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New Stand Types in Boreal Forestry

– Ecological Features and Silvicultural Consequences



Proceedings of a Nordic Symposium
Vaasa, February 10-11, 1998

MUHOS RESEARCH STATION

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Foreword

During recent years new aspects of forestry and its effects have been recognized in the Nordic countries and internationally. An improved awareness of non-commercial forest values has provided a wider base for the current evolution of forestry practice. As a result, forest owners and managers in the Nordic countries have started to emphasize "sustainable forest management" and "conservation of forest biodiversity" when formulating silvicultural goals. A change of direction can also be observed in the forest. The number of trees retained after final felling on sites that would previously have been clear cut has increased and forest owners have become more inclined to include advance growth of different sizes when establishing new stands. The succeeding stands are characterized by a multi-layered and heterogeneous structure and their future management will require other silvicultural methods than the ones applied today.

Scientific knowledge of stocking, yield and economy of the new stand types is, however, limited. In addition the desired composition and structure for optimising nature preservation values is largely unknown. In order to compile relevant Nordic knowledge, the symposium "New Stand Types in Boreal Forestry - Ecological Features and Silvicultural Consequences" was organised in Vaasa, Finland, on February 10-11, 1998. Another purpose of the symposium was to inspire Nordic researchers within the field to exchange experiences and consider future co-operation.

The symposium gathered 29 participants from Denmark, Finland, Norway and Sweden. After the introduction "How close to nature should silviculture in Europe develop" by Dr Jari Parviainen, 22 papers dealing with forest yield, regeneration, biodiversity, risks and economics were presented. The second day of the program included inter-disciplinary group work concerning urgent research needs and cooperation within the fields of practical forest ecology and applied silviculture.

We thank all invited speakers and symposium participants. We are also very grateful to Mrs Sirpa Haataja for her skillful administration of the practical arrangements and for her editing of this Proceedings publication in co-operation with Mrs Irene Murtovaara. Likewise, our thanks go to system analyst Jouni Karhu for designing the symposium's web page. Financial support received from SNS played a key role in making this symposium possible.

Jörgen Bille-Hansen Finn Brække Göran Hallsby Eero Kubin

Editorial remarks

The abstracts and papers presented have not been peer reviewed and each author is personally responsible for the scientific content and language.

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HOW CLOSE TO NATURE SHOULD SILVICULTURE IN EUROPE DEVELOP?

Jari Parviainen



Parviainen, J. 1998. How close to nature should silviculture in Europe develop? New stand types in boreal forestry. Metla, Research Papers 714: 7-20.

Due to differences in the human impact on forests, fragmentation and naturalness of forests, vegetation zones and the tree species composition, the concept of nature oriented silviculture in the Nordic countries differs from that in Central Europe. In the boreal zone the main emphasis lies on maintaining biodiversity, whereas in Central Europe the goal is to guide the forest stand development towards the potential, original forest cover. The production forests in Central Europe are mainly altered and cultivated (50-70 %), whereas the production forests in Finland and Sweden are semi-natural with a proportion of 70-75% natural regeneration.

To maintain forest biodiversity in Europe, both protection of totally untouched reserves, as well as nature oriented silviculture are needed. Natural forests are generally accepted as a model for the nature oriented silviculture. There are still about 3 mill. hectares of natural forests left in Europe (1,7 % of the total forest area). The widest, continuous natural forests can be found in Finland and Sweden and in the remote mountainous areas of Central and Eastern Europe. As some examples the percentage of natural forests as forest reserves in Bulgaria is 8 %, in Romania 6 %, in Finland 5,5 %, in Austria 3 %, and in Germany 0,2 %. In the Netherlands there are no more natural forests left. The natural forest area in Finland is 1,3 mill. hectares, which is 1 % of the total forested area in Europe, and as much as 43 % of the European natural forests.

The key elements (like fire disturbance elements, dead wood component) of biodiversity are known, but their quantification is still very open and speculative. Realistic nature oriented silviculture is a large scale biodiversity protection effort, the influence of which has been underestimated in the discussion on forest protection.

Keywords nature oriented silviculture, naturalness, biodiversity, the species composition, protection of forests

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Introduction

Forestry and silviculture have attracted unprecedented public attention in the 1990s worldwide and in Europe. The following factors have contributed to this development:

- Forest sustainability discussion in international conventions and agreements (Rio-declaration 1992, Ministerial Con-

ferences for the Protection of Forests in Europe, in Strasbourg 1990 and Helsinki 1993, Helsinki Process since 1993, IPF-IFF United Nations Initiatives since 1994)
- Forest-certification discussions (ITTO criteria, development of FSC, ISO-14000-norms, EMAS-environmental accreditation-systems and the introduced "country of origin-"labels)
- Climate change forecast and agreements (Kyoto 1997, Forest as a sink in the carbon balance calculations)
- Low economic profitability of wood production and the use of wood as a renewable natural resource in Europe (ecobalance calculations)
- Worldwide campaigns for forest protection (e.g. introduced 10 % - limit of WWF-International, hot-spots of protection areas) and against to deforestation of tropical forests
- The central European non-governmental organisations' campaigns against the boreal forest silviculture since 1990.

