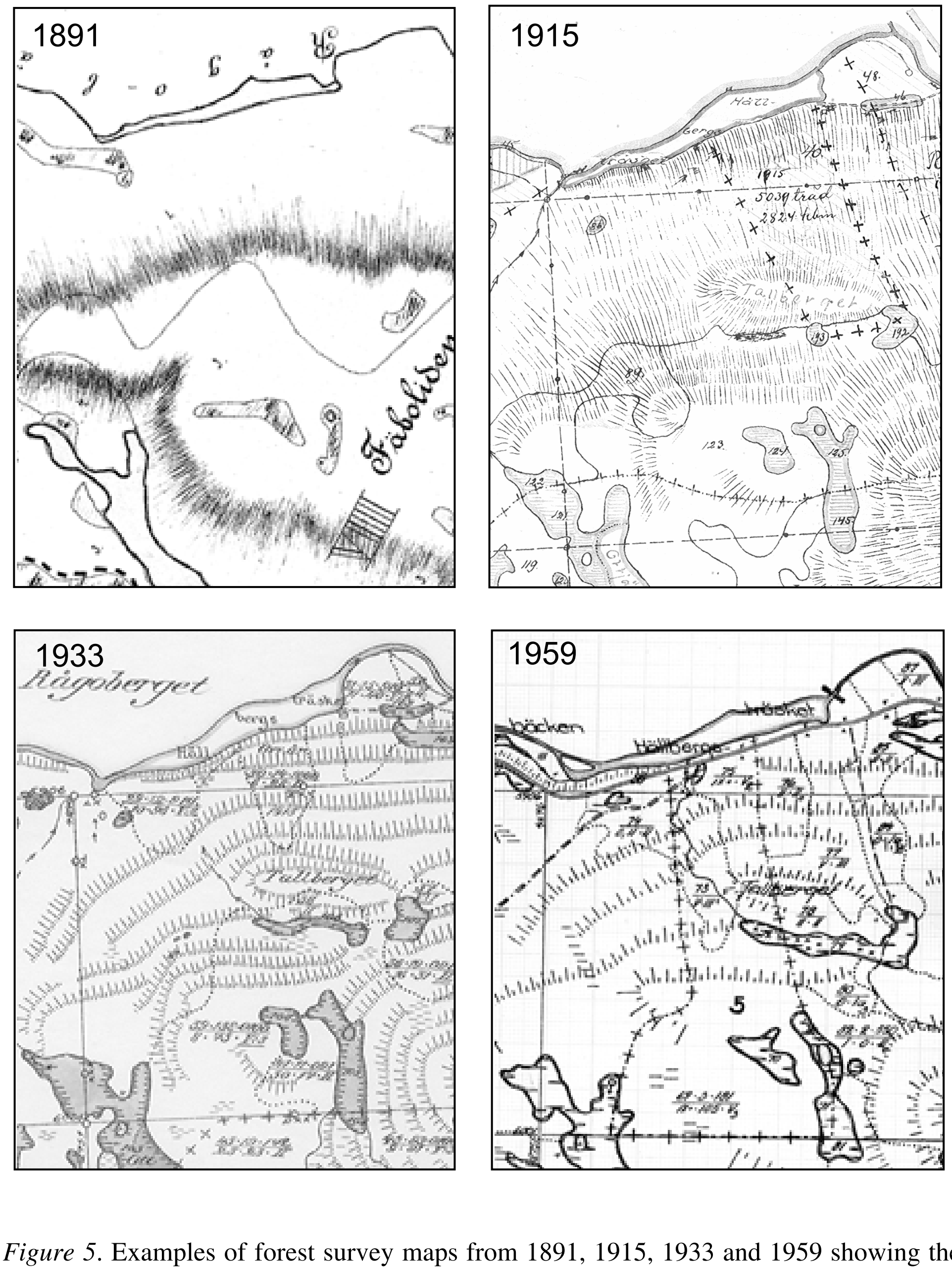

Figure 5. Examples of forest survey maps from 1891, 1915, 1933 and 1959 showing the same area in Bjurbäckslandet state forest park, Lycksele district.

stand. Only trees larger than 10 cm at breast height were included in the timber volume survey. Today, all trees larger than 5 cm DBH and higher than 1.3 metres are included in the volume estimations. The prevailing forest management ideas, which have profoundly changed during the course of the 20^{th} century, have influenced the characteristics of forest inventories. The 1930 surveys were performed in more or less the same manner as the 1910 surveys but 20-year age-classes were used instead of 50-year classes. The 1958-59 survey was performed during a transition period in Swedish forestry and the records are similar to early surveys in some respects, and in others more like later surveys. For example, descriptions of multi-aged forests were still used in the age-records in the 1950s, but were not included in the 1969 surveys. Here the forest age was recorded as average stand age. Another example is the use of remote sensing in forest surveying. Stands were delineated in all surveys from the 1950s onwards using aerial photographs or satellite images.

