International Institute for
Applied Systems Analysis
IIASA
www.iiasa.ac.at

Human Transformations of the Swedish Boreal Forestry

Fries, C.

IIASA Working Paper

July 1996

Working Paper

Human Transformations of the Swedish Boreal Forest

Clas Fries

WP-96-86
July 1996

IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Telefax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

Human Transformations of the Swedish Boreal Forest

Clas Fries

WP-96-86
July 1996

IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Telefax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

Contents

Foreword

Siberia's forest sector has recently gained considerable international interest. IIASA, the Russian Academy of Sciences, and the Russian Federal Forest Service, in agreement with the Russian Ministry of the Environment and Natural Resources, signed agreements in 1992 and 1994 to carry out a large-scale study on the Siberian forest sector. The overall objective of the study is to focus on policy options that would encourage sustainable development of the sector. The goals are to assess Siberia's forest resources, forest industries, and infrastructure; to examine the forests' economic, social and biospheric functions; with these functions in mind, to identify possible pathways for their sustainable development; and to translate these pathways into policy options for Russian and international agencies.

The first phase of the study concentrated on the generation of extensive and consistent databases for the total forest sector of Siberia and Russia. The study has now moved into its second phase, which encompasses assessment studies of the greenhouse gas balances, forest resources and forest utilization, biodiversity and landscapes, non-wood products and functions, environmental status, transportation infrastructure, forest industry and markets, and socio-economic problems.

In order to gain from experiences made and knowledge collected in other boreal countries concerning the management of the boreal forest sector, which could be useful for the formulation of future management programs of the Russian boreal forest sector, the IIASA Siberian Forest Study has taken the initiative to produce a book on the global boreal forests. This Working Paper by Dr. Fries of the Swedish University of Agricultural Sciences, Umeå, Sweden, is a contribution to the planned book on boreal forests.

Abstract

A successful production-oriented forestry has influenced nearly all Swedish boreal forests. Accordingly, the standing volume has increased continuously since official data became available in the 1920s. On the other hand, there is very little natural forest left, except in the sub-alpine area.

In the pre-industrial era, probably the most important human impact on the Swedish boreal forests (around two-thirds of the country's productive forest land may be considered as boreal) was the conversion of forests to arable land, e.g. on sediments around lakes and in river valleys. In the 19th century, fire suppression had become effective in the whole area. Until the beginning of the present century, the iron industry in the southern part of boreal Sweden needed large quantities of wood and charcoal. To ensure this supply, forest management based on the clear-felling harvest system was introduced in the middle of the 19th century. Today, most sites in this region carry their second or third rotation.

North of the mining district, i.e. the major part of boreal Sweden, a logging frontier moved northwards during the 19th century. Initially, large diameter Scots pine was cut in a purely exploitive manner. The standing volume was substantially reduced, probably from a level higher than today's. This selective cutting was replaced by the clear-felling system around 1950, when the state launched a restoration program to regenerate low-stocked sites. Since 1950, around 44% of the productive forest land in boreal Sweden has been cleared. Intensive regeneration measures and stand treatments have generated rather homogeneous stands dominated by conifers. Since 1970, lodgepole pine, introduced from western Canada, has been planted on 4% of the productive forest land in boreal Sweden.

These radical changes in the Swedish boreal forests have heavily altered the natural processes and structures at different spatial scales. Fragments of woodland key habitats containing red-listed plants (mainly cryptogams as fungi, lichens, and mosses) and animals (mainly insects) are embedded in a matrix of well-managed forests. From a biodiversity point of view, the most important management measures probably are to increase the number and quality of undisturbed forests and the amounts of coarse woody debris and deciduous trees, and to reintroduce fire.

Acknowledgments

This study was funded by the Faculty of Forestry (research program "Managing Forests for Industrial Products and Environmental Quality") at the Swedish University of Agricultural Sciences. The author thanks Anders Granström, Tomas Lämås and Lars Östlund for valuable comments on parts of the manuscript, and Peter Duinker for reviewing it.

Human Transformations of the Swedish Boreal Forest

Clas Fries

1. Introduction

The forest sector has been of great economic importance for Sweden for more than one hundred years. The net export value from the sector normally exceeds the total net export value from the second and third largest industrial sectors (mechanical and medical industries, respectively). This exceptional position has been, and still is, reflected in Swedish forest policy in which economic use of the forests always has been favored by the state. It is clearly expressed for example in the Forestry Act which was in force up to 1993 (Swedish Forestry Act 1979); however, it is somewhat moderated in the version in force at present (Swedish Forestry Act 1993). The result of this favored position is that almost all land suitable for tree growth which is not used for other purposes (e.g. farming, cities, communications, or nature conservation) has been used efficiently for high timber production, especially in the last decades. This intense and widespread single objective use of the forest has completed the transformation of the Swedish natural forest, which started many thousands of years ago by scattered farmers in temperate and hemiboreal southern Sweden, and only a few hundred years ago in the more northern, boreal parts of the country.

This paper describes some significant parts of this process of transformation of Swedish boreal forests, i.e. the forests in the northern two-thirds of the country (Figure 1). More specifically, what is the present forest state in this region and which activities gave rise to this state? The forest as a source of wood and biodiversity in the forest are the focus. The most significant changes took place after 1950 when the clear-felling system became the dominating silvicultural system in northern Sweden. It is, however, not possible to address this period without going back in the history of forest utilization. One reason for this is that forest histories differ between the southern (Svealand) and northern (Norrland) parts of boreal Sweden (Norrland) (Figure 2). The natural forest in the region, i.e. the starting-point for the transformation, is characterized in the following section.

The paper is a compilation of historic works on forests and forestry (e.g. Tirén 1937; Zackrisson 1976; Linder and Östlund 1992; Östlund 1993; Östlund and Zackrisson 1995), ecological work focusing on conservation issues (e.g. Esseen et al. 1992; Sjöberg and Lennartsson 1995), and of data describing present conditions in Swedish boreal forests.

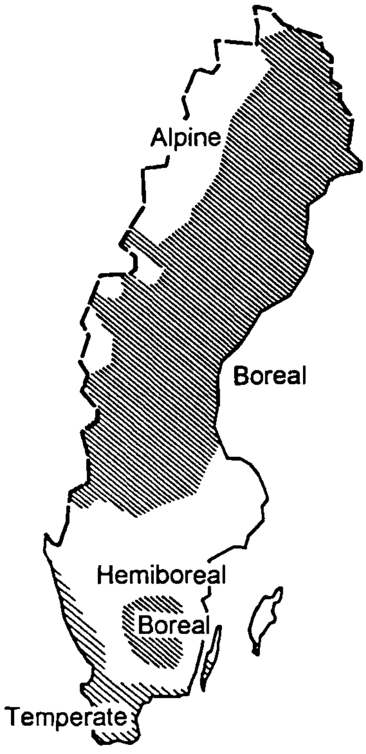

Figure 1. Vegetation zones in Sweden. Source: Ahti et al. 1968.

Figure 2. The three major regions in Sweden (Norrland, Svealand and Götaland) and the provinces in Norrland. The mining district with its own forest history is shaded on the map. Norrland, the main part of boreal Sweden, is 243,200 km^2, of which 52% is productive forest land (site productivity ≥ 1 $m^3ha^{-1}yr^{-1}$). High-altitude coniferous forest, mires, mountains (including parks, reserves, etc.) and agricultural land make up about 2, 15, 26 and 2%, respectively, of the land area. Of the productive forest land in Norrland, 39% is non-industrial privately owned, 53% is owned by forest companies, and 8% is under different kinds of public ownership. In 1996, about 4% of the forested land in Norrland was protected from cutting.

2. The Natural Forest

Before the forests in boreal Sweden were, to any large extent, used by humans, fire was the dominating large-scale disturbance factor (Zackrisson 1977). The fire influence differed with site type and region. On upland sites in boreal Sweden, three major types of virgin forests can be distinguished (Fries et al. 1995): (1) Scots pine (*Pinus sylvestris*) forest on dry or mesic sites, (2) deciduous or Norway spruce (*Picea abies*) dominated forests on mesic sites, and (3) Norway spruce forests regenerated by gap dynamics. These forest types actually form a gradient describing a decreasing fire frequency. In the present section, some characteristic features of these natural boreal forest types are outlined. In addition, today's stand management on sites which naturally carried the respective forest type is briefly described. However, it should be noted that detailed knowledge about natural processes and structures in boreal Swedish forests is lacking. The reason is, as earlier indicated, that natural processes have been suppressed on nearly all forest land in this region for at least a century.

2.1. Pine forests

Fire-influenced pine forest is the natural succession on most dry and some of the mesic sites in boreal Sweden. It is likely that large areas of glaciofluvial sediments along rivers as well as interior parts of northern Sweden with relatively low precipitation and/or coarse soils were naturally dominated by pine, mixed with about one-tenth white birch (*Betula pendula*). One-third of the boreal Swedish forests may have been dominated by pine. These were the sites in northern Sweden where fire was most frequent, with a mean return interval of around 50 years (Zackrisson 1977). Because of the short intervals and the relatively low site productivity which do not allow accumulation of large quantities of fuel, the fires were relatively low-intensity surface fires that allowed some large pines with thick bark to survive. Natural stands, therefore, often consisted of large and old pines which had survived several fires, overgrowing cohorts of younger pines. Many natural stands were, consequently, all-sized in structure (Zackrisson 1977; Engelmark 1984; Linder 1988), although more intense fires probably resulted in even-sized stand structures. In relation to today's managed stands, the natural pine forests surely contained higher standing volumes of both living and dead trees (Linder and Östlund 1992). On the driest sites logs might remain for several hundred years after a tree had fallen.

Relative to natural stages, today's stands lack variable structure, including pines several centuries old, height stratification, and dead trees. Because pine forests were adapted to fire, the absence of that process must be considered a major problem from the standpoint of maintaining biodiversity.