Due to this development, the demands to change silvicultural practices have been particularly strong. The content of traditional silviculture has changed and the terminology has had to be reassessed. Parallel to the term silviculture, taking care of the forests can mean ecosystem management, biodiversity oriented silviculture, close to nature silviculture, continuous cover silviculture, landscape management or landscape biological planning. The Pro-Silva movement has also initiated in Europe: this movement promotes the expansion of the goals within silviculture. The Pro-Silva movement originated from the Eastern and Central European deciduous forests since 1989 (in Slovenia), but it has also attracted supporters from the boreal forest zone. As a result of the discussions, the current concept of silviculture includes, apart from wood production, an emphasis on maintaining forest biodiversity, recreational, landscape, protective and socio-economic, as well as cultural questions.

Measures taken to change silviculture in the Nordic Countries and Central Europe in the 1990s

The demands for a change of forest management have spurred a response by both state authorities and forestry organisations as well as forest owners in their practical silvicultural activities in all the Nordic countries (Parviainen & Seppänen 1994, Parviainen 1996, Framstad 1996, Frivold 1996, Gemmel 1996, Knudsen 1996, Lawesson & Berthelsen 1996). The following account lists the central measures which were taken to bring changes into silviculture in the various Nordic countries and some Central European countries.

Development/Achievements in silviculture in the 1990s:

Finland

1990-93	Contribution in the Process of Ministerial Conference in Europe (Strasbourg 1990, Helsinki 1993, Helsinki-process 1993-96)
1991-94	New silvicultural guidelines
1994	Environmental programme
1995-96	Committees for Forest Protection, old forest protection programme
1997	Renewed legislation (Forestry Act, Nature Conservation Act 1997)
1995-98	Certification discussions

Sweden

1990	Levande Skog-education campaign
1991	Environmental policy for biodiversity
1994	New Forest Act
1995-98	Certification discussion

Norway

1995	New goals for forest protection
1995	Levende Skog-campaign
1995-98	Certification discussions

Denmark

1994	Strategy for Sustainable Forest Management
1994	Strategy for Natural Forests and other Forest Types of High Conservation Value
1993-	"Green forest management" - programme

Central Europe (Germany, France, Austria)

1990-98	Actions regarding especially the environmental aspects (restrictions of air pollution) in forest conditions
1989-92	Guidelines for nature-oriented silviculture for state forests in Germany
1995-98	Certification/label for the "country of origin" of wood

No changes in forestry legislation

The common feature for all Nordic countries has been making biodiversity factors part of silviculture (see Interim Report on the Follow-Up of the Second Ministerial Conference on the protection of forests in Europe, 1996). Biodiversity has been taken into account both at regional (landscape) and at the stand level. In Sweden and in Finland the new silvicultural policy has been included in the forestry laws. The forestry legislation, which came into force in 1997 in Finland, lists in detail those keybiotopes and rare forest ecosystems which have to be left untouched in silvicultural operations. Sweden, Norway and Denmark put special emphasis on education, with the aid of which the new silvicultural trend has been applied in practice. In Finland more attention has been paid to protection of old forests and expanding the protection network.

A corresponding discussion on sustainability in Central Europe has not lead to as great changes in the silvicultural guidelines or legislation as in the Nordic countries (Forest Report by the Federal Government 1997). In fact, in Germany, France and Austria there have been no changes in forestry legislation within the past decade which would have affected the silvicultural guidelines. This is partly due to the fact that, for example, in Germany new nature oriented silvicultural recommendations were introduced in the beginning of the 1990s for the state forests. Unlike in the Nordic countries, the emphasis of forestry discussion in Central Europe has been on maintaining the health and productivity of forests, and promoting their landscape and recreational values. The certification discussion has, however, emphazised the protection and biodiversity aspects.

Forest certification has become the most important theme all over in Europe during the past three years. The actual aim of certification is to promote "good" silvicultural practices and enhance the protection of forests. This is the goal of the forestry standards developed within certification which aim to quarantee the sustainability and to guide silviculture towards a more efficient direction in terms of, especially biodiversity. However, the certification discussion has been blended with environmental political and trade interests, which is why certification in Central Europe, in particular, is seen as a marketing tool for wood at present. The Central European forest owners as well as the govermental bodies share the view that

the certification is not necessary, because the present forestry laws and silvicultural recommendations quite sufficiently quarantee the sustainability in forestry. The Nordic countries have developed detailed indicators for assessing the silvicultural practices by certification procedure.

Biodiversity in forest ecosystems

The Helsinki process in 1994 defined the components of biodiversity in forest ecosystem (Ministerial Conference on the Protection of Forests in Europe 1993, 1994 and 1996, Interim Reports on the Follow-Up of the Second Ministerial Conference 1996). With the increasing amount of knowledge this definition seems to hold better than ever. Based on this definition the endangered species are seen as the indicators of changes in the forest ecosystem. Changes in the number of endangered species act as alarms if the forest quality starts to become impoverished due to silviculture. A similar indicator on the state of forest is the increase in environmental strain. Both the number of endangered species and the environmental strain have to be continuously monitored and possible critical limits should be defined.

There are two approaches in maintaining biodiversity in forests. At a regional level each country, for example, has to take care of the protection of rare and valuable forest ecosystems. In this case, a protection area network is created in each area. The density, representativeness, size and the total number of protection areas in the network depends, of course, on the variation in the forest stands, vegetation zones and the general state of the forest. The general concept is that the protection network should include, apart from old forests, also other stand compartments at other stages of the development cycle.

