Institutionen för skoglig vegetationsekologi
SLU
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Restoration of forests in boreal Sweden

gap analysis and dead wood management at Vitberget, Northern Sweden

Erik Nordlind

Examensarbete i skoglig vegetationsekologi, 20p.
Handledare: Lars Östlund
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FOREWORD

This report is my final (20 credit) thesis as a 'master of forestry' student at the Swedish University of Agricultural Sciences (SLU), Umeå.

Many people have, in different ways, helped me in the proceeding of this thesis:
My supervisor, Lars Östlund (Dpt Vegetation Ecology, Swedish University of Agricultural Sciences), inspired me to initiate the study. He was a great support during all stages of the project and made many valuable comments on my work.
Staffan Eriksson (Dpt Vegetation Ecology, Swedish University of Agricultural Sciences) made valuable comments on the manuscripts.
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AssiDomän (Olof Johansson and Herman Sundquist) provided me with the study area and financed the project.

Thank you all for your help!

Kalmar, March 2001

Erik Nordlind

CONTENTS

ABSTRACT

Sweden's boreal forest has suffered from radical human caused changes since the beginning of industrialisation. Ecological qualities, such as large trees, dead trees, and deciduous trees, have been removed from the forest. Natural processes, like fire, have been suppressed leading to ecosystem degradation, even in the forest reserves. Many species that directly or indirectly depend upon natural structures are disfavoured and the restoration need is evident.

In this study, the present status of a Swedish boreal forest is analysed in a biodiversity restoration context. Based on ecological qualities of a historic reference state, a restoration gap analysis is produced. Methods to recreate lost ecological qualities are discussed. Also, the efficiency of four methods to kill trees and thus increase deadwood, is tested. These methods are: clobbering, girdling, topping with explosives and inoculation of wood-rotting fungi.

A gap-analysis is one way to view forest degradation and measure its deviation from the reference state. Ecological qualities are relatively high in this area as compared to the region as a whole, mainly because of recent logging in the region. However, if compared with the reference state, the area has lost a great deal of ecological qualities due to human activity.

To be successful, strategies for restoring a degraded forest should ultimately have a landscape level approach. Therefore, restoration of ecological qualities not only includes reserves but also production forests. In production forests, forest management should be adapted to the natural functioning of the ecosystem. Fire is the most important natural process in this ecosystem. Fire-reintroduction and management is the primary goal in the restoration process. Although, it should be complemented by other methods.

Clobbering and girdling were the most time-efficient methods to kill trees and did not substantially differ from each other. Topping and inoculation were much less time-efficient. They are also more technically complicated and thus more costly. Due to lack of dead wood in the forest, clobbering, girdling and topping are recommended methods to be used at this time. Whereas, inoculation of wood-rotting fungi should be more thoroughly tested. Larger studies, with repeated sample plots in different stand types, must be implemented to gather more data for precise management recommendations.

Because of dramatic losses of old growth characters during the last centuries, it is imperative that restoration of old-growth characters is accomplished as well as retaining residual old-growth characters.

SAMMANFATTNING

Människan har orsakat stora förändringar i Sveriges boreala skogar sedan början av industrialiseringen. Ekologiska kvalitéer såsom stora träd, döda träd, lövträd och skogsbränder har motverkats och minskat drastiskt vilket har medfört en försämring av ekosystemets funktion, t o m. i områden avsatta som reservat. Många arter som är direkt eller indirekt beroende av dessa kvalitéer missgynnas därmed och det finns därför ett stort behov av att sätta in restaureringsåtgärder.

I den här studien har jag analyserat en boreal skog i norra Sverige utifrån ett restaureringsperspektiv. Jag visar hur man kan använda sig av en bristanalys av ekologiska kvalitéer genom att jämföra dagens skog med ett historiskt referenstillstånd. Jag diskuterar även metoder för att återskapa de ekologiska kvalitéer som försvunnit eller minskat kraftigt. Bl a. testas fyra olika metoder att döda träd för att öka mängden död ved. Dessa fyra metoder är "knackning", ringbarkning, sprängning och inokulering av rötsvamp.

En bristanalys av ekologiska kvalitéer i en skog ger en uppfattning om hur mycket och på vilket sätt skogen avviker från ett "naturligt" referensekosystem. Den undersökta skogens ekologiska kvalitéer visade sig vara relativt höga jämfört med övrig skog i regionen, mest p g a. få sentida avverkningar. Jämfört med referensekosystemet så har skogen ändå förlorat en stor del av sina ekologiska kvalitéer.

Strategier för restaurering av ekologiskt degraderade skogar bör tillämpas på landskapsnivå för att vara framgångsrika. P g a. detta behov av stora arealer bör restaureringar inte uteslutande ske i reservaten utan även i produktionsskogen, genom en anpassning av skötseln till att efterlikna naturliga karaktärer och processer. Återinförsel av skogsbränder anses vara det primära målet med restaureringar i Sveriges boreala skogar. Där brandens effekter och möjligheter inte räcker till för att återskapa de önskade ekologiska kvalitéerna bör andra metoder användas som komplement, ex. gallring och träddödande.