2.2. Deciduous or spruce-dominated forests on mesic sites

Spruce gradually replacing deciduous trees was a common natural late-successional phase on most mesic sites in boreal Sweden, i.e. on about half of the productive forest land in the region. This kind of succession was initiated by fire with a mean return interval of 100-200 years and burned-over areas were generally extensively colonized by pioneers such as white birch, hairy birch (*Betula pubescens*), aspen (*Populus tremula*), goat willow (*Salix caprea*) and pine (Zackrisson 1977). Because of the relatively long fire-return intervals and relatively high productivity in these forest types, fires were probably more intense than in the pine-dominated forests and may sometimes have caused total death in the tree layer. Since deciduous trees characteristic of early successions are often out-competed by the shade-tolerant spruce, dying and dead deciduous trees were common during the later successional stages (e.g. Linder 1983). The development of successions on these types of sites varies in relation to such factors as fire intensity, fire severity, and distance to seed source (Granström 1991; Schimmel and Granström 1991). Areas that escaped fire often occurred. On some of those, relatively pure spruce stands which regenerated by means of gap dynamics probably developed. These stands may have functioned as refugia for species dependent on more stable conditions.

Stands on these intermediate site types have been homogenized during the last several decades. One deficiency of importance to plant and animal diversity is that there are no natural successions of deciduous trees that normally occur after fire. This leads to a shortage of deciduous trees in general and of dead deciduous trees in particular. The total absence of fire also reduces plant and animal diversity on these sites.

2.3. Spruce forests regenerated by gap dynamics

This type of forest develops on sites with very low fire frequency, i.e. moist or wet sites, or sites with field layers dominated by herbs or where fire seldom occurs from climatic reasons (e.g. in high altitudes where snow is late to melt) (Zackrisson 1977). Perhaps 10-20% of the productive forest land in boreal Sweden was covered by this type of spruce forest. Regeneration is initiated by single or multiple tree-fall, the so-called gap dynamic (Hofgaard 1993; Hörnberg et al. 1995). Tree mortality begins with roots or butts affected by rot or other weaknesses. Subsequently, storm felling, snow breakage, and insect infestations are often final causes of tree death. Mortality and regeneration patterns in natural spruce forests result in a negative exponential age and size distribution, in which spruce is predominant but about 10% of the standing volume consisted probably of other tree species, primarily hairy birch.

These uneven-aged spruce stands have largely been replaced or have gradually been converted to relatively well-tended stands with an even-aged structure. Most of the significant structures and processes in natural spruce forests have therefore been lost, e.g. continuity of large logs and stable microclimatic conditions.

3. Domestic Forest Use

When the vegetation about 10,000 years ago started to recolonize the Scandinavian peninsula after the latest glaciation, tribes living off hunting and fishing followed northwards. In the part of Sweden which today is boreal, they settled at favorable places along the Gulf of Bothnia, preferably near the mouths of the large rivers draining the Fennoscandian mountain range and the forest land closer to the coast. The forests were of course influenced very little by these scattered settlements, perhaps with the exception of fire that might have been used as a tool for hunting and for improving grazing conditions for hunting game. Because fire was a natural feature of the ecosystem, an active use of it could, at the most, locally alter a natural disturbance regime.

A large proportion of northern Sweden has since long been used by a sparse Saami population for reindeer husbandry (Helle 1995). On a domestic production level, the Saami activities have probably not affected the northern Swedish forests to any large extent compared to the effects of natural disturbances such as fire and wind falls.

Farming was successively playing a larger role for people living off hunting and fishing in Norrland. There is documentation of agrarian settlements in the early 14th century along the coast of what presently is the province of Västerbotten (Figure 2). Recent research has, however, indicated that this type of settlement had existed long before that (Vikström 1994). Over the centuries, colonization was very slow. In different periods, agrarian settlements in sparsely-populated northern Sweden were encouraged by state subsidies and other measures aimed at making the first years' living less burdensome. A basic reason for this was the government's aspiration to enrich the country by using the natural resources of the north. Besides a few campaigns in the first part of the 20th century, the agrarian colonization of boreal Sweden was finished during the first half of the 19th century. The population in Norrland did not exceed 0.5 persons per km^2 until about 1700. Today's population density is 5 per km^2.

Until the beginning of the 19th century, the forests were used almost exclusively for domestic purposes, i.e. for firewood, material for buildings, fencing, etc. Where people lived, the forest was influenced by fire suppression, burn-beating (clearing forest by means of fire for temporary cultivation of, for example, rye), cattle grazing, and fire regularly used under controlled conditions on some site types to improve grazing conditions (Zackrisson 1976; Larsson 1995).

4. Wood for the Mining Industry

In parts of Svealand, deposits of ore were the basis for a mining industry which was widespread in the region already in the 17th century (Figure 2) (National Atlas of Sweden 1990). In the beginning of the 18th century, iron contributed with about 75% of Sweden's export (Heckscher 1971, p. 110). Iron works needed large quantities of wood, but also charcoal which was produced on plots in the forest. Cutting for charcoaling consumed mainly small trees and was, during some centuries, done in a purely exploitive manner. Larger trees were used for different purposes, e.g. as pit props. Because of its economic importance, iron production was favored by the state and a system was launched where public forest land was leased to iron works for ensuring the supply of charcoal and other essential wood products. This was also the reason for the introduction of forest management based on the clear-felling system in the middle of the 19th century (Carbonnier 1978). Such a forest history explains why large areas in Svealand carry their second or even third rotation. Because wood was locally becoming scarce, iron works were also located in places along the Gulf of Bothnia where this limiting resource was abundant (Arpi 1951). These few locations influenced the forests in the vicinity of the iron works but left the bulk of them untouched.

5. Pre-Industrial Forestry in Norrland

Before the international demand for lumber and other wood products reached Norrland in the early 19th century, tar and potash, but also charcoal (see Section 4), were produced in this part of the country (Tirén 1937; Borgegård 1973; Östlund and Zackrisson 1995). The production of tar and potash peaked in Norrland in the middle of the 19th century. The raw material for tar was pine stumps and snags. Tar was primarily used for maintaining ships built of wood, which explains why production went down in the beginning of the present century. Because the tar barrels were floated on rivers down to the coast, production could also take place inland, e.g. at the typical pine sites on coarse-grained sediments along the rivers. Potash (K_2CO_3) was another pre-industrial product produced from ashes of deciduous trees, primarily birch, but also aspen. The production of potash may have resulted in local decline of deciduous trees. Potash was used for glass and soap manufacturing.

6. Industrial Forestry in Norrland Up to 1950

In the early 19th century, when industrialism was developing in Europe, the boreal forests in Sweden outside the mining districts and denser populated areas, primarily along the coast and in the lower reaches of the large river valleys, were almost untouched by the ax. It was an enormous economic resource, a timber mine, waiting for exploitation and export to a relatively nearby market. Large quantities of lumber were needed in Europe and a logging frontier began to move northwards over northern Sweden, i.e. Norrland (Figure 3).

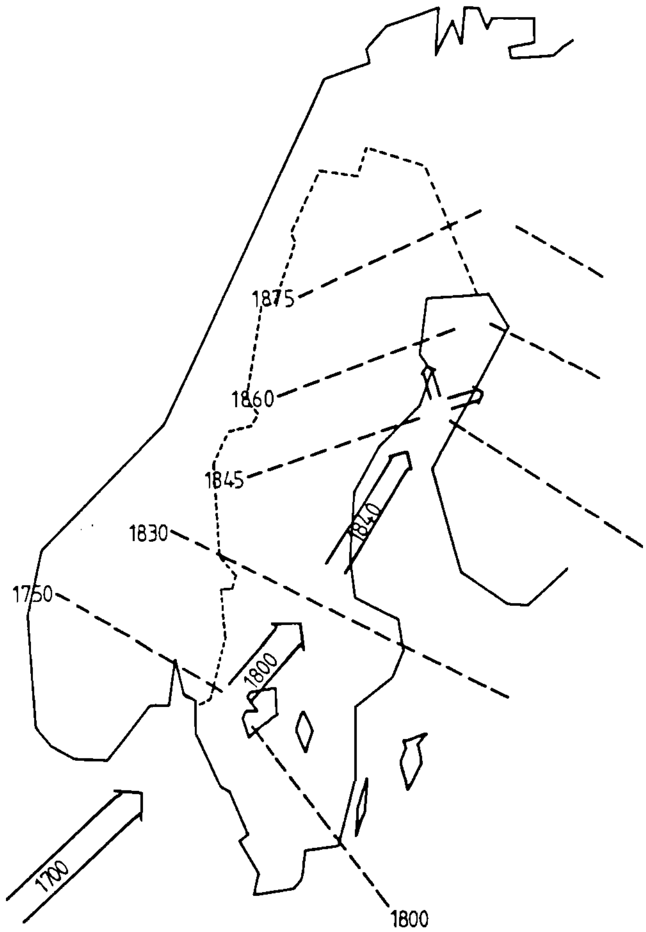

Figure 3. The spread of the international demand for wood products to the Nordic countries under the industrial revolution. Source: Bunte et al. 1982.

The forests were exploited for large-diameter pine timber, which was abundant all over northern Sweden. Only the largest logs were extracted from the forest, which meant that a few trees per hectare, on average, were cut in the beginning of this new era. Because harvest levels far exceeded the ingrowth of large trees, the diameter limit was successively reduced (e.g. from 30 to 25 cm in the top end of the logs). The dimensions were, however, generally larger than those of trees cut in today's forests. Square-cut balks, 10-15 meters long and 30-40 cm wide, were an extremely valuable assortment. Dead trees were sometimes used for construction in creeks and rivers to facilitate floating of timber to the sawmills, which mainly were located along the coast (Östlund 1993).

The pulp and paper industry developed in northern Sweden towards the end of the 19th century, but the large expansion occurred first in the 1930s. The fact that smaller trees and spruce were now valuable led to an increasing interest in using the clear-felling system also in the north. Although it became more and more evident that the desired regeneration generally did not occur after selective cutting, this management system was kept. Under the economic depression in the 1930s, selective cutting actually got a renaissance. On the few clear-felled areas regeneration measures were normally not taken, which contributed to successively decreased stocking levels.

The successive decline in standing volume was, naturally, observed by the Forest Service which managed large areas of state-owned forest in Norrland. In the late 1930s, plans were developed for speeding up needed regeneration work on the low-stocked sites (Höjer 1950). A program with similar objectives for privately-owned forests was presented by a committee in 1940. The ambitious plans were, however, postponed because of World War II. However, parallel to selective cutting and clear felling without providing for regeneration in the northern Swedish forests, experiments with new regeneration methods after clear felling were carried out on a forest district in northern Västerbotten (Wretlind 1934). These experiments had great influence on the quick change to the clear-felling system that were to come. As early as the 1920s, the forester Joel Wretlind had realized that the desired pine forest did not develop in stands, not even if they were low-stocked. He started to develop methods for solving this silvicultural problem and soon found that clear felling, preferably followed by prescribed burning (Wretlind 1948), was necessary if a good future stand should develop.