Because total protection only secures locally a certain number of habitats of rare species, silviculture is essential for maintaining large-scale biodiversity in production forests. This includes the majority of forested areas outside protection, which in many countries means at least 80-90% of the forested area. In some Central and Southern European countries like Ireland and Portugal the wood production can be ensured efficiently by intensive tree plantation forestry, but in the countries of the northern boreal zone forestry involves nature oriented silviculture in large areas. The chosen direction in silviculture also determines the amount of those forested areas needed which are completely outside commercial forestry activities in order to secure the maintaining of living organisms. The hypothesis is that the closer to nature the activities are in production forests, the less need there is for total protection of forests.

Natural forests as a silvicultural model and protection areas

Natural forest is accepted generally as a model for the realisation of nature oriented silviculture (Leibundgut 1978, 1982, 1986, 1989, Schütz 1986, Schmidt-Vogt 1991, Thomasius 1992, Sturm 1993, Parviainen & Seppänen 1994). It is, therefore, necessary to analyse what type of natural forests there are in Europe and how they are used as comparison and experimental areas in silviculture.

The area of natural forests

It is difficult to have a conclusive summary of the amount and the area of natural forests in Europe, because the aims of forest protection and the degree of protection vary a great deal between the countries. Apart from natural conditions, the reasons for this include differences in the traditional use of forests, the degree of originality of forests, the regional continuous forests cover and the concepts of protected areas, as well as the allowed interventions.

In the Nordic countries, the primary goal of forest protection has been during last 10-20 years the preservation of the remnants of old forests. This is forest protection for the maintaining of fauna and living organisms outside forest operations. In Central Europe, however, forests are protected rather as part of the landscape, as a cultural factor or a specimen of the original nature.

In North America and Canada a reserve ideology applied in forest protection means, that large, continuous areas are defined and left untouched. This kind of protection strategy is suitable for forested areas, which, due to sparse population and vast forest areas, have not been affected by man at all. Canada has been able to declare over 12 % of its forests as legally protected, in addition of that about 30 % of considered commercial forests are as reserves, because parts of these are situated far from populated areas and do therefore not have human or industrial value.

This reservation idea cannot be applied in the densely populated Europe, where forests have been under human influence for thousands of years. In Southern and Central Europe forests gave way to human settlement and diminished into forest islands during the Middle Ages at the latest. Because of settlement activities, hunting, mining, glass mills and traffic, forested areas outside agricultural land were under constant strain caused by human activities (Bücking et. al.1994, Unser Wald 1998, Romane 1997).

Contrarily to what is generally believed, human impact on forests in North Europe has also been extensive, even though it has not been as long-term as in Southern and Central Europe, lasting only for 300-400 years. In Finland, forests were used for tar production, hunting and reindeer husbandry between the 17th and the 19th centuries (Parviainen & Seppänen 1994). During the same period of time in Central-Sweden and Central-Norway the forest structure has been largely influenced by the ore mining industry (Esseen et al. 1997).

The most extensive influence on Finnish forests was the slash and burn agriculture, which was used during the settlement period of the entire southern Finland starting from the 16th century. According to Heikinheimo (1915), as much as 50-75% of the Finnish forests had been treated by the slash and burn agriculture method before the beginning of this century. The greatest change in the forest environment has, however, in Finland and Sweden occurred during the past century, due to the powerful expansion of the forest industry.

Based on the historical use of forests, it is known that there are few true, untouched virgin forests in Europe. The largest virgin forests can be found in boreal forest zone from the European side of the Russian Federation, in the states of Komi and Archangelsk and in some parts of north-west Karelian Republic near Finnish border.

The European forest protection concept has shaped to be more versatile than the American one. Forest protection includes different degrees and types of restrictions on forest areas regarding their use. Different regionally located protection areas build up a network. In Finland, for example, protected forest areas include the following types of forests: national parks, strict nature reserves, wilderness areas, protected peatland areas, old forest protection areas,

lake shore protection areas, herb-rich forest protection areas, ridge protection areas and the protection forests in Lapland created to prevent the shifting of the northern timber line. The latest addition, according to the requirements of the EU/Natura 2000 -programme, are those areas which are specially protected as valuable for birds and flora habitats. The protected areas in Finland amount to 15% of the total forested area (Parviainen et al. 1998).

Even though the European concept of forest protection network is parallel in the Nordic countries and Central and Southern Europe, the Nordic conditions differ significantly from the other European countries. Compressed by people, Central European forests have been fragmented into forest islands. Forests are mainly bordered by fields, settlement, road zones or industrial plants. There are plenty of border zones, but a large scale continuous forest cover has disappeared. Even the largest unbroken forest areas are often only sized thousands of hectares.