The Swedish National Forest Survey

The Swedish National Forest Survey started in 1923 and was the first survey that covered the whole country (Figure 6). The aim of the survey was to get a better overview of the available forest resources at a regional level in Sweden. The same type of survey was also performed in Finland, where the work started a year earlier than in Sweden (Ilvessalo 1924). During the first survey, transects were 2000 by 10 metres in size and were arranged in parallel continuous inventory lines. The distance between transects varied from 1 km in the south to 20 km in the north (Anon 1932). On each transect three different types of survey were performed simultaneously: 1) an areal description 2) a tree count 3) measurement of sample trees. In the areal description each transect was subdivided into smaller segments and the productive forest was classified according to forest type and age-class distribution. In the tree count all trees larger than 15 cm DBH were tallied at each transect while smaller trees were counted on subplots. Based on the tree count, sample trees were objectively selected in each diameter class. Later the sampling procedure changed and circular plots were used instead (Segebaden 1998). The survey was originally constructed for regional analysis but individual transects and sample tree data can also be used to analyse local forest structure (Paper III) or regional variation (Paper IV). The strengths of this dataset are that objective sampling procedures were used, and that all owner categories were surveyed. The dataset provides spatial information on forest structure at stand scale. However, transects were far apart and only a minor part of the landscape was surveyed.

Results and discussion

Characteristics of the pre-industrial forest landscape

The regional scale

The early forest surveys (Papers I and II) describe a forest landscape dominated by multi-aged, Scots pine dominated forest. Deciduous trees were present but occurred mainly as a minor component in conifer dominated stands (Papers I, II and III). At a regional scale there were large variations between different state forests, with respect to the proportions of both multi-aged forest and deciduous stands with more than 30 % deciduous trees (Figure 7). In 1914 the proportion of multi-aged forest varied between 50 and 100 % of the total forested area. Deciduous stands generally covered less than 10 % of the area, but in one state forest more than 70 % of the area was covered with deciduous stands (Figure 7). These large-scale variations resulted from complex interactions between natural and human factors (Paper III) and cannot be explained by any single factor. However, a possible connection between high proportions of deciduous trees and

Figure 6. Survey team during the second Swedish National Forest Survey 1935 in Arvidsjaur, Norrbotten county. Photo: Börje Mineur. Skogens photo archive.

early logging intensity can be discerned (Paper III). Individual state forests with more than 50 % deciduous trees are aggregated in one specific part of the region (Figure 7). This area was intensively logged during a large logging programme called the "million logging operation" ("miljonstämplingen") in the 1880 and 1890s (Holmgren 1959). These results indicate that the earliest logging operations resulted in regeneration of deciduous trees. One factor that also could have influenced this pattern is that the forest surveys in these particular state forests were performed earlier and with different guidelines than in other state forests (Axelsson, unpublished data).

The landscape scale

A characteristic landscape pattern created by interactions between topography, tree species composition and earlier fire influence can be discerned at landscape level (Paper II). Multi-aged Scots pine forest dominated the studied landscape but the proportion of Scots pine decreased with increasing altitude. In the studied landscape Norway spruce dominated stands mainly occurred as isolated islands at higher elevations (>400 m). The most important agents involved in creating and maintaining this landscape pattern were recurrent fires. In the Vindel river valley dry sites burned more frequently than mesic sites (Zackrisson 1977). Apart from the fire return interval it is important to recognise that there were large variations in fire behaviour between different fires. The occurrence of large areas with multi-aged forest (Papers I and II), and a relatively high proportion of older trees suggest that most fires were of low intensity. Each individual fire created a unique pattern of surviving trees (cf. Kolström and Kellomäki 1993, Linder et al. 1998) but the spatial survival pattern created after any specific fire might not be valid for other fires (Schimmel 1993). The fire pattern also varied at a smaller scale (Paper III). Smaller depressions, usually dominated by Norway spruce, burned less frequently than the surrounding drier forest and here trees could escape repeated fires. However, in a longer time perspective fire-free refugia are rare even in swamp forests (cf. Hörnberg et al. 1998).

At lower altitudes a large number of Scots pine trees survived the fire and multi-aged forest dominated (Papers I and II). However, in smaller patches where the fire intensity had been high and a larger proportion of the canopy was killed, even-aged forest occurred. At drier sites in lower elevations these patches were often dominated by Scots pine, sometimes mixed with deciduous trees. In Norway spruce dominated forest at higher elevations, fires killed a larger proportion of the canopy and successional forest with relatively high proportions of deciduous trees occurred (Paper II). These areas were attractive for grazing due to their open conditions and one of the mountains in the studied landscape is named Fäbodliden (in Swedish), which roughly could be translated as the "summergrazing mountain" (Figure 8). The pre-industrial forest use around villages and homesteads created early land-use gradients in the landscape. Along these gradients the abundance of deciduous trees, dead trees and timber trees varied and diffuse ecological boundaries occurred (Östlund et al. 2001). The gradual expansion of permanent settlements also caused changes in the fire regime (Niklasson and Granström 2000). Holmgren (1950) has suggested that anthropogenic fires, which started in the valley bottoms close to settlements, could have contributed to the domination by Scots pine in the forests that occurred in the lower river valleys. In other parts of boreal Sweden the spatial distribution of different tree species was reversed, in some respects, since Scots pine dominated on mountain summits while Norway spruce grew in the lower river valleys (Nilsson and Norling 1895). In this type of landscape, fire disturbance probably created spatial patterns different from those in the studied area.