7. Human Impact on the Swedish Boreal Forest Up to 1950

Because 1950 is a turning point for forestry in the major part of boreal Sweden, it is important to try to evaluate human impacts on the forests so far. In the mining district in the south, about a century's use of the clear-felling system had at that time reduced variation within stands and eliminated natural forest structures, for example large old and dead trees, and deciduous trees. The standing volumes were relatively high, but the diversity of animal and plants was probably reduced, maybe to similar levels as in today's boreal forests further to the north (see Section 9). There were, however, regional differences in forest transformation due to cutting. Many privately-owned woodlots, often extremely small or narrow (e.g. 500 m × 10 m) (Sporrong 1995), were left unmanaged when the demand for wood from the iron industry successively decreased from about 1900, while the management was more intense on company-owned forest land where the clear-felling system was well developed.

North of the mining district, human impact on the forest was small and concentrated in populated regions. The tree-species distribution in the virgin forest was altered by active use of fire (burn-beating and for improving grazing conditions) as well as fire suppression. Cutting of trees for buildings, fencing, firewood, and production of tar and potash contributed to changes in forest structure. As a result, the forests were locally drained of primarily pine (also dead trees) and birch, but they were seldom cleared by this cutting. The vegetation in the outfields of villages and settlements was influenced by the grazing of sheep, goats and cattle (Zackrisson 1976). It reduced regeneration, especially of deciduous trees, and damaged trees which could result in sparse forest stands dominated by dwarfed trees. In places, forest land was transformed to arable land. Ditch-draining of mineral soils in regions suitable for farming drastically reduced habitats for *Alnus incana*, and probably also for spruce which, however, was much more widespread. Mires were also ditched for cultivation. Draining for cultivation was locally an important factor inducing vegetation changes. About half of a 700 km^2 relatively flat area around Umeå was drained between 1867 and about 1940, mainly for cultivation but also for increasing forest acreage (Zackrisson 1976).

In the first phase of industrial forestry in northern Sweden, large-diameter pines were the resource of interest. Cutting those pines affected the structure of the forest, which, however, was seldom clear felled. Large quantities of small, damaged or dead trees, spruces and deciduous trees, as well as rejected timber, were left after a site was cut. More or less pure spruce stands were probably still relatively unaffected by cutting. On the whole, the forests in northern Sweden successively became more open and spruce-dominated. During this first period of large-scale industrial forestry until the first National Forest Inventory (NFI) (1923-27), the standing volume in Norrland decreased by around 35% (Linder and Östlund 1992). The continuous decrease in standing volume until the 1940s was due to an ongoing decrease in volume of large-diameter trees, now in more remote areas, and to an expanding cutting of smaller trees for the pulp and paper industry (Holmgren 1950). This may be illustrated by a decrease in standing volume in a forest district in the center of the province Norrbotten from 88 m^3 per ha in 1910 to about 40 m^3 per ha in the late 1930s (today it is about 60 m^3 per ha) (Linder and Östlund 1992).

The volume of dead trees was also substantially reduced during this large-scale exploitation of the forests. Linder and Östlund (1992) report a reduction of standing dead trees from around 12 m^3 per ha before the forests were exploited, to < 1 m^3 per ha in the 1960s in two areas close to the border between Svealand and Norrland. This decline in volume of dead trees seems to have been quite fast. In relatively densely-populated areas of northern Sweden, the average volume of dead trees at the first NFI in the 1920s was about the same as the present average volume of dead trees, i.e. about 2 m^3 per ha (SOU 1932; Anon. 1995). In a recent comparison between the average volume of dead trees in a managed boreal forest landscape in the province of Västerbotten and in two neighboring natural forests, Lämås and Fries (1995a) found large differences. The volumes in the natural forest stands were 25-50 times higher than the mean volume in the managed forest landscape. The proportion of large dead trees was also higher in the natural forests than in the managed forest landscape.

The effects on biodiversity of the way forests were used in northern Sweden up to 1950 can only be roughly judged. No inventories like the ongoing (1993-1997) mapping of "woodland key habitats" (Nitare and Norén 1992) had been done at that time. However, by examining the probable impact of those early practices on some key structures, one can discuss the potential situation for biodiversity (expressed, for example, as today's red-listed species (Groombridge 1993; Aronsson et al. 1995)) at that time.

Because of fire suppression, many fire-dependent species (e.g. the beetle *Agonum quadripunctatum*) were probably rare compared to natural conditions. Because the number of large pines had been heavily reduced, population sizes for species associated with the pine forest type were probably substantially reduced. Species richness may have been the same, but the populations were certainly fragmented due to destroyed habitats. Because of small amounts of dead trees, species dependent on that structure probably also had relatively low population sizes. This would have been more pronounced for species dependent on pine (e.g. the lichen *Cladonia parasitica*) than for those dependent on spruce (e.g. the wood-inhabiting fungus *Fomitopsis rosea*). The reason is that pine wood generally was higher valued than spruce wood.

Species dependent on spruce forests naturally regenerated by means of gap dynamics are those which are the most sensitive to cut (Fries et al. 1995). Before the development of the pulp and paper industry, this type of forest was not as attractive for cutting, as the fire-disturbed forests containing pine. Several of today's red-listed species dependent on features typical of the spruce forest type (e.g. continuity of old trees and large logs, and stable microclimatic conditions) were probably more numerous than today. A large proportion of the then relatively untouched sub-alpine forest along the Fennoscandian mountain range was, and still is, of this type.

Around 1950, the larger part of the forested area in northern Sweden had not been cleared after the regeneration which followed a natural disturbance, mainly fire. Many typical structures which are rare in today's once artificially regenerated forests were therefore still quite frequent. One example might well be large, old or dead deciduous trees, e.g. aspen on which many red-listed species (e.g. the lichens *Collema curtisporum* and *C. furfuraceum*, and the Grey-headed Woodpecker *Pinus canus*) depend. The way the selective cutting was done left forested strips more or less untouched along mires, lakes, and streams. These areas, which often were thoroughly cut in the following decades, may have functioned as refugia for species which today are on the red-lists.

8. Forestry in Boreal Sweden from 1950

In January 1950, the director general of the Forest Service delivered a note to his subordinated foresters responsible for the management of the state-owned forests in Norrland (Cirkulärskrivelse nr 1/1950 1950). It was the start of an ambitious restoration program which would influence not only the forests but also the people in the region. The basic idea was to clear fell and regenerate the low-stocked and low-producing stands to increase timber production in the future. New forests should be established by investing in thorough regeneration efforts such as prescribed burning, scarification, planting, or, when conditions were good, natural regeneration under seed trees. In the note it was said that "forest districts having large and difficult regeneration tasks ahead need not contribute to the Forest Service's profit to the same degree as other districts where the conditions were better in this respect." The Forest Service had strong influence on the management on company and non-industrial privately-owned forests, i.e. a new forestry paradigm was emerging in northern Swedish forestry.[1]

Through clear felling of the old forest, the ambition was to create large, cleared areas (they often covered more than one thousand hectares), partly because one thought that it was necessary to form large homogenous stands for efficient future management, and partly because it was believed that this would reduce the risk for disastrous snow blight (*Phacidium infestans*) infestation in pine regeneration (Ebeling 1957). The prescription was to clear fell all the way out into mires or low-productive swamp forests. The conception was that the resulting relatively thin and compressed snow cover would inhibit the spread of the fungus.

In the early 1950s, chain saws were beginning to replace manual felling with crosscut saws, and the delimbing by axes. Logging was done in winter and horses were used for transportation of the timber to creeks and rivers for further floating. In the 1960s, most log transport was done with machinery, in some areas first by means of modified farm tractors which soon were replaced by large forwarders.

Regenerating the large clear-felled areas was a challenging task for foresters at that time. Few people were experienced in scarification, the handling of seedlings, and planting. Training programs were therefore initiated for forest workers as well as for foresters on different levels. The clear-felled areas were burned, manually scarified or, when the large forwarders came, scarified mechanically. Planting was a higher priority than seeding because of limiting seed resources. Natural regeneration should be done only when suitable pine seed trees were present, on drier site types, and at relatively low altitudes. On many selectively cut and low-stocked stands, birch grew abundantly and sprouted vigorously when cut. To eliminate negative competition from these birches on the future conifer regeneration, they were sprayed with herbicides. This was the first time herbicides were used on a large scale in Swedish forestry. Nearly all clear-felled areas were regenerated with pine. Seedlings were, in the beginning of the restoration epoch, grown in temporary nurseries close to the areas which

[1] It was, of course, realised that it was inefficient to restore the timber production capacity on all forest land with old and sparse stands with the same intensity. This was an important reason for the Forest Service in 1952 to establish a 'sub-mountain forest line' along the Fennoscandian mountain range in the western and northern part of northern Sweden (Cirkulärskrivelse nr 12/1952 1952; Linder 1987; Domän 1992). No state-owned forest west of this border should be clear felled. The restoration should instead be concentrated to sites with better climatic conditions where the chances for regeneration success were considered to be higher. Conservation aspects were also included in the basis for settling the border (Höjer 1954). The border was formally removed in 1982.

should be planted, then in large, permanent outdoor nurseries and finally, in the late 1960s, in greenhouses.

Many resources were needed in restoring the low-stocked forests. It can be illustrated by means of the time used for regenerating a site in a large area which was 'restored' in the province of Norrbotten. After clear felling, the site was burned, planted with bare-root pine seedlings in combination with manual scarification, and manually sprayed with herbicides five years after planting. This needed 5, 10.5, and 3 person/days per ha, respectively (unpublished data presented at an excursion in 1978).[2]

The yearly clear-felled area was large in the beginning of the restoration epoch. In the mid-1950s, an average of 1.22% of the productive forest land in Norrland was clear felled every year (data from NFI). This corresponds to an average rotation time of 82 years. The corresponding figures for 1983-1993 are 0.72% and 123 years, respectively. During the period 1950-1995, about 5.8 million ha (44%) of the productive forest land in Norrland were clear felled (Figure 4). The proportions are 40% in northern Norrland and 50% in southern Norrland. Most of the clear-felled areas have been regenerated by means of planting with pine, but since around 1970 also with lodgepole pine (Figure 5). Up to 1995, this Canadian species was planted on about 4% of the productive forest land in Norrland (i.e. on about 575,000 ha). One reason for the recent decline in use of lodgepole pine is severe damage by the fungus *Gremmeniella abietina* to plantations in some regions (Karlman et al. 1994). Increased environmental awareness among the forest companies has probably contributed to a more restrictive planting of this species. Spruce has been planted to a small extent, mainly on more fertile sites and in relatively humid areas, e.g. in the western part of the province of Jämtland. Naturally regenerated spruces have, naturally, been included in the stands when considered suitable.