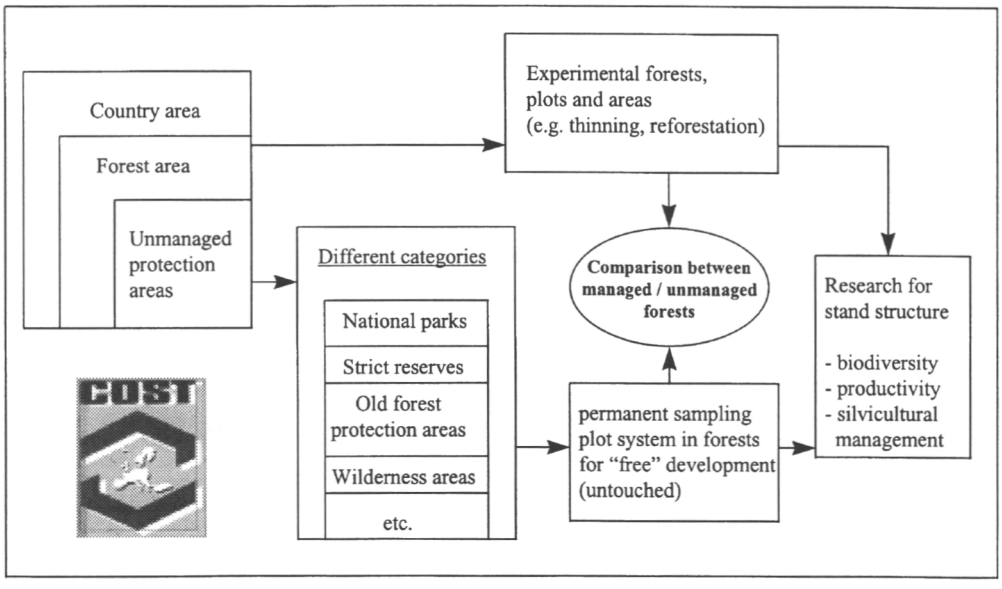
In terms of protecting mammals and birds this is a significant difference compared with the Nordic countries, where the protected forests and regular production forest compartments are right next to one another. Due to the continuous mosaic-like forest cover, big land animals like the bear are able to move freely in the entire Southern Finland. The border between protected and production forests is then more vague in the Nordic countries than elsewhere in Europe.

When comparing the forest protection in different European countries the most interesting segment is the amount of strictly protected forests. They are left for free development in a state which is as original as possible. The European Union COST research project Forest Reserves Research Network has charted the concepts related to protected areas and the amount of untouched forests in different countries (Schuck et.al. 1994, Parviainen 1997, Fig 1.). The preliminary estimates suggest that there are about 3 mill.ha of natural forests left in Europe, that is 1,7 % of the total forest area (Parviainen 1997, Table 1). The number of them cannot be further increased, but what is still left, has to be carefully secured and guarded. The majority of the remnants of natural forests are legally protected. The areas in need of further protection have been identified (like the old forest protection programme in Finland) and need to be included to the network of protected forest areas.

The largest continuous natural forests areas are situated in Finland and Sweden and in the mountainous regions of Central and Eastern Europe (Schuck et. al. 1994, Bücking 1997, Naturnähe Österreichischer Wälder, Bildatlas 1997). In Bulgaria e.g. the proportion of the natural forests outside of the total forested area as forest reserves is 8 %, in Romania 6 %, in Finland 5,5 %, in Austria 3 %, and in Germany 0,2 %. In the Netherlands there are no natural forests left. In Finland the share of natural forests is 1,3 mill.ha, which is almost one per cent of the total forested area in Europe and as much as much as 43 % of the European natural forests.

Natural forests as a model for new silviculture

Even though natural forest is generally accepted as basis for realisation of close to nature silviculture, the natural forest model needs some conceptual clarification. It is necessary to distinguish between **close to nature** and **nature like** silviculture (s. Leibundgut 1986, Schmidt-Vogt 1991, Thomasius 1992, Sturm 1993, Eder 1997). Close to nature silviculture means that the development cycles of natural forests are mimicked and nature's own development potential and productivity are used in for-



Kuva 1. Forest relevant for research of COST E4. Action and the research goals.

Table 1. Strict forest reserve area or untouched forests in some European countries.

	FIN	GER	AUT	FRA	NET	GRE	BUL	ROM
Total land area (mil. ha)	30,5	34,9	8,3	54,3	3,4	10,1	11,3	23,7
Forest area (mil.ha)	23,0	10,7	3,9	14,6	0,3	2,5	3,4	6,4
Forest cover (%)	76	30	46	27	10	25	30	27
Strict forest reserves (1000 ha)	1300	20	116,3	175	18,5	35	270	370
Strict forest reserves (%)	5,6	0,2	3	1,2	5,5	1,4	8	6

estry. In other words, the activities are guided by nature itself. In nature like silviculture natural processes are transferred as such into silviculture. This, however, cannot be the goal of sensibly managed forestry, because hazards and risks have an uncontrollable role in nature. When left entirely at the control of natural forces, forestry would be economically unsustainable and would lead, from time to time, into forest calamities on large areas, such as devastation by insects.

Natural forests develop in different ways in different vegetation zones. The development of northern, natural boreal forests is interrupted by disturbances and catastrophes, which destroy forest in large areas and promote the forest regeneration. The most important disturbance factor in the boreal ecosystem is fire. Even today millions of hectares of forest in one year may be destroyed in the vast untouched forest areas of Canada and Russian Siberia because of uncontrollable forest fires. Depending on the moisture and the tree spe-

cies composition of the site, forest fires have occured at intervals of 30-120 years in the boreal zone (Esseen et. al. 1997). In peatland, on wet soils and on islands forest may have been able to develop for centuries without disturbances or fires. In these cases forest regeneration has occurred through gap dynamics by the death of solitary trees in cycles (Kuuluvainen 1994).