Undersökningen av metoder för att döda träd visade att knackning och ringbarkning var mest tidseffektiva och de visade inga större variationer sinsemellan. Sprängning och inokulering visade sig vara mycket mer tidskrävande. Dessa metoder är dessutom mer tekniskt komplicerade och kostar således mer. P g a. den stora bristen på död ved i skogen kan knackning, ringbarkning och sprängning rekommenderas att användas vid restaureringsprojekt medan inokulering av svampmycel är en metod som måste utvecklas och testas mer innan den kan rekommenderas. Mer utförliga studier med upprepningar och uppföljningar i olika beståndstyper måste göras för att få tillräckligt med data för att kunna ge mer utförliga rekommendationer.

Förekomsten av karaktärer av hög ålder har minskat drastiskt under de senaste århundradena. Det är därför viktigt att de spillror av värden av denna typ som finns kvar i landskapen sparas och skyddas, och att restaureringsåtgärder sätts in för att öka förekomsten av sådana karaktärer.

INTRODUCTION

Restoration ecology

A new scientific discipline, restoration ecology, studies the problems of degraded or destroyed ecosystems. The application of restoration ecology occurs along a continuum from the rebuilding of totally devastated (or even toxic) sites, such as those associated with mining, to the limited management of relatively unmodified sites (Hobbs and Norton 1996). The purpose and reasons for restoring and rehabilitating ecosystems also varies. Restoration could increase the opportunities for food production, provide industries with raw material, or prevent a decrease in biodiversity.

The science of restoration ecology includes designing and implementing a plan to attain a certain defined goal (a reference state). Usually this reference state is historic and refers to the particular ecosystem before a certain development occurred. To do this the restoration ecologist has knowledge from a number of different disciplines: population biology, disturbance ecology, historical ecology, and soil science. Current and former land use as well as political goals should be considered. The primary goals of ecosystem restoration projects are determined by numerous site-specific factors such as: level of degradation, abiotic factors (climate and soil characteristics), history of land use, landscape context, and social circumstances (the political, population and economic situations). To succeed in restoring ecosystems, identification of structures and functions is necessary. Therefore, restoration ecology is considered to be the ultimate test for ecological theory (Jordan et al. 1987). So far, many restoration efforts have been made without knowledge and guidance from advances in theoretical principles and technical solutions from other parts of the world. A need for a conceptual scientific base for restoration ecology and a framework for its practical use has been discussed and this has led to a more complete platform for the restorationist (Hobbs and Norton 1996, Urbanska et al. 1997, Allen et al. 1997).

Restoration of forests

Due to anthropogenic influence, degradation occurs in forest ecosystems all over the world. Consequently, ecosystem health and biodiversity are threatened. Forest restoration projects are initiated to prevent erosion, enhance regeneration, increase production, suppress insect out-breaks and diseases, avoid catastrophic fires, and prevent loss of biodiversity. Complete restoration, by the strict definition (cf. Bradshaw 1997), is problematic due to current human activities affecting forest ecosystems. Also, historic human interactions with the forest have ceased, causing further problems. Even current forest reserves must be managed to ensure ecosystem health (White and Bratton 1980, Linder 1998).

Structural restoration.
Restoration of structural complexity to an ecosystem must meet landscape as well as local criteria. On a landscape level, the restoration of mosaic patterns and the distribution of habitats is important. On a local scale, tree species composition and structure, from single to multi-storied stands should be considered. The abundance of dead and dying trees as well as large and old trees is also important.

Natural disturbance restoration.
Restoring natural disturbance dynamics is a key-issue in the restoration of many ecosystems. However, not all kinds of disturbances can be managed (volcanic eruptions, storm-felling). Fire and flooding are important factors in many forest ecosystems and can be handled with restoration practices. They are key processes, necessary for the survival of many species and favourable for many more, but can also be used to create important structural characters. Fire is an integral part of many landscapes and large areas are necessary for natural fire behaviour. The size of reserves is seldom large enough to allow this and active management is advised for appropriate reintroduction. In many cultures, indigenous peoples used fire to alter the landscape and thus have been an important natural factor in the evolution of ecosystems (Pyne 1982, 1997). Therefore, historical fire use cannot be excluded if the restoration effort is to be effective. At times, conflicts arise between the conservation of species and restoration of natural disturbances. Habitats of rare species could be destroyed if the disturbances are not controlled.

Species restoration.
Many species re-establish when structure and disturbance are restored. However, because of limited dispersal or recolonization problems, as an effect of changed concurrence patterns, some species need to be reintroduced. Key-stone species play important roles in the restoration of other species as well and therefore, need special attention.

Retrospective analysis is an important component of all aspects of restoration. Furthermore, data on past conditions and processes must be integrated to produce base-line conditions.