Compared with clear felling, larger areas in northern Sweden have actually been influenced by thinning since 1950. During the period 1950-1995, nearly 7 million ha (53%) of the productive forest land in Norrland have been thinned (data from NFI) (Figure 4). The proportions are 44% in northern Norrland and 65% in southern Norrland. Because some stands probably have been thinned more than once, the area actually influenced by thinning probably is somewhat smaller. Between 1954 and 1963, an average 2.6% of the productive forest land was thinned every year. The high thinning intensity in this 10-year period was mainly for homogenizing selectively cut forests in which the tree distribution often was patchy. Thinnings were usually directed towards such dense patches. The volumes cut per hectare were therefore small. At the forest company MoDo, with forests in central Norrland, an average of 23 m^3 per ha, of a standing volume of 103 m^3 per ha, were cut in thinnings between 1951 and 1957. In the period 1968-78, MoDo cut 41 m^3 per ha in thinnings in stands which had about the same stocking level as in the 1950s (Andrén 1992). Another reason for the extensive thinning in the 1950s was that it substantially contributed to the industries' timber supply which was insufficiently satisfied by clear felling of low-stocked stands (Andrén, personal communication). Since 1985, the yearly thinned proportion of the productive forest land in Norrland has been only 0.6%. During the last 10-year period, the low-thinnings have primarily been aimed at avoiding self-thinning and promoting diameter growth of conifers. In this period, thinning in some areas, for example the province of Norrbotten, was done for the first time ever in stands established after clear felling.

[2] Mechanical scarification and manual planting, which today are the normal measures when regenerating a clear-felled site, now take about 0.2 and 1 person/days per ha, respectively. Efficiency in logging has also increased. In 1985, the produced volume per hour of delimbed logs at roadside was 8.6 times higher than in 1950 (Andersson 1988).

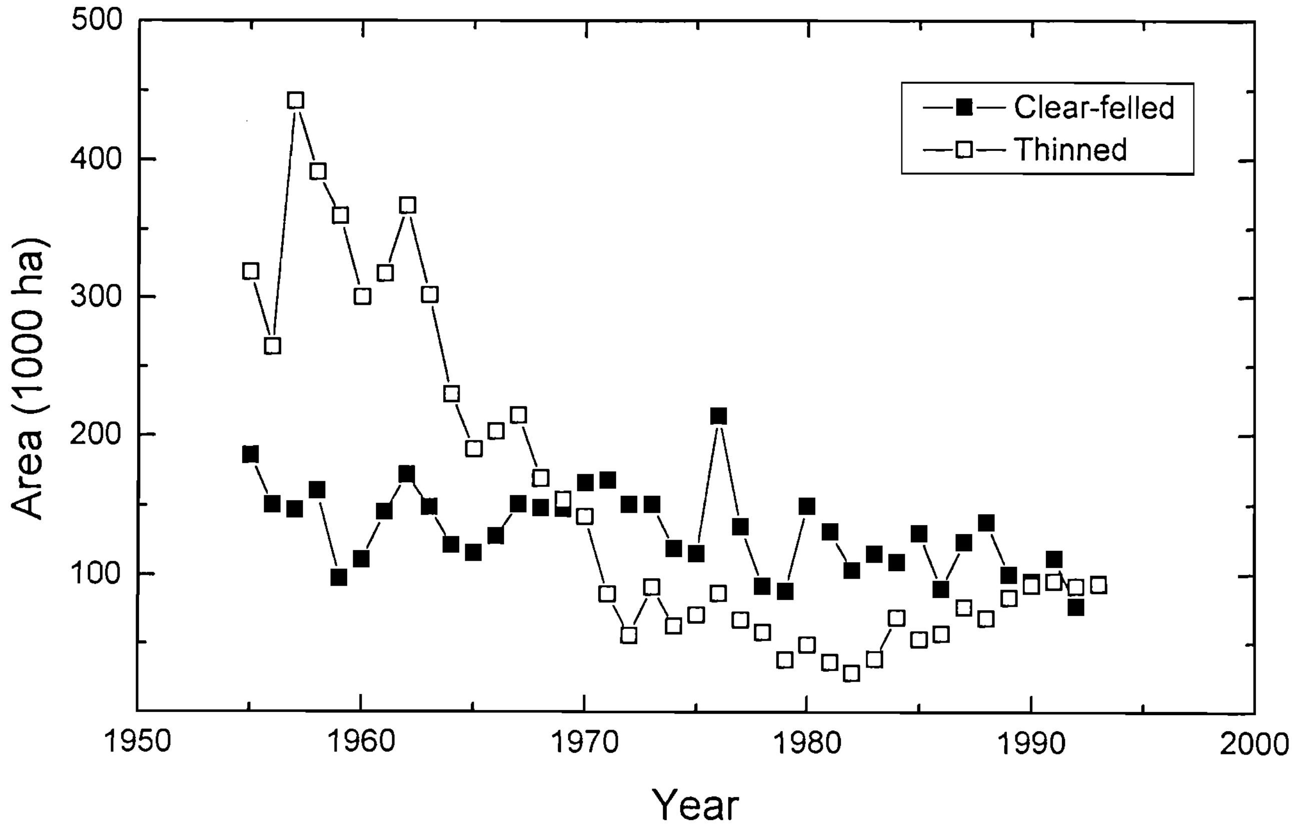

Figure 4. Clear-felled and thinned area in Norrland from the beginning of the restoration epoch around 1950 up to 1995. Data from NFI.

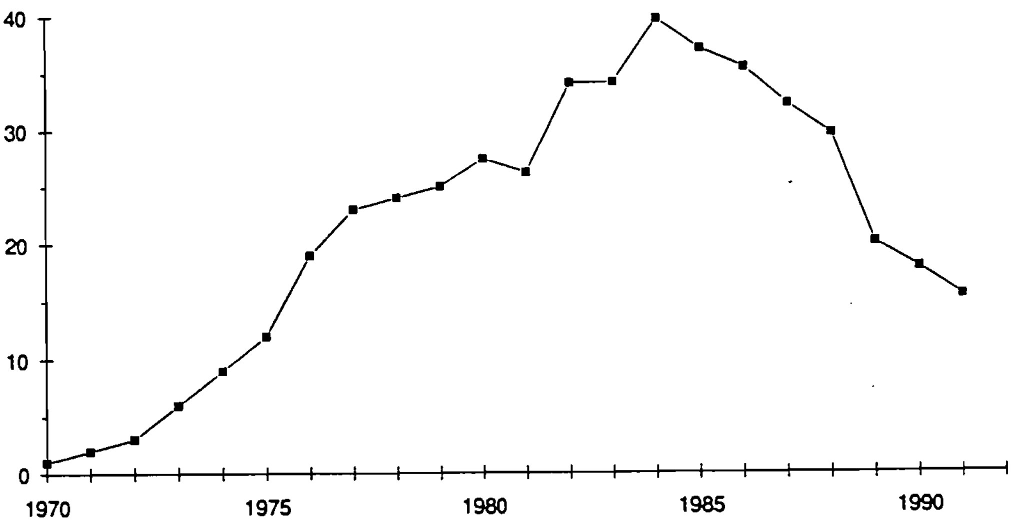

Figure 5. Area planted with lodgepole pine in Sweden (1000 ha). (About 90% has been planted in Norrland.) Source: Lindgren et al. 1992.

Pre-commercial thinning of young stands has during the period 1950-95 influenced about 32% of the productive forest land in Norrland (data from NFI). Some stands have probably been thinned twice.

The need for labor in northern Swedish forestry increased as a consequence of the launching of the restoration program. Extensive and ambitious regeneration measures now occupied forest workers the whole year round. This contributed to the waning importance of both small-scale farming and logging. This can be illustrated by the typical forest commune Arvidsjaur in southern interior Norrbotten, in which the number of farming enterprises with > 2 ha arable land decreased from 836 to 30 during the period 1950-1988. The decline in area was as high as 85% in the same period (National Atlas of Sweden 1992a). In the provinces of Norrbotten and Västerbotten, on the whole, the area of arable land decreased by 50% since the 1950s, at which time the arable area was the largest ever.

Some villages for forest workers with fairly good services such as stores, post offices, and schools were established in the 1950s in interior northern Sweden. These were in general rather short-lived, because mechanization of logging soon reduced the possibilities for forest workers to get employment in this part of the country. Furthermore, forest workers who did not get into industry in southern Sweden rather preferred to commute to the forest from places with more developed services than was the case in the forest worker villages. The decreasing number of jobs in forestry has contributed substantially to the decrease in population in the communes in interior Norrbotten and Västerbotten, with a few exceptions, by 20-40% since 1960.

The introduction of machinery in logging was an important motive for building forest roads. This changed the access to the forests dramatically and was probably necessary for efficient restoration of the northern Swedish forests (Figure 6).

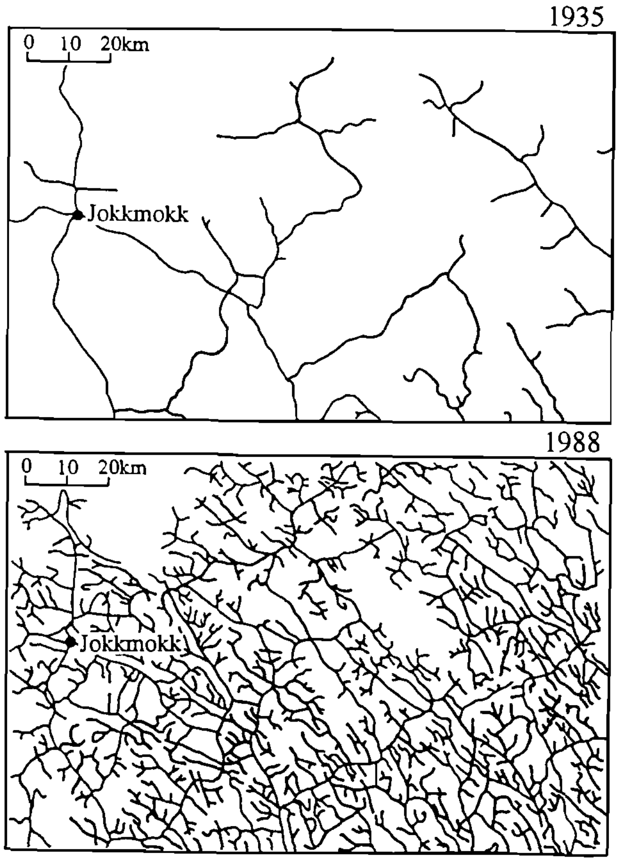

Figure 6. The forest road system in northern Sweden developed mainly after 1950. The example is from the interior of the province of Norrbotten. Source: National Atlas of Sweden 1992b.