On the contrary, large scale disturbances and natural disasters are an exception in the temperate forest zone in Central Europe (Schmidt-Vogt 1991, Thomasius 1992). The decisive factor is the small cycle, which means the regeneration of forests though gaps by the death of solitary trees or the creation of small openings. In Central Europe this is made possible by the typical mixed beech/spruce/fir natural forests, where the shadow trees are able to regenerate even under a very dense canopy layer.

Due to the differences in the development cycles of natural forests, the area of forest cover and the differences in the traditional forest use, the concept of close to nature silviculture is different in the Nordic countries to that in Central Europe. In the Nordic countries the silvicultural trends have paid attention to, in particular, the differences between great and small cycles, fire ecology and those stand factors which are crucial in terms of preserving living organisms. These factors include charred wood, the share of decaying wood, small biotopes and the appearance of deciduous trees in the stands. Silviculture is management of **coniferous** forests. In order to maintain biodiversity at a regional level, landscape ecology planning issues have been charted, the basic idea being maintaining the mosaic-like structure at a regional level (Kouki 1994, Angelstam 1997, Angelstam und Petterson 1997). The present remnants of natural forests can serve as a valuable reference areas and research objectives for the silvicultural orientation.

In Central Europe that basic principles of close to nature silviculture have been determined based on the gap disturbances and light factors regulated by the small cycle in forest stands. The main goal is to chart site-specifically the potential original vegetation cover so that the altered tree species composition could be directed towards the original tree species composition for the site (Thomasius 1996). Silviculture favours **mixed forests** dominated by **deciduous trees** (Schütz 1986). There have also been some demands regarding leaving total reserves alongside the production forests, which could serve as reference sites to enhance the nature oriented development of production forests (Der Wald hat ein Problem 1996, Mayer und Spellmann 1997).

The most relevant guiding factor for Central European silviculture has been the definition of naturalness (Thomasius 1996, Koch et.al. 1997, Naturnähe Österreichischer Wälder, Bildatlas 1997, Peterken 1997). Generally speaking, naturalness in silviculture refers to those conditions and processes which have been affected very little or not at all by people. When applied to forestry, the concept of hemeroby is defined. This means potentially natural forest association, where man has no longer interrupted the development and the vegetation has had time to develop up to its final state. The term naturalness also helps to define the present quality and state of forests between different countries.

This concept of naturalness is, however, not straightforward. There are many overlapping or close terms such as native, ancient woodland, virgin forest, old growth forest, primary forest and old forest (Peterken 1997). Furthermore, decisions will have to be made on how the human impact will be taken into consideration in the definition. Examples of this include, for instance, the fact that the household-use of wood, the acquisition of heating and firewood or the

selection felling are still visible in the stand landscape, or what is the impact of forestry practised 100 years ago. Also the naturalness classes will have to be proportionally defined and adjusted to fit the local conditions.

An inventory, which covers the naturalness of forest cover in the whole country, was carried out first time in Europe by Austria in the beginning of the 1990s (Naturnähe Österreichischer Wälder. Bildatlas, 1997). The following figures are some examples of the naturalness of forests:

Austria Inventory results 1997, forest area 3,9 mill. ha

natural forests	3 %
semi-natural forests	22 %
moderately altered	41 %
altered	27 %
artificial	7 %

Germany Change of tree species composition in Black Forests (Bücking et al. 1994)

	at time Ch.b.	today
spruce	3 %	45 %
beech	53 %	19 %
conifers	23 %	65 %
broadleaves	77 %	35 %

exotic tree species (Douglas fir, red oak in whole Germany) 4 %

Great Britain (Peterken 1997)
67 % plantations with exotic tree species (Sitka spruce and others)
83 % of all ancient woods extend to no more than 20 ha

Finland (Parviainen & Seppänen 1994) regenerated

by planting/sowing	5,2 mill.ha	23 %
natural	17,8 mill.ha	77 %
in total	23,0 mill.ha	100 %

no exotic tree species

Sweden (Esseen et al. 1997)
regenerated

by planting	6,5 mill.ha	28 %
natural	17,1 mill.ha	72 %
in total	23,6 mill.ha	100 %

exotic tree species, plantings

with P. Contorta	0,5 mill.ha	~ 2 %

According to the historical forest use and data on the present forest structure we see that in Central Europe the production forests are mainly altered or cultivated whereas in the Nordic countries the production forests are semi-natural. Even though in Finland and in Sweden about a quarter of forests have been established by sowing or planting, due to the natural seedlings in the regeneration areas, forests develop to be more or less mixed forests and resemble primary forest after a fire succession. The tree species development is mostly influenced through the management of seedling stands and through thinnings in young forest.