Ecosystem degradation and need for restoration in boreal forests of Sweden

Due to human utilisation during the last two centuries, the Swedish boreal forest ecosystem has experienced radical changes. Human colonisation started prior to that time, but increased intensity in forest use, due to industrialisation, has changed the structures and functioning of the ecosystems in radical ways. Species that directly or indirectly depend upon such structures are disfavoured. Important ecological qualities have been successively removed from the forest: large trees, dead trees, and deciduous trees (Östlund 1993, Östlund et al. 1997). Ecological processes, such as fire and natural tree death, have been suppressed (Zackrisson 1977, Linder 1998). High-grading in the nineteenth century and intensive silviculture in the twentieth century have produced relatively young and even-aged forest stands dominated by one tree species (Östlund et al. 1997). Drainage of forestland and mires to increase forest production as well as transformation and cleaning of allogenic material in streams and rivers for the floating of timber and production of hydro-electric power has changed runoff and outflow patterns (Törnlund and Östlund 2000).

The restoration need is evident. There are 1487 forest species on the Swedish national red-data list and approximately 40% of these can be found in the boreal forest that covers almost 70% of the Swedish forestland (Berg et al. 1994). At present, the protected land does not cover all the biological needs and the forest areas that could be candidates for protection lack many of needed qualities. Complex food webs and symbiotic relationships among organisms evolved in the presence of virgin forest characters and the modern simplified forest does not provide for these relationships. In the restoration of this ecosystem, we need to develop methods to recreate diversity in a shortened time span to prevent further loss of biodiversity.

For example, dying and dead trees are of great ecological importance in forest ecosystems (Samuelsson et al. 1994) and effective methods to restore these components are needed.

Purpose of the study

Many different aspects are important in ecological restoration of the Swedish boreal forest. The aim of this study is to:

i) Analyse the present status of a Swedish boreal forest in a biodiversity restoration context.
ii) Produce a restoration gap analysis of this forest based on ecological qualities of a reference state.
iii) Test the efficiency of different methods to kill trees and thus recreate lost qualities.
iv) Discuss the results and need for restoration in the Scandinavian boreal forest.

MATERIALS AND METHODS

The study site

The study area, Vitberget mountain, lies within the Lycksele Parish and border to the Vindeln Parish (64°27′ N, 19°00′ E) in the county of Västerbotten in the middle boreal forest zone of Sweden (Sjörs 1963). The topography of this region is moderately broken landscape and the Umeälven and Vindelälven rivers drain the land from the Scandes in the west to their outflow in the east, the Baltic Sea. The bedrock is mainly Archaean gneisses and granites. Soils are fine-grained to coarse glaciofluvial outwash on the river valley floors and moraine at higher elevation (Malmström 1949). The study area is predominately forested and comprises approximately 300 hectares. Two peaks on Vitberget mountain range in elevation from 390 meters (northern) to 370 meters (southern). To the south of Viberget mountain, the Umeälven river is 180 meters above sea level. Extensive historical records are available for the study area and its surroundings. Östlund et al. (1997) describes the history and transformation of this forest landscape.

Site history- the reference state

Population density in the region was below 1 person/km^2 until the late nineteenth century. Early agricultural colonisation (1670-1750) made an impact on the forest by firewood cutting adjacent to settlements, cattle grazing, and slash and burn agriculture. However, only small areas were transformed to arable land. The major agricultural colonisation period began 1750 and continued to 1900. Potential agricultural land was claimed and forestland was divided between farmers and the Crown. Mires were ditched and cattle were grazed causing alterations to the forest ecosystem (Bunte et al. 1982). In the nineteenth century deciduous trees were cut for potash burning, and snags as well as stumps of pine (*Pinus sylvestris*) were collected for tar production. Industrial forest exploitation started in the 1860s and large old pines were selectively cut (Tirén 1937). Modern forestry, with intensive forest management and forest exploitation, was introduced in the beginning of the twentieth century and included most of the forest. This had a major impact on forest structure. Between 1910 and 1920, more than 83% of the forest in the region was classified as old growth. In the 1980s, no more than 3% of the forest was considered to be older than 160 years. The change from two-storied and multi-storied stands to even-aged, single storied stands has been near total. Twenty percent of the forest in the region was described as recently burned in the late 1800s or early 1900s. Today this figure is almost zero (Östlund et al. 1997). The last fires in the Vitberget mountain area occurred in 1832 and 1888 (Anna-Lena Axelsson, personal communication).

The inventory

In September, 1999, an inventory of vegetation, structures, and human activities was conducted on Vitberget mountain. Data was collected to get an overwiew of the area and to identify key habitats. Five transects, running south to north, were placed 100 m from each other covering the entire mountain area. The mountain was divided into stands by differences in vegetation, structure (age, amount of dead trees), or successional stage. Stumps and other human-caused traces were noted. Stand borders were marked and approximated using an ortophoto of the area. Stands were categorised by the dominant tree species (pine, spruce, aspen or mixed) and the approximate ecological qualities of the stand (high qualities, some qualities or no qualities).