The stand scale

Around 1900 the logging had started to reshape the age structure at stand level (Paper II) but the landscape pattern created by a combination of physical factors and recurrent forest fires was still discernible (Paper II). In the early forest surveys the stands were usually large (Figure 5) but there were also major variations in stand size (Paper II). Some stands covered several hundred hectares but very small individual forest stands were also present. Today the stand size is

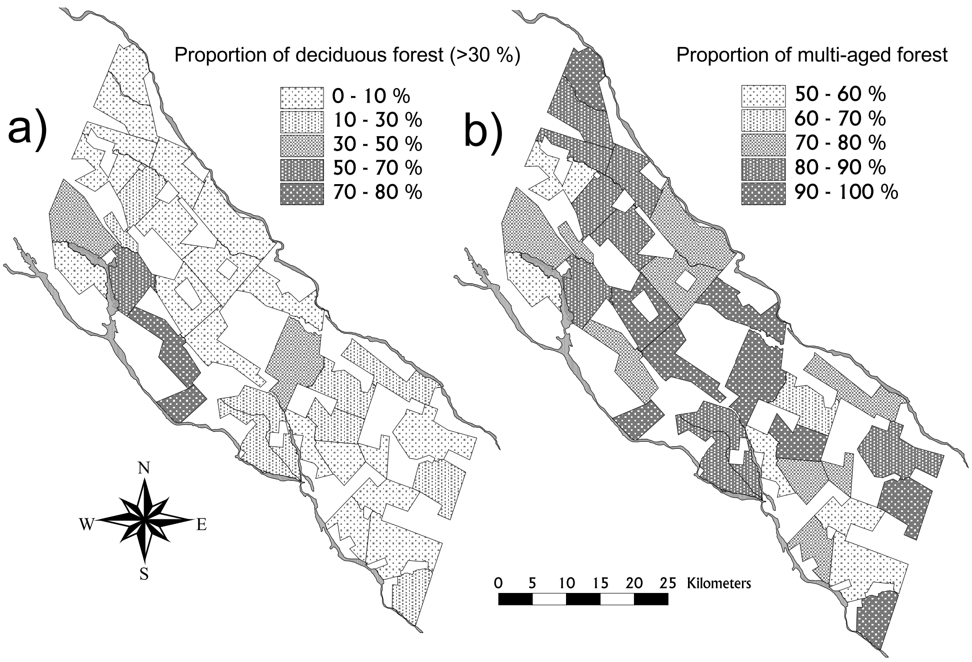

Figure 7. Variation of proportions of a) deciduous and b) multi-age forest at a regional scale in the 1910s.

Figure 8. An inscription from 1866 in an old Scots pine, Fäboliden, Bjurbäckslandet state forest park, Lycksele district. Photo: Anna-Lena Axelsson

more uniform (Paper II). The results in this thesis show that the early stand delineation probably reflects the natural landscape pattern better than the delineation in later surveys, where policy and technical considerations guided the size of the stands. Between 1850 and 1900 most forests in the area had been selectively logged at least once, but the logging intensity was relatively low compared to later clear-cutting operations (Papers I and II). Only the largest trees were removed during this early logging phase, and the stands still had a largely multi-aged structure, with different age cohorts regenerated after low intensity fires (Papers I and II). Trees older than 200 years were present in most forest stands. As the data from forest management plans describe the mean stand conditions it is not possible to determine if different age-classes were evenly spread out or aggregated within the stand directly from the tabular data. However, narrative stand descriptions from the early forest surveys indicate that trees of different ages grew more or less mixed in the forest without forming spatially distinct patches. This spatial pattern has been described from other areas in boreal Sweden (Wretlind 1934), and are also documented in detailed stand scale studies from Finland (Wallenius et al. 2001).

There were large variations in the age of larger diameter trees, and even for trees within the same diameter class. According to the NFI data (Paper IV) the age span between the youngest and oldest sample trees in inch-class 13 was almost 300 years. In the age reconstruction performed in Orsa Forest Common in Dalarna county, 18 % of the Scots pines and 6 % of the Norway spruces (>33.76 cm DBH) were older than 300 years (Paper IV). It is clear that large individual trees, older than 700 years, were extremely rare even in natural forests. According to the reconstruction, there was one living Scots pine older than 700 years per 8 hectares in Orsa Forest Common in 1885. The chance of finding very old Norway spruces was considerably lower, since only one Norway spruce per 160 hectares was older than 600 years.

Changes during the 20th century

During the last 100 years a sharp reduction in complexity in the forest structure has occurred at all spatial levels. The current landscape structure is more homogenous than in the early 1900s. Patches are more even in size and the multi-aged matrix has been replaced by a patchwork of forest stands of various ages. Straight linear borders, created by earlier clear-cutting operations, are clearly discernible, while most stands are younger than 100 years old and dominated by even-aged forest (Paper III). During the last 100 years the earlier structural variation has been gradually evened out by uniform forest management (Paper I). The landscape signature created by forest management is different from the landscape structure created by fire disturbance. The stands were larger and variation in age and tree species composition was accepted within each stand to a greater extent in the early 20th century than it is today. Today, multi-aged structures occur in some forest stands, but the current method of describing forest age in the records only reveals the average stand age, and not the real age variation. Anthropogenic landscapes often have more regular patterns and a uniform grain compared to more natural landscapes (Mladenoff et al. 1993), but it has to be recognised that large changes in complexity have also occurred in rural landscapes during the last 200 years (Skånes and Bunce 1997).