Close to nature silviculture in Germany

The principles of close to nature silviculture have been prescribed as official silvicultural guidelines in most German states as early as in the beginning of the 1990s. The central principles of close to nature silviculture are the following:

1. Avoidance of clearcuttings (Dauerwald, clearcutting area no more than 0,5 ha)
2. Mixed forest stands aiming towards the original tree species composition
3. Multistoried structure of the stands
4. Promoting natural regeneration instead of plantings
5. Selective cuttings
6. Use of canopy shadow by growing the understorey (Backmann's growth rule)

7. Protection of soil and the humus layer
8. Short intervals and light removals by thinnings
9. Use of pioneer tree species as shelterwood when the canopy shadow is missing

The forestry recommendations also include guidelines for leaving key biotopes and buffer zones untouched. It is estimated that there are this kind of key biotopes in about 6-8% of the forested area in Germany (Naturschutz im Wald 1997).

There are no exact figures on the share of dead wood in production forests. The amount of dead wood depends on the tree species and the conditions of the forest stands. The general recommendation is to leave 2-3% of dead wood of the total growing stock, which means about 15m^3 per hectare (Naturschutz im Wald 1997). Another way is to evaluate that in each site the share of dead wood should be 10-12% of the dead wood volume in a corresponding site in a natural forest (Korpel 1997). It has been recommended, that 60% of the dead wood should be fallen decaying wood and 40% standing wood.

So far there has not been detailed economical calculations as to how much additional expenses these biodiversity factors cause for forest management. It is, however, estimated that when deducting decaying wood from that timber which is found to be of poor quality or useless in logging, leaving the required amount of dead wood does not cause unreasonable additional expenses. The practical guidelines also favour leaving fallen dead wood, because logging which is carried out manually is dangerous if a considerable part of the dead wood is standing and can fall on the forest workers. On the other hand, leaving dead wood requires a new kind of attitude with respect to the local people's right to use state forests. It has been a long-term custom that the logging residue and the reject wood left in the cutting areas have been sold to the local people as firewood, provided they have collected it from the forests themselves. The new concept of silviculture is against this right of forest use.

A special type of close to nature silviculture has been applied in the forest areas of the City of Lübeck since 1994. In the beginning of the 1990s Greenpeace ordered a report from researcher Knut Sturm (1993) regarding nature oriented silviculture in Europe. Based on Sturm's report an ecological model of silviculture was created, and the forests of the City of Lübeck were chosen as an experimental area.

If the demands of ecological silviculture are met in forestry, a **Naturland**-certificate can be awarded. In addition to Greenpeace, Naturland certification is supported also by the environmental organisations BUND, Robin Wood and WWF in Germany (Der Wald hat ein Problem 1996). The main principles in ecological silviculture are:

- no clearcutting, no exotic tree species, no chemicals
- only selection cuttings are allowed
- 10 % of the forest area should be left as reference area without any human influence as a total reserves
- 10 % of the tree volume should be left as a dead wood component.

The forest area of the City of Lübeck (about 4800 ha) is optimal growth area of European beech (Fagus silvatica). Due to the earlier commercial forest activities, the region also includes planted Norway spruce forest as well as exotic tree species such as red oak and Douglas fir stands. Exotic tree species will not be preserved.

In the autumn of 1997 an outside evaluator, Borchers (Zertifizierungsmodell ohne Rationalisierungseffect 1998) assessed the economic situation related to the forest management of the forests of the City of Lübeck. According to this report, the de-

crease in the management level of silviculture and the establishment of the reference areas created losses for the wood producer and additional expenses related to silviculture of 80-240 DM per year per hectare. As a conclusion Borchers states that this kind of forest management is only possible in forests which are managed as park areas, where there is no need to set demands for the expenses related to silviculture. This silvicultural model seems to be applicable only in forests which are owned by cities or communities like Lübeck, where the additional costs can be covered by tax revenues. In private forests this type of silviculture is not profitable. There is no evidence that this silviculture favours the wood or stem quality or that consumers would be more willing to pay extra stumpage for the wood.

Conclusions

The main trend in European forestry is nature oriented silviculture. The development cycle of natural forests is considered as the guiding model in forestry. The concept of nature oriented silviculture in the Nordic countries, however, differs from that in Central Europe due to differences in vegetation zones, the history of forest use, tree species composition and the naturalness of forest cover as well as its uniformity. In the boreal zone close to nature silviculture operates in conifer forests and emphasises the maintaining biodiversity, whereas in Central Europe the goal is to guide the forest stand development towards the original tree species composition. In this way the Central European silviculture acts as a main emphasis on mixed forest stands.

The basic elements of close to nature silviculture are known, but their quantification (such as the adequate amount of decaying wood) is still not well studied and remains uncertain. It is important to include economic calculations to assess forest management, because the implementation of the biodiversity demands is only possible if forestry is profitable for forest owners. An example of extreme nature oriented silviculture are the forests of the City of Lübeck in Germany, where the decrease in the level of silviculture and the transfer of 10 % of the forest area as forest reserves outside commercial forestry activities cause additional expenses of 80-240 DM and a decrease in income per hectare per year.

Maintaining biodiversity in forested areas can be organised through an adequate network of protected areas and by the realisation of large-scale nature-oriented silviculture. Production forests, however, have the greatest influence in terms of preserving living organisms, because they represent 80-90 % of the total forested area in most European countries. Close to nature silviculture is at the same time large-scale protection effort of biodiversity, but its significance has so far been undervalued in forest protection discussion.