Study sites and methods to kill trees

Two stands were chosen to test methods for producing dead wood. One aspen-dominated stand (*Populus tremula*) as well as one spruce-dominated stand (*Picea abies*) were chosen. The aspen stand is on the southwest slope of the northern peak of Vitberget mountain. It is characterised by old and sometimes large aspen as the dominant tree species. However, spruce is growing vigorously and will eventually out-compete and replace the aspen. Birch (*Betula pendula, B. pubescens*) are frequent species in the crown layer and pine occur sporadically, as single trees or in groups. Tree density is variable. Stumps from early cuttings occur in the stand. Among the red-listed species present in this stand, there are lichens in the genus *Collema spp.* (*C. curtisporum* and *C. furfuraceum*).
The spruce stand is in a ravine between the two peaks. It is characterised by a multi-dimensional forest dominated by spruce. Aspen and birch are frequently occurring species in the crown-layer. Old stumps from early cuttings occur in the stand. Among the red-listed species present in this stand, there are the fungi *Fomitopsis rosea* and *Asterodon ferruginosus*.

Four methods to kill trees were tested: cambium destruction by hitting the stem with the neck of an axe (hereafter referred to as clobbering) (figure 1), cambium destruction by girdling with an axe (girdling), topping the trees with explosives (topping) (figure 2), and basal inoculation of wood-rotting fungi (inoculation). Clobbering and girdling were compared in similar sampling plots (20 x 20 m), with a distance of 50 meters between each other in the aspen stand (see above). The cambium was damaged around the base of the trees, approximately 1 m above ground. All spruce with a diameter exceeding 5 cm were included in the test (56 and 64 for clobbering and girdling respectively). In addition, one group of 7 aspen and one birch was clobbered. In addition, 5 aspen, 3 birch and 4 pine were girdled. These trees were subjectively chosen to maintain a sufficient tree layer of untreated aspen. Tree diameter and treatment time for each tree was measured. Topping and inoculation were

Figure 1. Clobbering- Hitting the stem of the tree with the neck of an axe will destroy the cambium and thereby, stop the transportation of nutrients and water. (Photo: Lars Östlund)

Figure 2. Topping- A detonation chord is placed around the stem of the tree, about 8 meters above ground. (Photo: Erik Nordlind)

tested in the spruce stand (see above). The trees to be treated were spread over the ca. 0.5hectare stand and the two methods were not spatially separate. The trees were subjectively chosen to maintain and accelerate the gap dynamics of the stand. Mainly large diameter trees were chosen. One birch, two aspen and ten spruce were topped. PETN (pentaerythritol tetranitrate) detonating cord (150 g) was placed around the stem of the trees at a height of 6-8 meters. For the smallest spruce (ca. 30 cm dbh) the cord was wound twice round, and for thelargest spruce (ca. 45 cm dbh) the cord was wound three times around the trunk. For the birch (40 cm dbh) a triple round was wound, and for the aspen (31 and 36 cm dbh) cord was wound two and a half times around the tree. The cord was ignited by a chock-tube system. Four spruce were inoculated with the parasitic fungi, *Inonotus leporinus*. The fungi were taken from an infected stump: Increment cores were extracted close to fruit-bodies of the fungi and were assumed to contain vital mycelia. For the inoculation, increment cores were taken out from the trees to be inoculated and the infected cores were pushed into the drill hole. The hole was drilled in an approximately 30 to 45° angle from the ground and water was pored into the hole to prevent drought. Each hole was plugged with parts of the increment core from the inoculated tree. Tree density within the two stands was measured with a relascope. Tree diameter was measured at breast-height and total time for each experimental event was noted.

RESULTS

The inventory

An overview of the study area and its ecological qualities is presented in figure 3. Signs of cuttings and human utilisation were detected over the entire mountain. The two peaks of the mountain have been least affected and possess most natural structures. The southern peak contains a large number of old-growth and dead trees, and artificial stumps are rare. Many trees were blazed (marked to be cut) before the 1888 fire. Fortunately, they were not. The last fire occurred in 1888: Fire-scares, burned wood, dead standing and lying trees can still be seen. The slopes next to the peaks and the remainder of the area have signs of early tree harvesting as evidenced by forest openings and remaining stumps.
In addition, most trees are not as old here. However, large and sometimes old pines are still present on the mountain. Soil on the peaks and surrounding area is poor as shown by the scant under-growth of spruce. Further down slope, the soil conditions are more favourable and spruce grows as understory and occasionally dominates the stands. Deciduous trees are abundant over the entire mountain. Large aspen are common as well as birch and goat willow, (*Salix caprea*) but these are often in a state of dying. Recent clearcuts were found in the west, south and south-east (figure 3). The exotic species, lodgepole pine (*Pinus contorta*) has been planted on a southeastern clearcut. In the south-west, north-west and east, areas have been recently thinned. Forty-four ha (13.7%) of the area are considered to contain high ecological qualities, 63 ha (19.6%) some qualities, 129 ha (40.1%) no particular qualities, and the total area of clear-cuts are 79 ha (24.6%) (figure 3 and table 1).