Clear-cutting has had a large impact on the landscape structure in Lycksele district (Papers I, II and III). The fragmentation analysis shows that the patch size of continuous areas with older trees (>100 years) has decreased considerably during the last century. Today old forest stands cover a small proportion of the landscape (Papers I and II) and occur mainly in smaller patches (Paper II). Furthermore, these old stands have been intensively managed and lack most old-growth qualities. The main reason for this radical transformation of the forest structure from multi-storied to even-aged stands is that logging methods have changed. In the early 1900s, when multi-aged forest dominated the area, most of the logging was selective (Nilson 2001). Most stands were naturally regenerated and strenuous efforts were also put into site improvement (Paper I). However, after the 1950s clear cutting has been the most common logging method. In the management records changes from one year to another are clearly discernible.

(Paper I). Some changes could be correlated with changes in policy towards forest management in the state forest administration. For example, planting of containerized seedlings increased drastically and became an important method of regeneration when the restoration program (Ebeling 1959) was launched in state owned forests in Northern Sweden in the 1950s (paper I). Wider changes and events in the surrounding world also affected forest management. For example the depression in the 1930s, the Second World War and the emerging conservation movement during the late 1960s all caused immediate changes in forest management at a regional scale (Paper I).

High-altitude Norway spruce forests were not logged to the same extent as Scots pine forest during the early logging phase in the Lycksele district. However, during the 1970s and 1980s large areas of Norway spruce forests at higher altitudes were logged. These stands were not usually reforested with Norway spruce, but instead they were planted with Scots pine or Lodgepole pine (*Pinus contorta*) (Paper II). As well as clear-cutting, selective logging has also influenced both stand and landscape structure. Deciduous trees were systematically removed, first by girdling and thinning (Paper III) and later by large-scale herbicide spraying

Figure 9. High-altitude Norway spruce forest in the state forest park Rönnliden, 1929. Photo: E. Wibeck. SLU photo archive.

from the air (Paper I). Today most deciduous trees occur in young stands (Paper II). At the end of the 19th century, deciduous patches were relatively large and connected to recently burned areas at higher altitudes. Today deciduous stands are not clustered and site-specific as they were before, instead they are distributed more evenly in the landscape and connected to logging disturbance (Paper II). Selective logging operations have also changed the forest age structure at stand level. Forests that have never been clearcut have gradually been converted from multi-aged to even-aged stands. The overall impact of different types of logging and forest management has led to a decrease in the mean age of old large diameter trees during the 20th century (Paper IV). Since 1923 the mean tree age of large diameter trees has decreased by around 25 % for coniferous tree species in the county of Dalarna. Also, the age variation for larger trees has decreased. Today larger trees older than 400 years are very rare (Paper IV).

Choosing the relevant spatial scale

One important factor that facilitated extrapolation between different scales in this study was that the same type of data was used at regional, landscape and stand levels (Papers I, II and III). Different methods were used to extract data at different spatial levels, yet results gained from different scales could be compared. Analyses of forest surveys at regional level (Paper I) were compared with results compiled from the same type of data at stand or landscape levels. For example, before choosing which site to use in the study described in Paper II it was possible to investigate how this particular landscape related to variations in age structure and species composition within the larger region (Figure 2). Also, when individual sites were selected for more detailed studies (Papers II and III), this multi-scale approach provided a means of assessing how these stands related to the structure of the total landscape. This multi-scale approach was also useful for validating results obtained from the coarse sampling procedure at regional level (Paper I) with results from the more detailed total landscape analysis (Paper II).

A trade-off between spatial extent and level of detail occurs whenever landscapes are studied. When moving towards larger scales, the time invested in the analysis is usually large compared to the results gained from the analysis. In theory it would be possible to digitize every individual stand on all state-owned forests in the Lycksele district and perform detailed spatial analysis on landscape structure over a large area. However, in practice this would be extremely time consuming and would not generate enough information in relation to the time invested to be cost effective. In Paper I we used a time series of five different forest surveys that were sampled using an 800 m by 800 m grid. From this analysis it was possible to obtain information over a larger area using a relatively small work input. This analysis also provided data on the variation in age and tree species composition between different state forests, which is valuable when sites are chosen for analysis at lower hierarchical levels. At a regional scale it is possible but very time consuming to analyse landscape patterns and directions of change. Another factor that complicates analysis at this scale is the variation in data availability, which is correlated with the land ownership patterns, resulting in areas without historical information on stand and landscape structure.

The ideal scale to choose when extrapolating landscape structures from historical data depends on the scale at which the field data were recorded (cf. Manies and Mladenoff 2000). The forest surveys used in this thesis were collected at landscape level. If the data are used at larger spatial scales, the patterns can easily be converted to coarser grain and resolution. However, when the same data is analysed at smaller scales than those the original survey was designed for, there is a risk that the structural complexity will be oversimplified. For example, when spatial information concerning the same area, collected at two different scales were compared, the results differed significantly between the two scales (Paper III). The deciduous stand concerned was described as homogenous forest in forest surveys from the early 20^{th} century. However, analysis of transect data from the NFI, which was recorded at a much more detailed spatial scale, revealed a complex mosaic of different age classes and mixtures of different tree species within the same stand.