9. Forestry from 1950: Impacts of Clear Felling on the Northern Swedish Forests

The most important impact of forest management after 1950 on the Swedish boreal forests is that sites that never were clear felled before were thoroughly cleared and, in most cases, ambitiously regenerated with one tree species. Emphasizing pine in regeneration has successively raised the proportion of pine forests at the expense of mixed forests (Figure 7). The proportion of deciduous-dominated forests in northern Sweden has, according to the NFI, changed little since the 1920s. In the natural stages, the area with dominance of birch and aspen was probably much larger than in this century (Zackrisson and Östlund 1991). The introduction of an exotic tree species (lodgepole pine) has, at least locally, changed conditions for the native fauna and flora (Danell and Sjöberg 1992). The transfer, normally northwards, of pine provenances at planting is also contributing to the transformation of a natural ecosystem (Liljelund et al. 1992).

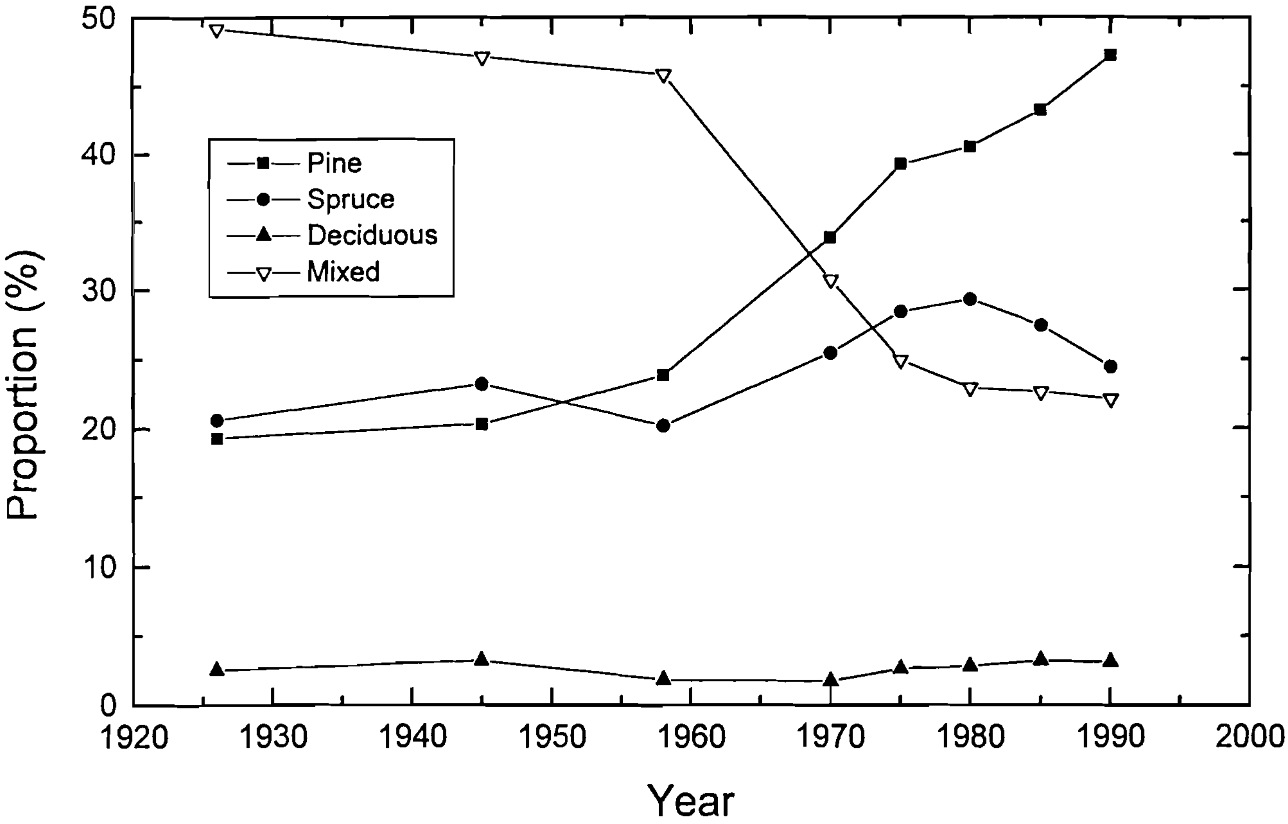

Figure 7. Proportions of pine, spruce, deciduous, and mixed stand types in Norrland from the time of the first NFI in the 1920s to 1990. Until 1962, respective forest type was defined by having a standing volume of dominating tree species ≥ 80%. Since then the limit has been 70%. Source: Data from NFI.

The standing volume in Norrland decreased from the 1920s to the 1930s, but has, partly as a result of the restoration work, generally increased since the 1950s (Figure 8). Pine is slowly passing spruce with respect to growing stock. The discrepancy in changes in growing stock volume and changes in forest type (compare Figure 7 and Figure 8) is due to the pine forests being generally younger than the spruce. This will lead to increasing differences in proportions of growing stock volume between pine and spruce. This development is clearly illustrated when comparing data from the forest company MoDo's forests from the late 1940s with data from the mid-1970s, at which time pine totally dominated the younger age classes (Figure 9).

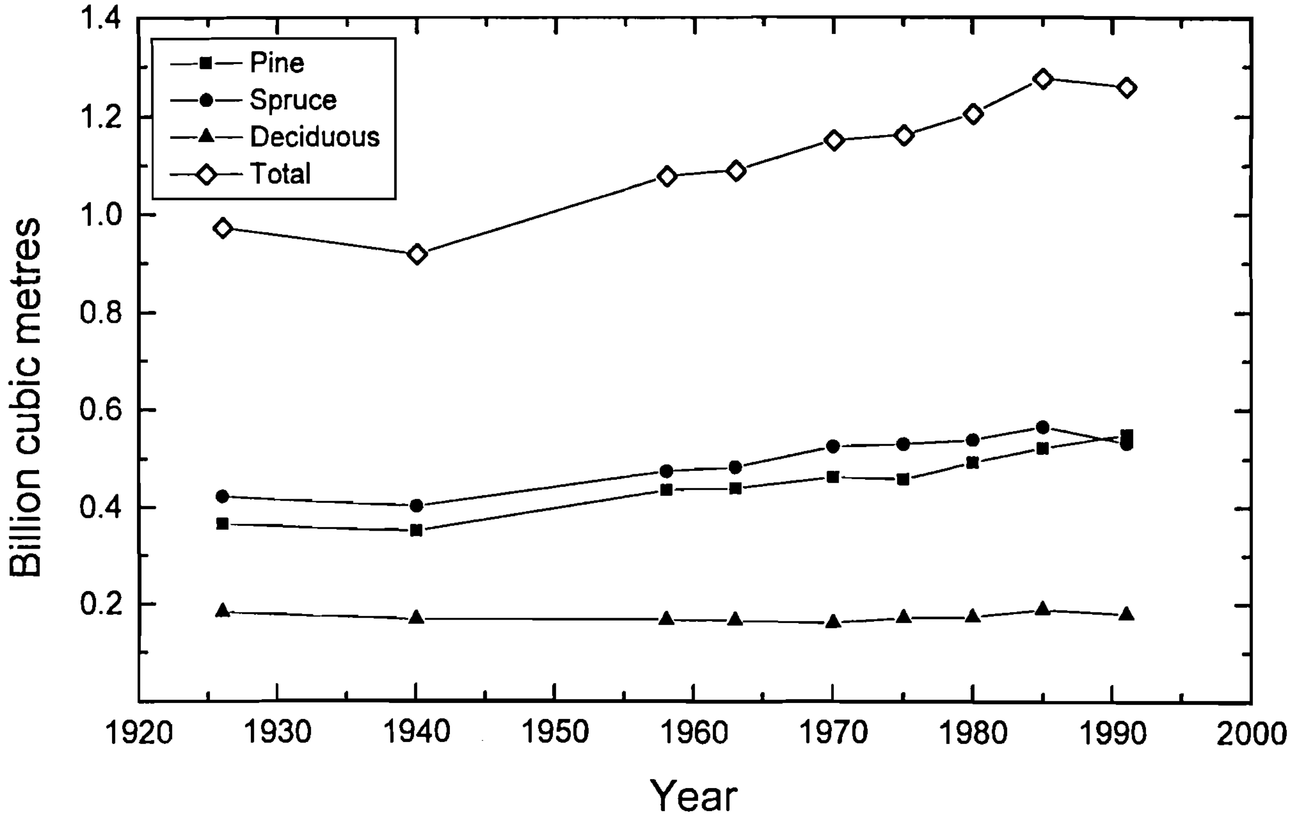

Figure 8. The growing stock volume in Norrland from the 1920s to the 1990s. (Lodgepole pine is added to Scots pine.) Source: Data from NFI.