Study of methods to kill trees

No difference in time efficiency between clobbering and girdling of Norway spruce could be detected (figure 4). For the other tree species, the tree diameter varied considerably between the two sites and the total number of trees in the test was low. Therefore, no difference in time efficiency could be detected. The total time used for each sample plot was 1h 40min for

Table 1. Stand types and ecological qualities in the study area. Size and percentage of the total area.

	Pine	Spruce	Aspen	Mixed	Clear-cut	Total
No particular qualities	43.5 ha ca. 13.5%	73.5 ha ca. 22.9%		12 ha ca. 3.7%	79 ha ca. 24.6%	208 ha ca. 64.7%
Some qualities	52 ha ca. 16.2%	8.75 ha ca. 2.7%		2.25 ha ca. 0.7%		63 ha ca. 19.6%
High qualities	39.25 ha ca. 12.2%	2 ha ca. 0.6%	2.75 ha ca. 0.9%			44 ha ca. 13.7%

clobbering and 2h 10min and girdling. Thus, clobbering is the more time efficient method. However, the girdling site comprised eleven more trees than the clobbering site and the number of trees represented in each diameter class differs between the two sites (figure 5). Average time per tree was 1 min 38 seconds for clobbering and 1 min 48 seconds for girdling. The sum of the average time per tree for each diameter-class for spruce also shows less difference between the two methods, 1 min 56 seconds and 2 minutes 1 second, for clobbering and girdling_respectively. The total time for topping, performed by two people, was about 5 hours. 13 snags were created: 10 spruce, 2 aspen and 1 birch, averaging 23 minutes per tree. The total time for inoculation, not counting the extraction of the fungi, was about 40 minutes. Four trees were inoculated, averaging 10 minutes per tree.

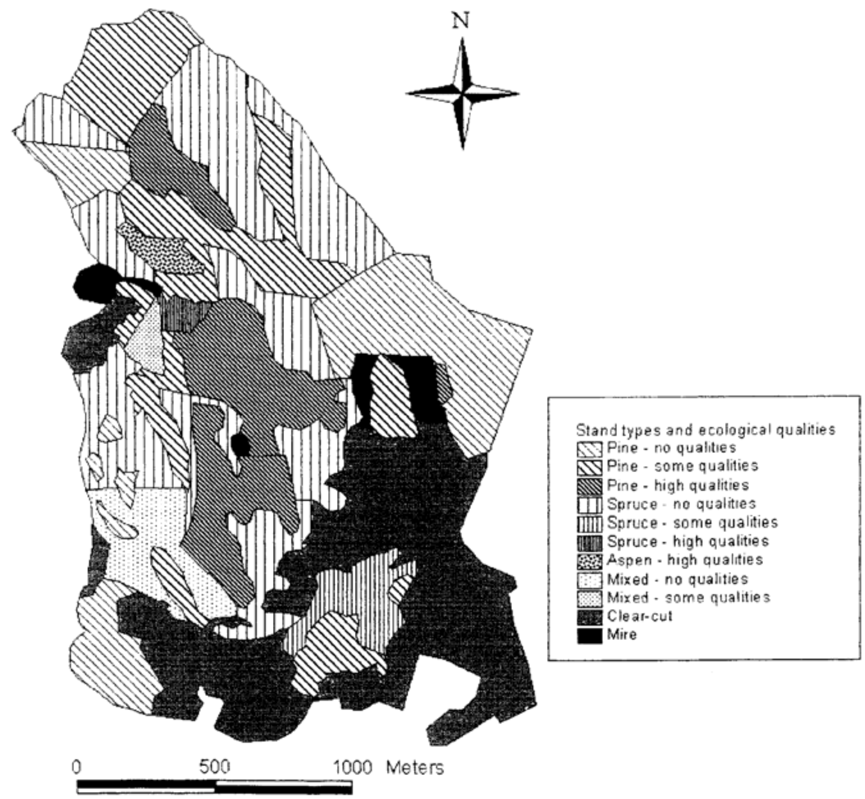

Figure 3. Stand types in the study-area, Vitberget. Categorised by the dominating tree species and the ecological qualities of the stand.