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FUNDAMENTALS OF FOREST PRODUCTIVITY –

Functions and resources for regeneration and growth in boreal forests

Finn H. Brække



Brække, F. H. 1998. Fundamentals of forest productivity - functions and resources for regeneration and growth in boreal forests. New stand types in boreal forestry. Metla, Research Papers 714: 21-28.

Forest functions are defined by utility, protection, realisation and perception which should all be considered in practical forestry. These functions have initiated the discussions about introducing «new stand types» which is actually not new in Central European forest practice. More mixtured stands and irregular storied high forest as well as successive regeneration by shelter-wood or group systems are recommended. The basic resources of forest productivity are defined as energy, water, nutrients and the DNA-pool which combines and conveys available resources into biomass. The sub-factors, which are in minimum in the boreal forests, are discussed. It is concluded that more knowledge is needed about: i) water and nutrient cycles in mixed forests and multi-layered forests, ii) stress shared by species with two-sided competition in mixed forests and multi-layered forests, iii) main effects and interactions of the minimum factors on advance growth in the regeneration process under stand canopies.

Key words basic resources, forest functions, new stand types
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Introduction

The first question to be addressed is how to define the boreal forest zone in the Nordic countries. The Nordic Council of Ministers (NMR 1984) has published a regional map where the boreal zone excludes south-west Finland, the regions of south Sweden and the south-east central part of Norway and also most of the coastal areas. The boreal zone includes the areas where natural oak (*Quercus spp.*) is non-existent. If the boreonemoral zone is included, all regions of Finland, and nearly all of Sweden and Norway will be the target of our symposium. This means that the mixed forests of spruce (*Picea abies)*, pine *(Pinus sylvestris)* and deciduous species other than birch (*Betula* spp.), aspen (*Populus tremula*), and alder (*Alnus spp.*) also will be included.

Forest functions

Forest productivity will be defined broadly, not only by production of timber and other biomass products, termed as forest utility. This brings us to the definitions of forest functions, which are interrelated with the traditions of silvicultural methods. In Central Europe forest functions were discussed and defined long ago, and the mutual relationships have been continuously discussed and updated.

Dietrich (1953) described the classical functions of Central European forests (Fig. 1). These were: utility functions (timber production etc.); hygienic functions (drinking water reservoir protection etc.); cultural functions (scenic beauty etc.). The forest research institutions have had a central role in their research function to broaden the knowledge about the natural basis of forest production and to develop silvicultural methods to secure sustainable yield of the defined functions.

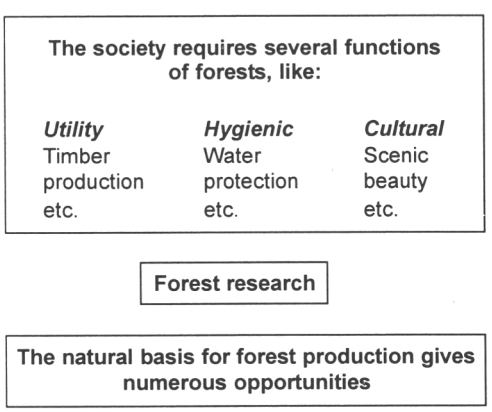


Figure 1. Classical forest functions by Dietrich (1953) after Assmann (1961).

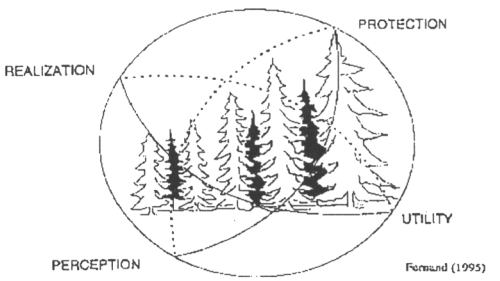


Figure 2. Revised forest functions by Fernand (1995).

A broad discussion about forest functions is relatively «new» in the Nordic countries, and was initiated by the protection movement which became rather intense in the 1970'ies. Nowadays these principles are accepted and integrated in the educational programs at the faculties of forestry, and have influenced the silvicultural methods which are recommended in commercial forestry. Fernand (1995) has suggested an updated version of forest functions which in some respect are different from those given by Dietrich (1953). Only utility has about the same definition, while the hygienic function is expanded and is renamed to protection and the cultural function is renamed to perception. In the perception - protection area is biodiversity included. The additional function called realisation is defined as the human use of the forests without basic commercial interests, like; berry and mushroom picking, jogging, walking etc. (Fig.2). The four functions overlap in the forest stands and all interrelations between these should be considered in practical forestry.

The concept of «New stand types»

The adaptation of forest functions to boreal forestry has initiated needs for a revising of the traditional silvicultural methods; to introduce «*new stand types*» in commercial forestry. These are hardly new in Central European practice (Troup 1955), and have also been described earlier in boreal forest silviculture. The new approach is that these have now become the subject of discussions about how to adjust them to modern technological practice in the Nordic forests. The new stands will as far as I can see, be characterised by: more mixtured stands of needle species or mixture of needle species and deciduous trees; irregular storied high forests (two or more layers); successive regeneration by shelter-wood or group systems.