Historical stand data is very useful for analysis of historical forest structure at landscape and regional levels. The use of forest surveys allows large areas to be assessed with high degrees of spatial detail; no other types of data can provide such a wealth of information on the pre-industrial boreal landscape at such a low cost. Forest surveys are useful for describing historical landscape structure and structural changes from larger stand level (>100 hectares) up to a regional level. At smaller spatial scales the resolution of the forest survey maps are too coarse and analyses have to be complemented with other types of historical records; for example NFI records. At these scales other historical methods that provide more precise information, for example dendrochronology (Niklasson 1998) or analysis of relict old growth stands (Linder 1998a) may be useful and efficient means of gathering valuable data. In the study discussed in Paper III we were interested in obtaining detailed information of early logging operations in individual stands, to enable logging to be related to the regeneration in each stand, but this data proved to be almost impossible to collect from forest surveys. Therefore, future historical studies at the forest stand scale would benefit from combining different methods; historical records, dendrochronology and pollen analysis (cf. Hörnberg et al. 1999). By using dendrochronology and pollen analysis the time perspective can also be extended.

The results presented in this thesis are mainly based on studies conducted in two Scots pine dominated areas, but the results have also been used as a reference for other areas in boreal Sweden (Kellner and Johansson 1999). Most historical forest studies at landscape level in Sweden have so far been performed in Scots

Figure 10. Multi-aged Scots pine forest with a fire-scarred tree. Lycksele district 1909. Photo: Gunnar Schotte. SLU photo archive.

pine dominated landscapes (cf. Zackrisson 1977, Engelmark 1987, Linder and Östlund 1998, Niklasson and Granström 2000). Few landscape scale studies have been undertaken in Norway spruce dominated areas, although they may have important differences in their disturbance dynamics and landscape patterns. Thus, there is an urgent need for complementary historical studies at landscape and regional scales in Norway spruce dominated areas. However, it is not possible to use dendrochronology to study former fire disturbance in these forests, as Norway spruce trees seldom survive repeated fires (Niklasson 1998). The proportion of former state forest is low in the Norway spruce dominated south-western part of Lycksele district (Figure 1), which also complicates the compilation of historical records over larger areas. One possibility is to further explore the delineation surveys, which cover the whole district, and combine this information with data from older forest surveys that are available from many different forest companies and archives. Another alternative is to investigate historical records adjacent Norway spruce dominated landscapes on former state owned land.

Methodological considerations

Selection of study sites

Whenever historical records are used in ecological studies, the choice of study area is guided by the availability of high quality historical data. In Sweden, the best and most extensive forest historical records are those of the state forests. In the Lycksele area the proportion of former state-owned forest is high compared to the rest of the county and also compared to the rest of the country. However, state forest parks were unevenly distributed in Lycksele district (Figure 1). In the south-western, Norway spruce dominated part of the county private land holdings dominated. Here forest surveys started later and were not performed in a uniform manner comparable to the surveys of state forests. This uneven distribution guided the choice of study area in Paper I. In Paper II, the landscape studied was selected since a detailed early forest inventory was available, of much higher quality than surveys from other areas. Furthermore, the same map scale (1:20 000) was used as in later surveys (Figure 5). When sites were selected for the stand level study described in Paper III, the requirements were that selected deciduous sites should have one transect from the NFI 1923 within the deciduous stand, which strongly limited the number of potential study sites. The reconstruction of age of large diameter trees in Orsa Forest Common (Paper IV) provides another example where the availability of historical data guided the selection of study site. The tree count from 1884 is unique and is not available for any other area.

Classifying data from forest surveys

Investigation of historic changes in landscape patterns requires a classification system that can be applied uniformly over the time series (Dunn et al. 1991, Burgi 1999). Differences between data sets can be easily confused with landscape changes (cf. Radeloff et al. 1999). Therefore, careful and critical analysis of the historical data is crucial before a classification is performed. This project focused on changes in age structure and tree species composition, and the classification was designed to address these features. The landscape is Scots pine dominated, so different types of Norway spruce forest (e.g. high-elevation and swamp forest), were referred to as being the same forest type. If the same type of retrospective analysis was performed in a Norway spruce dominated landscape, another classification scheme would have to be developed, in which variations between different types of Norway spruce forest were taken into consideration.

Specific requirements were that the classification should allow comparisons between different spatial levels but at the same time it should be easy to change the grain and resolution of the data to allow analysis at different spatial scales. To fulfil these requirements, a hierarchical classification scheme was used (Paper I). Each stand was assigned one age class and one tree species class, which could be used separately or combined. For example, even-aged young Scots pine forest was designated ”11”: the first ”1” describing the species composition (>80 % Scots pine) while the second ”1” stands for even-aged young (<50 years) forest. This scheme allowed comparisons to be performed between different spatial scales, while at the same time details could be kept and used if necessary. For example stands with two different age-classes were simply coded “4”, but more detailed information concerning the relative proportion or actual age of these two classes could also be included if necessary. When qualitative stand scale analyses were performed in relatively small and homogenous areas it was possible to keep a high level of detail by combining the age class and tree species class data (Paper II). When changes were analysed at landscape level this created a very complex pattern of changes and, therefore, age and tree species composition were analysed separately (Paper II). In the fragmentation analysis (Paper II) the classification was simplified even further and only two different age-classes were used. The possibility of referring back to the database to analyse the whole range of stand data was also exploited (Paper III).