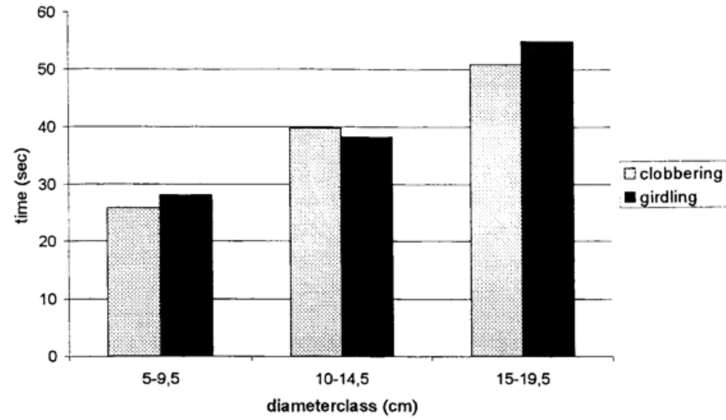

Figure 4. Average time per diameter-class for clobbering and girdling of spruce

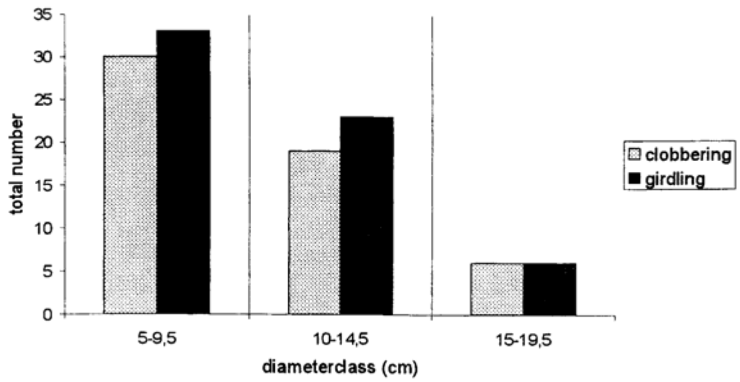

Figure 5. Number of spruce in each diameter-class of clobbered and girdled trees.

DISCUSSION

Inventory / gap analysis

Ecological qualities are relatively high in this area as compared to the region as a whole, mainly because of recent logging in the region. However, if compared with the reference state, the area has lost a great deal of ecological qualities due to human activity.

Due to suppression, fire has lost its function as the most important disturbance factor and generator of the ecosystem. Approximately 20% of the regional forest was burned in the late 1800s or early 1900s. Since that time, fire has been rare in the region and is also rare in the study area, which has not had a fire since 1888. Fire suppression has caused problems in fire dependent forest ecosystems worldwide (Pyne et al. 1996) and fire management is essential for ecosystem restoration (Hardy and Arno 1996). Restoring the fire regime will promote restoration of other degraded ecological qualities: multi-dimensional structures, dead and dying trees, burned ground and wood, early successions of deciduous trees and pine, and a landscape mosaic. Therefore, I consider re-introduction of a natural fire regime as the primary goal for forest restoration.

Old growth qualities are relatively high in the study area. However, if compared with reference data, these qualities have greatly diminished. From 1910 to 1920, more than 83% of forested areas in the region were old growth. In the study area today, old growth qualities are restricted to high quality pine stands that comprise 12.2% (see figure 3). Scattered old pines were found in other stands. In the 1980s, three percent or less of the forest in the region was older than 160 years. The study area comprises about 4 times more old growth than the regional average; but compared to the reference state, it has lost 85% of these qualities. In a restoration effort, residual old growth should be retained and managed. Where there is a lack of such qualities, formation of old growth structures should be promoted with suitable techniques to reach a "natural" level in the future. For example, Kohm and Franklin (1996) suggested thinning or fertilisation of individual or groups of trees to make selected individuals grow faster.

The change from two-storied and multi-storied stands to even-aged, single storied stands is near total for the region. In the study area, stands with some or high qualities (33% of the area) still possess these qualities even though they have decreased due to selective cuttings. Management should strive to restore multi-dimensional structures over the entire study area. In nature, such structures are created and maintained by fire. Fire management, in combination with thinning, could be an appropriate tool for restoring such qualities.

There is a lack of historical data amount about deciduous trees and dead wood. It is likely that these qualities diminished like other qualities due to logging, fire suppression and fire wood collection. Fire reintroduction will help restore parts of this degradation but other methods may also be needed. For example, the manual killing of trees to create dead wood.
Due to limited knowledge of a reference ecosystem some important ecological qualities will be foreseen. Therefore, restoration should be planned and evaluated to increase knowledge about and early detection of such qualities.

Study of methods to kill trees

In this study clobbering and girdling were the most time-efficient methods and did not differ substantially from each other (table 2). Girdling successfully removed the cambium of the

Table 2. Factors of importance for cost-efficiency. A comparison of the studied methods.

	Clobbering	**Girdling**	**Topping**	**Inoculation**
Average time/ tree	1 min 38 sec	1 min 48 sec	~23 min	~10 min
Extra time needed			Security	Extraction/ production of inoculation material
Labour needed	1 person	1 person	2 persons	1 person
Cost of material	Low	Low	High	Low
Grade of success	High	Probably high	High	Unknown