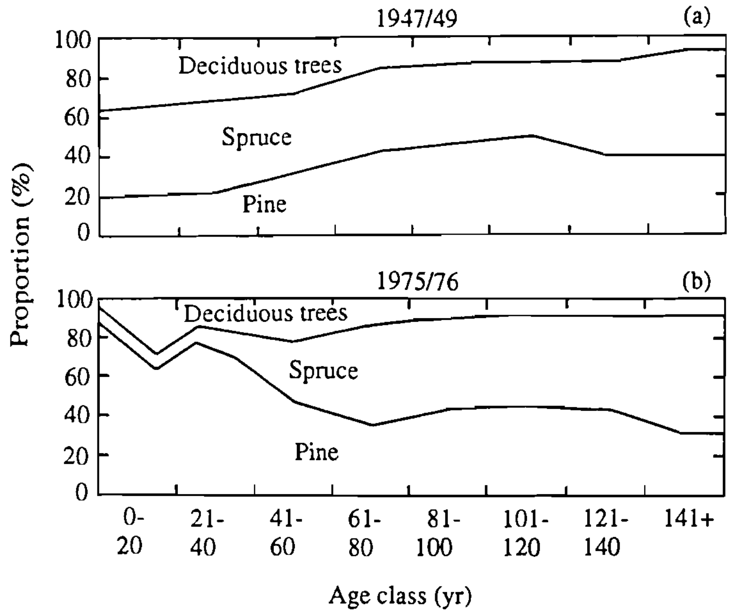

Figure 9. Proportions of pine, spruce and deciduous trees of the growing stock volumes, separated in age classes, in the late 1940s (a) and in the mid-1970s (b) in the forest company MoDo's forests. Redrawn from Andrén 1992.

The way clear felling normally was done rarely transferred any biological legacies (cf. Franklin 1992) in the form of large old or dead trees from the old stand to the future stand. The relatively few old trees which were remaining from earlier cuttings, have, consequently, been eliminated from about >40% of the productive forest land in northern Sweden since 1950.

By means of thinning, multi-storied stands have been converted to single-storied stands on a large proportion of the forest land in Norrland. These stands are, however, not by necessity even-aged. The relatively homogeneous stands in northern Sweden which today are clear felled often contain trees with ages varying from 80 to 150 years. Because spruce is more shade tolerant than pine, this situation is more typical for stands dominated by spruce than for pine-dominated stands.

The amounts of large-diameter trees have locally been much reduced due to selective cuttings for a long period of time (Linder and Östlund 1992). In general, however, large trees have slowly increased in number in Norrland since the first NFI (Figure 10). An important ecological aspect of today's large trees is that they are younger, more uniform and grow in more-uniform stands than the large pines which were cut in the 19th century. The volume of dead trees has been constantly low since the first NFI (about 2 m^3 per ha, on average).

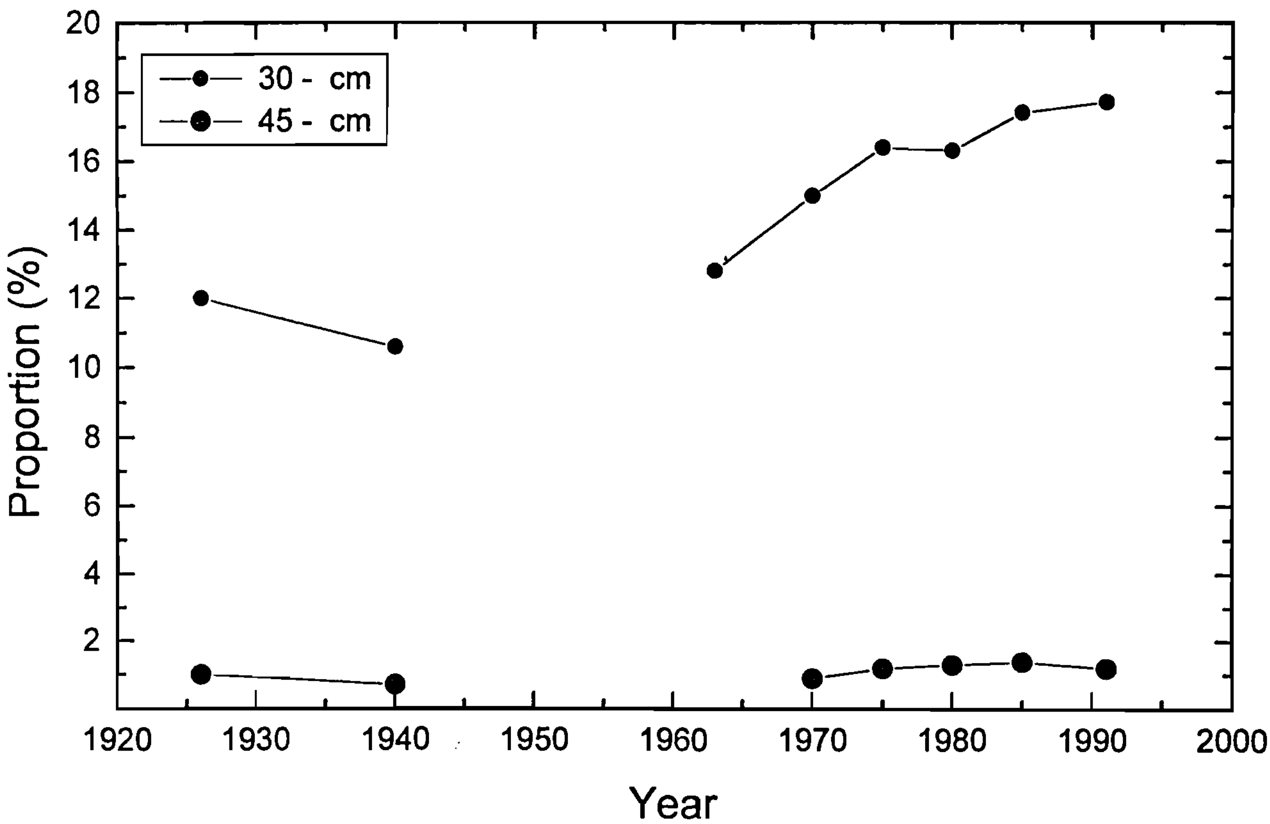

Figure 10. The proportions of growing stock volumes made up by trees ≥ 30 cm and ≥ 45 cm at breast height in Norrland from the 1920 to 1990. Source: Data from NFI.

Changes in landscape structure are more difficult to trace than the described stand-level changes. However, the main difference between the forest landscape influenced by natural fires and today's forest landscape is probably that fires resulted in more complex patterns of patches than forest management. Moreover, today's anthropogenic edges between patches are certainly much sharper and straighter than those in the natural forest landscape.

Because forestry based on the described clear-felling system has been less widespread far from industrial plants, natural or natural-like forests are still remaining in some regions (Figure 11). These forests are typically located in relatively high altitudes along the Fennoscandian mountain range (e.g. west of the former 'sub-mountain forest line') and are therefore not representative of Swedish boreal forests or Swedish forests in general.

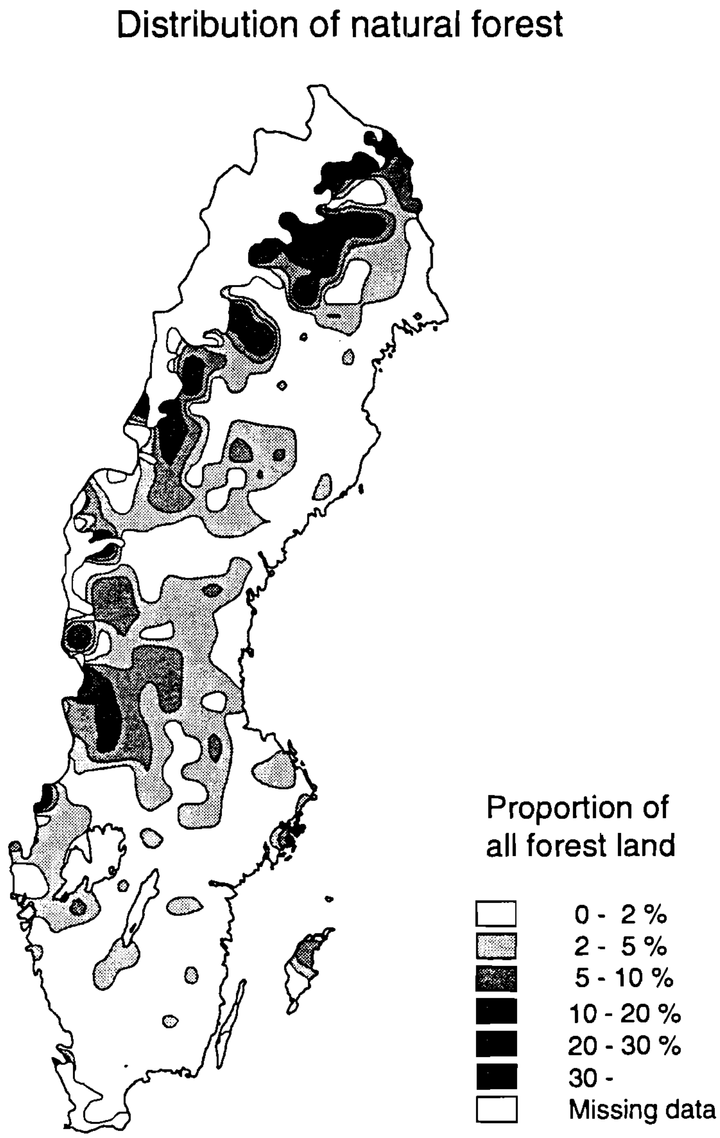

Figure 11. Map showing the location of remaining old forests with relatively high proportions of natural stand features in Sweden. Source: NFI, Swedish University of Agricultural Sciences, Umeå.

There are still, however, patches of natural (or natural-like) stands spread out in a matrix of managed forests. The earlier-mentioned so-called woodland key habitats are now being mapped on non-industrial privately-owned forest land (about 50% of the productive forest land in Sweden) (Nitare and Norén 1992) by personnel at the Swedish National Board of Forestry, and is planned to be finished by the end of 1997. Forest companies are doing a similar inventory themselves. Woodland key habitats should be designated so that red-listed species are likely to occur in them.

During the first 1.5 years' mapping (up to 1994), about 10,000 woodland key habitats were found in Sweden as a whole (Swedish National Board of Forestry, unpublished data). It is forecasted that woodland key habitats will comprise around 200,000 ha, i.e. about 1% of the productive forest land in the country. The patches that actually correspond to the definition are quite small. In boreal Sweden the mean size of woodland key habitats so far is 3.4 ha (median 1.5 ha). The inventory confirms that it is the relatively old and unmanaged forest which has high conservation values. At about half-way through the inventory, 87% of the woodland key habitats found in boreal Sweden are located in stands which are at least at economic maturity. Examples of habitat types are, so far: conifer-dominated stands on upland sites, spruce swamp forests, or deciduous-rich mixed forests (about 46%, 8%, and 6%, respectively, of the number of registered woodland key habitats in boreal Sweden). Common structures indicating high conservation values have been large spruce logs, snags, old large pines, and old large aspen (in about 60-70%, 65%, 30%, and 20%, respectively, of the cases). Some of the species found during the inventory which indicate high conservation values are the wood inhabiting fungi *Phellinus ferrugineofuscus* and *Fomitopsis rosea*, and the lichen *Lobaria pulmonaria* (in about 25%, 13%, and 20%, respectively, of the cases). There are relatively many red-listed species related to aspen, e.g. lichens of the genus *Collema* (Aronsson et al. 1995). Furthermore, aspen has been found to be the most common 'key structure' in fire-influenced key habitats (cf. Kuusinen 1994).