Automated classification was tested in the early phase of the study but proved to be insensitive to important ecological differences between forest stands. This classification was therefore complemented with a manual classification, which required a good insight and general understanding of variations in the historical stand data. The same person that compiled the historical GIS database also performed the stand classification. Classification of historical surveys can in some ways be compared with the process of aerial photograph interpretation, where automated vegetation classifications provide less detailed results than a classification made by an experienced interpreter (Skånes & Bunce 1997). The classification was also an iterative process, in which different classification schemes were tested on sub-samples before the final classification was applied to the whole sample. All available historical data were integrated into the digital database from the start, but only a selection of the data was used in the first test classifications. The fact that all available data were integrated from the start proved to be time saving in the end, despite the large amount of data that had to be handled initially. Some parameters that were not judged to be important in the early phase of the work proved to be crucial for the final manual classification.

Fading record

Most historical time series suffer from a ”fading record” problem, i.e. the reliability of the time series decreases with increasing time before the present (Swetnam et al. 1999). For forest surveys this problem can be illustrated by comparing the large stand records and large-scale maps produced in the early surveys to the generally more detailed recent surveys. However, some data were recorded in much more detail in early surveys than they are today. For example, the diameter of every individual large tree was measured at a landscape level in Orsa Forest common in 1885. Today most forest surveys are performed using some type of sampling scheme and only small proportions of the area are investigated. Age records in individual stands have also become less detailed. Up to five different age-classes were used in the 1910s surveys, whereas nowadays only the average age will be reported, even if a stand has trees of different ages. In some time series the same type of methods have been used to collect data over long time intervals. For example, sample tree data from the Swedish NFI, where individual tree age data have been collected using the same technique for almost 80 years.

Changes in significance of ecological terms

During the interpretation of the historical records (Papers I-III) interesting shifts in meaning of the Swedish term for fire-regenerated deciduous forest ("lövbrännor") were encountered. This term has been shown to encompass a wide variety of forest stands in old forest surveys: from mixed coniferous deciduous forests with overstorey trees to pure deciduous stands without overstorey. What the early surveyors classified as a fire-regenerated deciduous forest clearly differs from the current understanding of this type of forest. Furthermore, the forests to which this term is applied do not necessarily need to have regenerated following a fire; today in practical forestry the term is used for any deciduous forest with high conservation values. In Lycksele district "fire-regenerated deciduous stands" with high proportions of deciduous trees, which were recently designated as woodland key habitats (Nitare and Norén 1992), have been shown to originate not from fires, but from old-growth spruce forests that were clear-cut and in some cases drained in the 1930s (Ekman 1997). In the south boreal forest

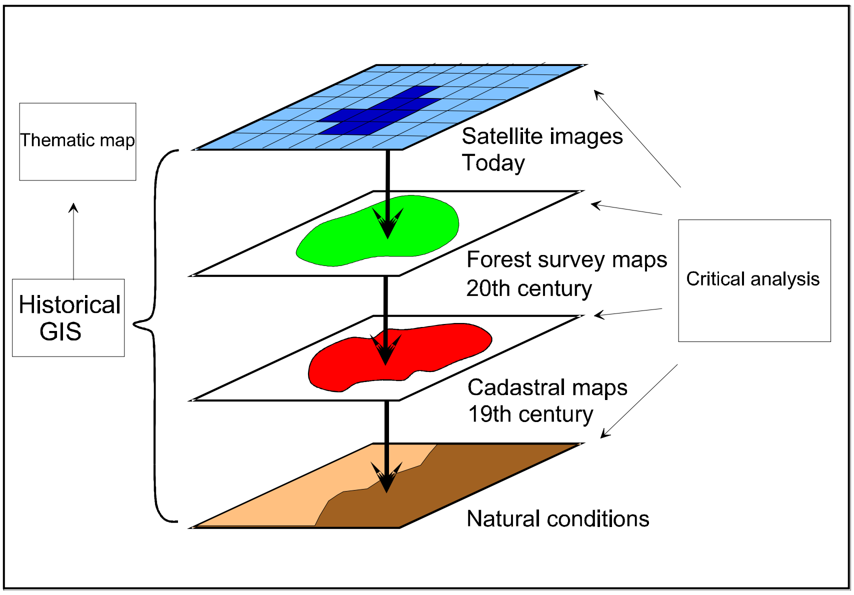

Figure 11. Conceptual model describing the analysis of historical maps using Geographic Information Systems.

a combination of logging and fire at the end of the 1800s created deciduous dominated stands (Hellberg et al. 2001). Similar stand conditions had not developed at these sites after earlier fires, which suggests that stands with a high proportion of deciduous trees were created by human disturbance.