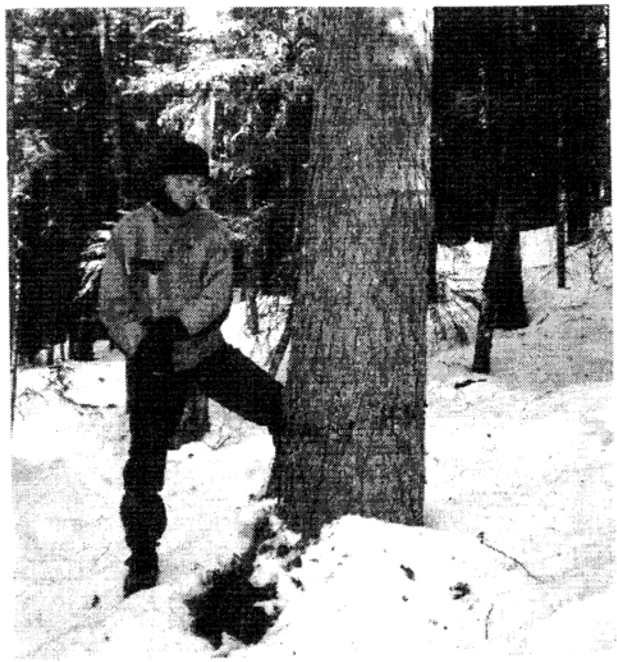

Figure 6. The tree has been clobbered and the outer bark is damaged. However, the effect on the cambium is hard to evaluate because of the thick bark of the tree.

trees, whereas cambium damage from clobbering was more uncertain. The thick bark of large pine and aspen and to some extent large spruce, stayed somewhat intact making the evaluation of the cambium damage hard to detect (figure 6). For birch and smaller trees of all species, the bark easily loosened revealing the wood inside of the bark. Topping and inoculation was much less time-efficient (table 2). However, the average tree diameter was larger than those in other studies were. These methods are also more technically complicated and thus more costly (table 2). However, improvement of these methods with new technical solutions could increase the efficiency. Topping the trees, with a detonation (figure 7), took long periods of time and visitor safety was a concern. More labour is needed for this method as compared to the others. Material costs are also relatively high when compared to the other methods. Inoculation of fungi takes a lengthy time period to perform, especially when considering the time for capturing fungal material. However, this could be more efficient if implemented on a larger scale. Mycelia could be cultured in prepared pieces of wood and this would increase the certainty of inoculating fresh and vigorous mycelia into the trees. Improvement of inoculated material could also be achieved if combined with a nutrient solution. For example, Carey and Sanderson (1981) found that a combination of inoculation of fungi and glycerol in routed holes proved to be more successful than if not combined. In this study, the outcome of the inoculation is uncertain and the small sample size gives little information for measuring success. The quality of dead wood produced will differ among the methods. With inoculation, the break down of the wood will start from the inside when the tree is still alive, resulting in a different quality of dead wood as compared to the other three methods, which kill the tree by damaging the outside.

To recommend a method for killing trees, it must be economically defendable. That is, the ecological benefits should exceed the cost. Future species colonisation, resulting from dead wood production and stand development, will be excellent criteria to evaluate the ecological effects of the four methods tested. Earlier studies of dead wood management have gathered data about cavity-nesting animals, mostly woodpeckers, and their use of snags (e g. Aulén 1991, Conner et al. 1981, Conner et al. 1983, McComb and Rumsey 1983, Bull and Partridge 1986). The study parameters were based on the animals' needs, such as the number of snags needed for each species, use of the created snags, amount of prey animals, and the time from the treatment to death of the tree and then to the time when the snag fell. Aulén (1991) compared girdling with notching of deciduous trees to improve food generation and acquisition for the endangered white-backed woodpecker (*Dendrocopus leucopus*). He found that the efficiency differences varied between tree species but generally notched trees died faster and fell down sooner than girdled trees and thus worked as food sites for woodpeckers for a shorter-time. A similar result was found by Conner et al. (1983). As compared to girdling, clobbering would likely make the trees die slower and thereby stand longer because of the more uncertain success of cambium damage. Bull and Partridge (1986) found topping to be the most efficient method to kill trees for cavity nesters, especially when the trees were also limbed. Trees treated in this way died quickly and stood up longer because of the reduced crown exposure to wind. Their studies found girdling, fungal inoculation, and use of insect pheromones to be poor techniques to kill trees for cavity nesters because the trees fell down too soon.

The parameters used in the cavity nesting studies are of importance when restoring an ecosystem. However, other considerations must be addressed as well: other groups of organisms and the character and quality of the dead wood over time. It would be beneficial to use more than one method for killing trees to achieve a more varied result (cf. Aulén 1991). All the methods in this study need further evaluation. Yet, with the exception of inoculation, these methods are recommended for restoration projects because of the immediate need to increase dead wood in the forest. Clobbering and girdling could be used on a large scale because of their low cost. Preferably, topping would be used as a complement to other methods. It is more expensive but generates somewhat different characters in the dead wood. Inoculation of fungi needs to be studied more before it could be recommended.

After my experiments, one important question remains to be answered: What are the long-term effects of the different methods? The sample sites must be inventoried again and death or dying processes should be evaluated. Furthermore, larger studies with repeated sample plots in different stand types must be done to get enough data for more precise management recommendations.