An example of a typical forest landscape (Lämås and Fries 1995a; Fries and Lämås, unpublished manuscript) may contribute to the conception of the present situation concerning remaining natural forests in boreal Sweden. The landscape is 10,000 ha (87% productive forest land) and is located about 60 km northwest of Umeå in the province of Västerbotten. About 46% of the productive forest land contains stands ≤ 50 years which are established by planting or natural regeneration under seed trees of pine after clear felling. About 13% contains stands > 100 years. Using a thorough inventory, about 6.1% of the productive forest land in the landscape was found to have high conservation values (Figure 12). (This figure should not be compared with the forecasted 1% woodland key habitats (above), because in the landscape inventory, patches with high conservation values were sometimes connected when located close to each other, and sometimes also somewhat enlarged.) Some stands with high conservation values are formed by late-successional forests following fires about 150 years ago. A few comprise spruce swamp forest. Common to the highest valued areas is that no or only light thinnings have been done during the last fifty years. Most of the 42 red-listed species found in the landscape are fungi using dead wood as substrate (mainly spruce logs), or lichens confined to old or dead conifers or deciduous trees.

Four of the six highest valued stands will probably gain protection, at least for some years from now, because they are located on company-owned land. One of the remaining stands will become a forest reserve (with full economic compensation to the few affected forest owners). The sixth stand will probably be partly cut, although it comprises several red-listed species. There is no legislation which can prevent a forest owner to cut if he is not reasonably compensated.

The effects of timber management on biodiversity in the Swedish boreal forests can be expressed also by means of red-lists (Berg et al. 1994a, b). In the beginning of the 1990s, 607 species associated with the boreal forest were on the Swedish red data lists. Of those, 275 are cryptogams, 275 invertebrates, 26 vascular plants, and 31 vertebrates. More than 70% are dependent on old or dead trees and 95% are judged to have timber harvest and silviculture as the main threat factor.

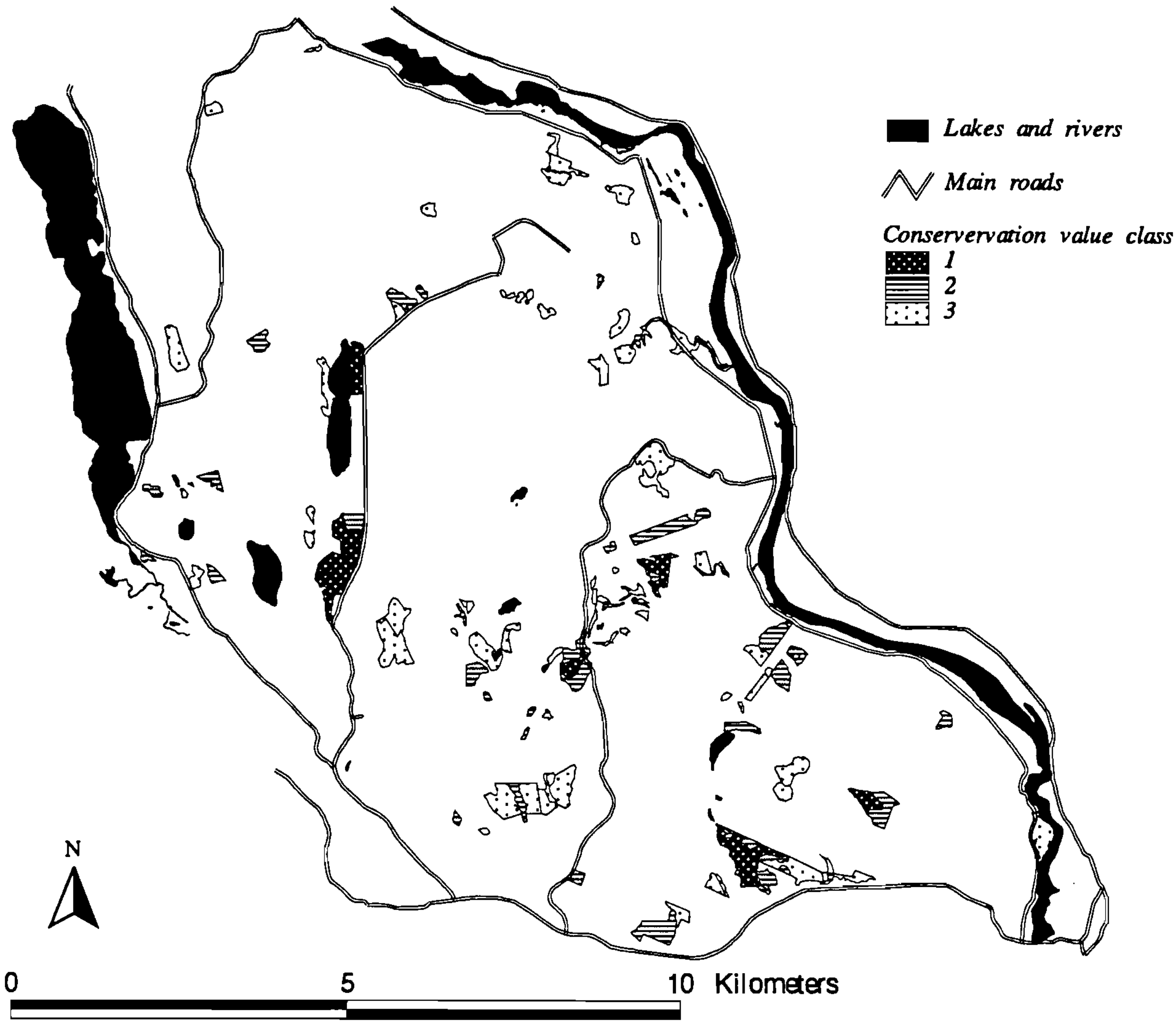

Figure 12. Areas with high nature conservation values in a Swedish boreal forest landscape used for timber production (see Lämås and Fries 1995a, Fries and Lämås unpublished manuscript).

10. Concluding Remarks

Nearly all of the Swedish boreal forest has been transformed by forestry. The transformation was rapid and drastic when the clear-felling system replaced different ways of cutting selectively. In parts of Svealand, close to mines and iron-works, this kind of 'modern' forestry began in the 19th century. In the major part of boreal Sweden, the clear-felling system was introduced on a large scale in the middle of the present century. Since 1950 nearly all forests have been clear felled or thinned so that stands are homogenized and many important structures for animal and plant diversity (e.g. coarse woody debris, and large old conifers or deciduous trees) have become extremely rare. This simplification of the forest ecosystem has, however, induced a continuous increase of the standing volume in the Swedish boreal forest, although it probably was higher before the exploitation started (Linder and Östlund 1992). More or less pure and homogeneous pine stands will dominate the future forest landscape, probably to a much higher extent than ever before. High conservation values are found only in woodland key habitats, which make up about 1% of the productive forest land in Sweden as a whole (perhaps somewhat more in boreal Sweden, because of the relatively large proportion of natural forests along the Fennoscandian mountain range).

In the new Swedish forest policy, the ambition is to maintain forest biodiversity by means of an increased reserved area (a figure of 5%, exclusive of sub-alpine forests, was commonly mentioned in the political debate) and by modified management in forests used for timber production (Lämås and Fries 1995b). Changes have started in Swedish forestry some years ago, but it is still uncertain if the political goal to maintain forest biodiversity can be achieved. Among the difficulties are imperfect knowledge of the ecology of most species of concern. By analyzing the red-lists, it seems, however, as if raising the amount of dead trees in the forest is an effective measure for maintaining, or even increasing, biodiversity. Enhancing deciduous trees, increasing the areas of old forests, and introducing fire as an ecological factor are probably also important. Other difficulties are lack of knowledge concerning silvicultural methods which efficiently combines timber production and nature conservation, and the limited economic resources for protection of conservationally valuable forests.

References

Ahti, T., L. Hämet-Ahti, and J. Jalas. 1968. Vegetation zones and their sections in northwestern Europe. *Annales Botanici Fennici* **5**:169-211.

Andersson, S. 1988. *50 Years of Forest Technology R & D in Sweden.* Report 6. Kista, Sweden: The Forest Operations Institute of Sweden. 45 pp. (in Swedish with English summary).

Andrén, T. 1992. *Från naturskog till kulturskog. Mo och Domsjö AB:s skogsbruk under 3/4 sekel 1900-1979.* Bjästa, Sweden: CEWE-förlaget (in Swedish).

Anon. 1995. Skogsdata. Aktuella uppgifter om de svenska skogarna från riksskogstaxeringen. Umeå: Swedish University of Agricultural Sciences, Department of Forest Resource Management and Geomatics (in Swedish).

Aronsson, M., T. Hallingbäck, and J.-E. Mattsson, Eds. 1995. *Swedish Red Data Book of Plants.* Uppsala: Swedish University of Agricultural Sciences, Artdatabanken (in Swedish with English summary).

Arpi, G. 1951. Den svenska järnhanteringens träkolsförsörjning 1830-1950. Meddelanden från Uppsala Universitets Geografiska institution. Nr. 78. Uppsala, Sweden (in Swedish with English summary).

Berg, Å., B. Ehnström, L. Gustafsson, T. Hallingbäck, M. Jonsell, and J. Weslien. 1994a. Threatened forest plant, animal and fungus species in Sweden - distribution and habitat preferences. *Conservation Biology* **8**:718-731.

Berg, Å., B. Ehnström, L. Gustafsson, T. Hallingbäck, M. Jonsell, and J. Weslien. 1994b. Threat levels and threats to red-listed species in Swedish forests. *Conservation Biology* **9**:718-731.

Borgegård, L.-E. 1973. Tjärhanteringen i Västerbottens län under 1800-talets senare hälft. Kungliga Skytteanska Samfundets Handlingar. Nr. 12. Umeå, Sweden (in Swedish).