It is possible that some of the confusion surrounding the origins of deciduous stands is due to large gaps in our ecological knowledge of regional differences in the genesis and natural landscape proportions of deciduous trees. The south-eastern part of Lycksele district is dominated by Norway spruce. Therefore, fires in this area were usually stand-replacing and the proportion of deciduous trees was high in young successional forest that regenerated after the fires (Andrén 1999). In the Scots pine dominated part of the district, overstorey Scots pines survived the fires in most areas, which resulted in multi-aged stands and high proportions of coniferous trees (Paper III). Several other studies have shown that the abundance and type of trees or propagules that survive different types of disturbance are important influences on subsequent tree regeneration (Palik and Pregitzer 1994, Turner et al. 1998).

GIS and landscape metrics

Geographic Information Systems (GIS) were used to compile spatially explicit data and perform different types of spatial analysis. By using GIS, historic datasets covering various areas could be digitalized and compared with each other or with recent surveys. It also facilitated transition analysis of specific forest types where changes could be followed through time using overlay analysis (Figure 11). Using GIS the digitized maps, which were based on vector data, could also be converted to raster data. This facilitated the calculations of landscape metrics (Paper II) and also comparisons between different map layers. GIS is also an excellent technical tool for visualizing spatial patterns and changes when disseminating information to other interested parties (Szegö 2000).

Various landscape indices are frequently used to describe and evaluate landscape patterns, although there is a vigorous debate about their ecological relevance (Skånes and Bunce 1997). There is often little or no biological foundation for the use of indices as measures of diversity in a given geographical region (Noss 1999). Therefore, the use of spatial indices as measures of diversity in management planning is a biological challenge rather than a technical one (Naesset 1997). In Paper II forest fragmentation was described by general landscape indices calculated using the Fragstats program (McGarigal and Marks 1995). In this fragmentation analysis forest with overstorey trees older than 100 years were studied. Fragmentation is a very crude concept of forest landscape change, as the size does not necessarily determine the quality of a forest fragment (McIntyre and Hobbs 1999). However, a fragmentation analysis provides valuable information if complemented with analysis of forest structure at stand scale (Paper II). Naturally, it is possible to calculate many other types of landscape indices from the current historical GIS database, but in my opinion these types of calculations should be based on specific habitat demands of different organism groups or individual species.

Management implications

Integrating reference information

Multi-objective forestry has made the task of setting management and policy goals more difficult. However, if the purpose is to restore structure and dynamics similar to those found in natural forests, it is clear that current methods of forest management need to be revised (Kuuluvainen 2001). In the Scots pine dominated landscapes that are the major focus of this thesis, the main conservation goal would be to leave old pines to restore the multi-aged forest structure. Comprehensive landscape management strategies will also need to consider the spatial pattern of stands and the rates and pathways of landscape change (Wimberly et al. 2000). Changes in management are therefore needed at both stand, landscape and regional level. Today there are large gaps in ecological knowledge, especially concerning larger spatial scales (Lertzman and Fall 1998). This gap, together with inefficient tools for multi-objective forest planning, often leads to vague planning processes at landscape scale (Kangas et al. 2000). Today, many concepts used in landscape scale planning are based on small remnant stands with high conservation values (cf. Naesset 1997, Öhman and Eriksson 1998, Carlsson 1999, Kangas et al. 2000). Naturally, these areas are of great importance for maintaining biological diversity, but at the same time the conservation strategies need to be regarded in a larger perspective. There is a need to develop new planning instruments where natural landscape patterns (cf. Mladenoff et al. 1993, DeLong and Tanner 1996) and long-term goals are incorporated more efficiently than in the current planning process.

The combination of the naturalness concept with spatially explicit planning requires a very long planning horizon and the need to look beyond the current landscape structure. In some landscapes there is a need to restore old-growth forest structures as very few stands have high conservation values. Today 10 years is a time horizon commonly used in tactical forest planning (Kangas et al. 2000). However, when modelling dynamics of natural disturbance much longer time horizons are needed (cf. He et al. 1999, Boose et al. 2001). If natural dynamics are to be seriously considered in forest management planning the time horizon needs to be extended to periods relevant to conservation planning and management (e.g. 100-500 years) (Poiani et al. 2000). The retrospective gap analysis described below could be one possible way to refine the basic ecological knowledge of local pre-industrial forest conditions and disturbance dynamics. Suggestions on how to integrate new quantitative data into systematic conservation planning, multi-objective forestry and forest certification are also presented.

Retrospective gap analysis

It has already been suggested that gap analysis could be used as a tool for conservation in Swedish forest ecosystems (Wallin et al. 1995, Angelstam 1997), but the concept presented here differs in one major point from earlier suggestions. Instead of using the general ASIO model (Angelstam 1998) to estimate disturbance dynamics and the proportion of different forest types in individual landscapes, a local historical analysis is performed of the actual landscape where the gap analysis is performed. Information on landscape and stand structure from historical records provide regional information that could guide both future conservation as well as multi-objective forest management. This information may be particularly useful for setting regional conservation goals in long-term forest planning, but could also be used both in management of already protected forest areas or in modification of forest management methods for enhancing biodiversity. In managed boreal landscapes where few old growth patches are left, references from *retrospective gap analysis* can serve as a goal for ecological restoration treatments. The method is intended for use at county administrations or larger forest companies in boreal Sweden. However, with some modifications it could also be applied in southern Sweden and on smaller forest properties. The use of local examples gives the method considerable educational value. The use of GIS together with different time layers from the same landscape makes it easy to visualise structures and changes for local forest managers.