Restoration of ecologically degraded boreal forests

By producing a forest gap-analysis, we get an idea of its state of degradation. That is, its deviation from the reference state. Knowledge of the deviating factors can then be used to decide if, where, when and how the restoration will take place. A well-understood reference state, as well as a present state, are the keys for producing a high quality gap-analysis. To achieve this, inventories must contain all the factors of ecological importance including the factors that led to the degraded functioning of the ecosystem.

Figure 7. Topping with explosives.
a) The detonation chords are placed at about 8 meters above ground, as could be seen at the center of the photo

b) One out of two serial detonations could be seen at the center of the photo.

c) The tops of the two trees fall down.

(Photos: Erik Nordlind)

In most cases, the desired reference state would be a former "natural" state of the ecosystem. However, the time when the ecosystem became "unnatural" is not easily definable and it could be difficult to decide which former ecosystem is best suited as the reference state. The reference state, in this study, is based on Östlund et al. (1997). It shows structural changes that occurred on the landscape since the nineteenth century. However, the character of human caused changes before that time is not well known. In fact, it is possible that the ecosystems we use as reference states, to some extent, were generated by human activity. Lack of knowledge about the effects such activities had on the ecosystem is a problem since we need to know the history of the reference state to understand its functioning. Still, I consider the large-scale influence on the forest introduced by industrialisation as degrading the forest from its "natural" state. Therefore, most pre-industrial forests could be seen as the reference state. It is also important that humans are not always seen as a destroyer of the ecosystem, but as an integral part of it. Knowing the history of a presumed natural state is also important when we describe present time sites as virgin, "untouched" forest and use it as reference ecosystems for restoration. Recent studies have shown that many of the biotopes considered to be key-habitats for biodiversity and are described as "close to virgin forest" have been affected by forestry in some way and do not resemble a reference ecosystem (Ekman 1997, Ericsson and Östlund 2000). These sites are products of two major anthropogenic factors, namely absence of fire for almost a century, and logging of the late nineteenth century and early 20th twentieth century (Ericsson and Östlund 2000). There is always need for historic analyses to avoid such problems. Another problem with the definition of a reference state is that it will be described as a fixed ultimate state, when in reality it is a state that continuously changes due to natural processes.

Natural processes and population biology act on a landscape level. To be successful, strategies for restoring a degraded forest should ultimately have a landscape level approach. With a large-scale strategy, continuity of fires and ecological qualities of different successional stages could be planned over time and across landscapes. This would make it possible for species populations to move around in the landscape as their environment changes due to succession. Because of the importance of 'large scale,' restoration of ecological qualities will not only include reserves but also production forests, with an adaptation of the forestry to natural characters and processes (cf. Fries et al. 1997, Angelstam 1998). At present, remnants of high ecological quality and rare species habitats are justification to form reserves. With a long-time perspective for conservation of species, possibilities for natural restoration and management need to be considered as well.

As mentioned above, fire reintroduction is suggested as the primary goal for restoration of this boreal forest. However, fire does not always produce the wanted qualities, at least not in a short time period, and other methods are needed as complements. For example, thinning and tree killing could be used to manipulate structures and create dead wood. Regulation of selective browsing pressure on some species could be achieved by fencing or by increased hunting (see also Blomqvist and Renberg 1999).

Restoring old-growth characters to a forest needs to be considered because of the lengthy time period needed for successful restoration. For example, a pine could live for 500 years and serve as an important substrate for many species for another 500 years. A gap in the continuity of old-growth structures will need special attention and methods for speeding the creation of old-growth characters must be used. In many cases large diameter trees or wide crowns are factors of importance and not necessarily old age itself. Thinning could be used to generate large trees and active creation of dead wood would increase the abundance of old dead wood substrate in the future. It is also imperative that residual old-growth characters are retained in the overall forest landscape, because of the dramatic losses of such characters during the last 100 years.

CONCLUSIONS

It is clear that restoration ecology is of great importance in species conservation, on a landscape level in the managed forest as well as in forest reserves. In production forests, forest management should be adapted to the natural functioning of the ecosystem. Consideration to restoration and management aspects in the planning and formation of reserves will be effective for species conservation in the long- term perspective.
Gap analysis is recommended as a tool for planning restorations and also for setting goals. This method clearly shows the differences of ecological qualities between a degraded forest and its reference state. Inventory and evaluation processes should be developed to reach a high quality analysis suited for restoration practices.
Fire is the most important natural process in the boreal forests. Fire-reintroduction and management is the primary goal in the restoration process. Although, it should be complemented by other methods. The management of dead wood is important for ecological restoration. Clobbering and girdling are recommended as methods to kill trees on a large scale because of the low cost. Topping could be recommended on a smaller scale or as a complement, since the cost is high but the ecological effects are somewhat different. Inoculation of the fungi *Inonotus leporinus* produces a different character of dead wood; breaking the wood down from the inside while the tree is still alive. However, inoculation is not recommended until the success of this method has been evaluated. Further studies on dead wood creation are needed.

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