Bunte, R., S. Gaunitz, and L.-E. Borgegård. 1982. Vindeln. En norrländsk kommuns ekonomiska utveckling 1800-1980. Lund, Sweden (in Swedish).

Carbonnier, C. 1978. Skogarnas vård och föryngring. Pages 85-126 in J. Fries and J. Zimmerman, eds. *Problem och idéer i svenskt skogsbruk 1828-1979.* Stockholm: Liber Förlag (in Swedish).

Cirkulärskrivelse nr 1/1950. 1950. Angående utsyningarna av revirens skogsvårdsåtgärder. Kungliga domänstyrelsen, Stockholm, Sweden (in Swedish).

Cirkulärskrivelse nr 12/1952. 1952. Angående skogsodlingsgränsen. Kungliga domänstyrelsen, Stockholm, Sweden (in Swedish).

Danell, K. and K. Sjöberg. 1992. Wildlife and lodgepole pine plantations - a review of present knowledge in Scandinavia. Pages 24-37 in D. Lindgren, ed. *Pinus contorta - From Untamed Forest to Domesticated Crop*. Report 11. Umeå: Swedish University of Agricultural Sciences, Department of Forest Genetics and Plant Physiology.

Domän. 1992. Sub-montane forests. Forests in focus. Domän skog, Falun, Sweden. September 1992. 8 pp. (in Swedish).

Ebeling, F. 1957. The new Norrland line of policy in Swedish forestry: A passing fashion or a well-founded reorganization? *Journal of the Swedish Academy of Agriculture and Forestry* **96**:264-288 (in Swedish with English summary).

Engelmark, O. 1984. Forest fires in the Muddus national park (northern Sweden) during the past 600 years. *Canadian Journal of Botany* **62**:893-898.

Esseen, P.-A., B. Ehnström, L. Ericson, and K. Sjöberg. 1992. Boreal forests - the focal habitats of Sweden. Pages 252-325 in L. Hansson, ed. *Ecological Principles of Nature Conservation. Applied in Temperate and Boreal Environments*. London: Elsevier Applied Science.

Franklin, J.F. 1992. Scientific basis for new perspectives in forests and streams. Pages 25-72 in R.J. Naiman, ed. *Watershed Management: Balancing Sustainability and Environmental Change*. New York: Springer-Verlag.

Fries, C., O. Johansson., B. Pettersson, and P. Simonsson. 1995. Stand management for timber production and biodiversity in boreal Swedish forests. Unpublished manuscript.

Fries, C. and T. Lämås. Different management regimes in a Swedish boreal forest landscape: Economic and ecological effects. Unpublished manuscript.

Granström, A. 1991. Elden och dess följeväxter i södra Sverige. *Skog & Forskning* **4/91**:22-27. Danderyd, Sweden (in Swedish).

Groombridge, B., Ed. 1993. *1994 IUCN Red List of Threatened Animals*. Gland, Switzerland and Cambridge, UK: The World Conservation Union (IUCN).

Heckscher, E.F. 1971. *Svenskt arbete och liv*. 7th Edition. Stockholm: Albert Bonniers förlag AB (in Swedish).

Helle, T. 1995. Reindeer husbandry and hunting. Pages 157-190 in M. Hytönen, ed. *Multiple-Use Forestry in the Nordic Countries*. Helsinki: The Finnish Forest Research Institute.

Hofgaard, A. 1993. Natural dynamics of old-growth Picea abies forest - spatial and temporal patterns. *Dissertations in Forest Vegetation Ecology* **2**. Umeå: Swedish University of Agricultural Sciences, Department of Forest Vegetation Ecology.

Höjer, E.W. 1950. Skogsodlingsgränsen på kronoparkerna i Norrland. Pages 425-446 in *Norrlands Skogsvårdsförbunds Tidskrift*. Stockholm, Sweden (in Swedish).

Höjer, E.W. 1954. Domänverkets föryngringsarbete i Norrland. Pages 233-253 in *Norrlands Skogsvårdsförbunds Tidskrift*. Stockholm, Sweden (in Swedish).

Holmgren, A. 1950. Norrlandsminnen. Stockholm, Sweden (in Swedish).

Hörnberg, G., M. Ohlson, and O. Zackrisson. 1995. Stand dynamics, regeneration patterns and long-term continuity in boreal old-growth Picea abies swamp forest. *Journal of Vegetational Sciences* **6**:291-298.

Karlman, M., P. Hansson, and J. Witzell. 1994. *Scleroderris* canker on lodgepole pine introduced in northern Sweden. *Canadian Journal of Forest Research* **24**:1948-59.

Kuusinen, M. 1994. Epiphytic lichen flora and diversity on Populus tremula in old-growth and managed forests of southern and middle boreal Finland. *Annales Botanici Fennici* **31**:245-260.

Lämås, T. and C. Fries. 1995a. Emergence of a biodiversity concept in Swedish forest policy. *Water, Soil and Air Pollution* **82**:57-66.

Lämås, T. and C. Fries. 1995b. An integrated forest inventory in a managed Northern Swedish forest landscape for estimating growing stock and coarse woody debris. Pages 296-311 in M. Köhl, P. Bachmann, P. Brassel, and G. Preto, eds. *Conference on Forest Survey Designs*, May 2-7, 1994, Monte Verità, Switzerland. Zurich: Swiss Federal Institute of Technology; and Birmensdorf: Swiss Federal Institute of Forest, Snow and Landscape Research.

Larsson, B., Ed. 1995. Svedjebruk och röjningsbränning i Norden: Terminologi, datering, metoder. *Skrifter om skogs- och lantbrukshistoria* **7**. Stockholm: Nordiska museets förlag. 190 pp. (in Swedish with English summaries).

Liljelund, L.-E., B. Pettersson, and O. Zackrisson. 1992. Skogsbruk och biologisk mångfald. *Svensk Botanisk Tidskrift* **86**:227-232 (in Swedish).

Linder, P. 1983. Naturskogen på Ysberget och Laxtjärnberget - en skogsbiologisk inventering. *Rapport* **1983**:1. Länsstyrelsen i Gävleborgs län, Naturvårdsenheten, Gävle, Sweden (in Swedish with English summary).

Linder, P. 1987. Om upprättandet av Domänverkets skogsodlingsgräns. *Sveriges Skogsvårdsförbunds Tidskrift* **4/87**:31-39. Danderyd, Sweden (in Swedish).

Linder, P. 1988. Jämtgaveln. Länsstyrelsen i Västernorrlands län, Härnösand, Sweden (in Swedish).

Linder, P. and L. Östlund. 1992. Changes in the boreal forests of Sweden. *Svensk Botanisk Tidskrift* **86**:119- 215 (in Swedish with English summary).

Lindgren, D., K. Lindgren, and P. Krutzsch. 1992. Use of lodgepole pine and its provenances in Sweden. Pages 238-263 in D. Lindgren, ed. *Pinus contorta - From Untamed Forest to Domesticated Crop*. Report 11. Umeå: Swedish University of Agricultural Sciences, Department of Forest Genetics and Plant Physiology.

National Atlas of Sweden. 1990. *The Forests*. Höganäs, Sweden: Bokförlaget Bra Böcker.

National Atlas of Sweden. 1992a. *Agriculture*. Höganäs, Sweden: Bokförlaget Bra Böcker.

National Atlas of Sweden. 1992b. *The Environment*. Höganäs, Sweden: Bokförlaget Bra Böcker.

Nitare, J. and M. Norén. 1992. Woodland key-habitats of rare and endangered species will be mapped in a new project of the Swedish National Board of Forestry. *Svensk Botanisk Tidskrift* **86**:219-226 (in Swedish with English summary).

Östlund, L. 1993. Exploitation and structural changes in the north Swedish boreal forest 1800-1992. *Dissertations in Forest Vegetation Ecology* **4**. Umeå: Swedish University of Agricultural Sciences, Department of Forest Vegetation Ecology.

Östlund, L. and O. Zackrisson. 1995. The north Swedish forest history. An ecological perspective. Unpublished manuscript.

Schimmel, J. and A. Granström. 1991. Skogsbränderna och vegetationen. *Skog & Forskning* **4/91**:39-46. Danderyd, Sweden (in Swedish).

Sjöberg, K. and T. Lennartsson. 1995. Fauna and flora management in forestry. Pages 191-244 in M. Hytönen, ed. *Multiple-Use Forestry in the Nordic Countries*. Helsinki: The Finnish Forest Research Institute.

SOU 1932:26. 1932. Uppskattning av Sveriges skogstillgångar 1923-1929. Stockholm, Sweden (in Swedish).

Sporrong, U. 1995. Ägandets reproduktion - om arvsregler och landskapsutveckling i 1700-talets Dalarna. Pages 99-108 in M. Widgren, ed. *Äganderätten i lantbrukets historia*. Skrifter om skogs- och lantbrukshistoria 8. Nordiska museets förlag, Sweden (in Swedish).

Swedish Forestry Act. 1979. Skogsvårdslag. SFS 1979:429. Stockholm, Sweden (in Swedish).

Swedish Forestry Act. 1993. Lag om ändring i skogsvårdslagen (SFS 1979:429). SFS 1993:553. Stockholm, Sweden (in Swedish).

Tirén, L. 1937. Forestry historical studies in the Degerfors district of the province of Västerbotten. *Meddelanden från statens skogsförsöksanstalt* **30**:67-322 (in Swedish with English summary).

Vikström. E. 1994. Medeltiden. Pages 54-63 in B. Sundin, ed. *Västerbotten genom tiderna*. Umeå: Västerbottens läns hembygdsförbund (in Swedish).

Wretlind, J.E. 1934. Bidrag till belysande av föryngringsbetingelserna på övre Norrlands tallhedsmarker. Pages 329-396 in *Norrlands Skogsvårdsförbunds Tidskrift*. Stockholm, Sweden (in Swedish with German summary).

Wretlind, J.E. 1948. *Nordsvensk hyggesbränning*. Stockholm: Svenska Skogsvårdsföreningens förlag. 56 pp. (in Swedish).

Zackrisson, O. 1976. Vegetation dynamics and land use in the lower reaches of the river Umeälven. *Early Norrland* **7**:7-74.

Zackrisson, O. 1977. Influence of forest fires on the north Swedish boreal forest. *Oikos* **29**:22-32.

Zackrisson, O. and L. Östlund. 1991. Elden formade landskapets mosaik. *Skog & Forskning* **4/91**:13-21. Danderyd, Sweden (in Swedish).