1. The first step is to define natural regions based on variations in physical characteristics of the larger region, without considering ownership patterns. This type of delineation has already been done in some counties (Anon. 1998, Kellner and Johansson 1999); or parts of counties (Gustafsson and Johansson 1998). The size of these regions determines the total cost of the historical gap analysis as well as the level of ambition. If smaller regions are delineated, more landscapes need to be analysed, but at the same time the quality of the ecological information is higher. A wise alternative would be to start out with larger regions that can be further divided in the future.

2. In each of these natural regions one landscape is chosen to represent the region. In this phase access to historical data of good quality is a crucial factor, guiding the selection of the landscape. It is also important to consider general land-use history and historical variation in tree species composition within the region to find a landscape that represents the larger area well. Selecting landscapes to provide information that can be scaled up to a regional level requires good general knowledge of natural conditions and forest history in each natural region being considered (Paper I). In this phase it is important to use all types of available historical information from stand to regional scale (Papers I, II and III). However, as the main objective is to determine the pre-industrial state of the landscape, the current landscape, i.e. the present proportion of old or old-growth forest, is of less importance in this phase of the analysis. The size of the landscape can vary between 5,000 and

25,000 hectares depending on the size and location of the region. This is the size range currently used in the ecological landscape planning performed at the larger forest companies in boreal Sweden (Johansson 1998). It is easier to perform spatial analysis if the forest in the chosen landscape is continuous and does not consist of smaller forest lots scattered in a larger area. To increase the efficiency and lower the cost of historical gap analysis it is crucial that forest companies and official institutions working in each natural region co-operate.

3. The next step is to compile old forest surveys and present quantitative data on the proportion of different forest types in the chosen pre-industrial landscape (Paper II). If historical data are integrated in a GIS it is also possible to perform spatially explicit analysis of the landscape structure (cf. Mladenoff et al. 1993). At this scale, other types of historical information can also be valuable, and it would be desirable if relevant data from different types of historical archives could be combined when considering each landscape. However, the cost of pollen analysis and dendroecology is often high and specialised expertise is usually needed for these analyses. In comparison, historical records are relatively easy to handle and the analysis could be performed locally at forest district level. After the compilation of all available information, the historical landscape is compared with the current status of the same landscape. GIS is a useful tool also in this phase, and facilitates the integration of new historical information with already existing digital survey data or satellite images.

4. Major gaps in important ecological structures are identified and compared with current conservation goals, which can be both quantitative and spatially explicit. Then current conservation goals are adjusted to local conditions. The results from landscape level analyses can be scaled up to a regional level and then gap analysis can be performed using regional data. Further important data needed in this phase of the gap analysis are the critical threshold levels of different ecological structures required by different organisms. Unfortunately this type of information is scanty and current statements on "how much is enough" are very general and based on a limited amount of data. Current knowledge suggests 10-30 % of the original habitat as a general critical threshold (Andrén 1994).

5. Now the process of defining management goals starts. This is mainly a political process, in which the general public should be involved. In the end a trade-off between historical and biological considerations on one hand and timber production on the other determine the final strategic management goals.

Forest certification

Recently criteria for multi-objective forestry have been adopted by most of the Swedish forest sector, working within different certification systems (Anon 1997, Anon. 2000). These criteria have had a strong influence on formulation of practical forest management practices, and are used as direct operational goals in many larger forest companies without local adjustments. In March 2001, around 10 million hectares of Swedish forest were certified within the Forest Stewardship Council (http://www.fsc-sweden.org: Accessed 8-April-2001) and around 1.3 million hectares within the Pan European Forest Certification (http://www.pefc.se/index2/statistik.htm: Accessed 8-April-2001). One efficient way to improve conservation in Swedish forestry is to develop regional goals in forest certification based on empirical knowledge of local disturbance dynamics and landscape patterns. Also, more qualitative criterias should be defined, for example concerning the use of prescribed fire in restoration. Today prescribed burns are usually performed without considering the ecological effect of individual fires (cf. Johnson and Miyanishi 1995).

The idea of using historical information as a basis for future forest management is widely accepted (Attiwill 1994, Fule et al. 1997, Björse and Bradshaw 1998, Seymour and Hunter 1999). According to Foster (2000) it is foolhardy to formulate policy in conservation or natural resource management without an historical context (Foster 2000). Understanding the history of ecological systems helps managers set goals that are more likely to maintain and protect crucial ecosystem functions (Landres et al. 1999). Characteristic patterns of old-growth landscape structure would be useful in enhancing and restoring ecosystem functioning in managed landscapes (Mladenoff et al. 1993). Until we significantly improve our understanding of the habitat requirement of specific red-listed species, mimicking the natural forest structure by reversing, or at least slowing down, trends with known negative effects is also one of the best means to protect biodiversity (Noss 1999). However, to ensure the utility of new ecological knowledge in practical management it is vital to study spatial and temporal scales that are relevant to practical forest management and conservation in future research. At the same time, scales and time frames relevant to natural processes have to be incorporated into practical forest management and conservation planning. This presents an enormous challenge to researchers, forest managers and conservationists alike.

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