At the turn of the century some of the cutting methods used in the Nordic forests were wrongly named. Wallmo (1906) for example, propagated for a cutting method of old forests in Norrland which he named selection cutting. The cutting method described by Wallmo (1906) was a Bavarian group cutting (Troup 1955). According to documented discussions, group cuttings seem to have been widely used in Sweden at that time. In addition the systematic dimension cuttings were probably widespread. Lovén (1911) has presented a large field material on recovery of advance and suppressed growth of pine and spruce after release. The main conclusions were that suppressed pine often failed whereas recovery of spruce was satisfactory.

In Finland Aaltonen (1919), Cajander (1934) and Sarvas (1950) have studied regeneration of pine and spruce. It is my impression that systematic dimension cuttings, which were named selectively cuttings, were still prevailing at the beginning of the 1950'ies. Sarvas (1950) recommended the foresters to change system and leave the best quality trees as seed trees and to clean out low quality trees and undergrowth to improve the natural regeneration. One specific problem by the earlier cutting systems in Finland was that low productive spruce stands took over typical pine vegetation types, which often spoiled the later possibility of a proper natural regeneration by pine.

At this centennial start the Norwegian forests were much degraded by the same type of cutting systems which prevailed in Sweden and Finland (Barth 1916). This was one major argument for establishing The Norwegian Forest Research Institute in 1917. About 20 years later the clear-cutting system with either natural regeneration or planting of spruce on the high productive sites, was officially announced. Systematic strip-cutting with planting of spruce had already been introduced 10 years earlier in Middle Norway. Pine forests have only occasionally been clear-cut and planted in Norway. These have been regenerated by seed trees at rather high numbers (50-150 trees per ha) compared with the seed tree density conventionally used in Sweden and Finland. The cutting and regeneration systems which were introduced about 50-60 years ago in Norway, have been successful with respect to timber resources. During the 62-year-period, 1924-1986, the stem volume in the Norwegian forests increased by 69% (Brække 1991), similar trends have been reported from Sweden and Finland. It is important now that the introduction of new silvicultural methods does not bring the forests one step backward with respect to a reasonable good timber yield.

Basic resources of forest productivity

The basic needs for growing trees have been known for a long time, but the numerous interactions within an ecosystem have been poorly understood. Cajander (1934) discussed the three basic resources, energy, water and nutrients, when he studied recovery of suppressed spruce plants, and he referred to quite many reports, mostly from Sweden and Germany. The illustration in Fig.3 emphases the strong interrelation between the three basic factors and the dynamic DNA-pool of forest ecosystems. The DNA-pool is the main vector in the living system which conveys available resources into biomass. The size of the DNA- pool expresses the biodiversal potential of a particular system. This potential is principally determined and balanced by the three pools of resources and adjusted by the silvicultural methods applied. If one sub-factor in one of the pools turns into minimum, this sub-factor will usually override the others and will become the determining factor of growth capacity and development in the different ecosystem compartments. If one such minimum factor becomes permanent and creates a long term specific stress, like the general nitrogen deficiency in the boreal forests (Hesselman 1917, Romell & Malmstrøm 1944) as concluded by Tamm (1991), we might assume a genetic selection towards a community adapted to and tolerating the stress.

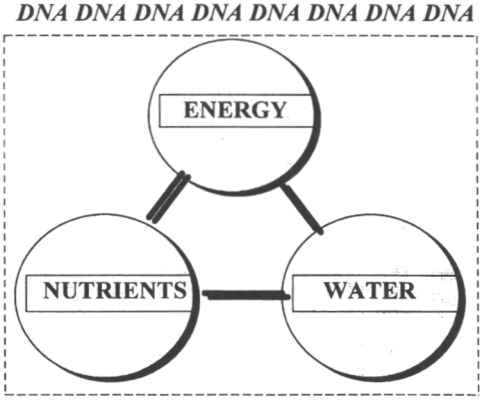


Figure 3. The three main pools which are fundamental for the forest ecosystem productivity.

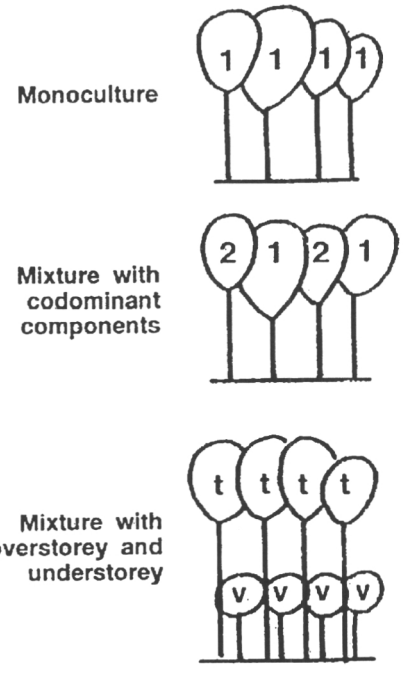
Traditionally, three sub-factors of minimum are discussed in the boreal and the boreonemoral zones. These are when we consider north-south and high altitude-lowland gradients: air and/or soil temperature at high altitudal boreal forests; frequent nitrogen deficiency in the boreal and boreonemoral zones; temporary water deficit in the boreonemoral zone.

Mork (1941) developed growth units, which express the relation between air temperature and height growth, in a mountain forest in south-central Norway. Later these were transformed to respiration equivalents by Dahl & Mork (1959). Based on these and other results Mork (1968) concluded that the growing season air temperature is the minimum factor for growth of spruce in the mountain forests. He also suggested that the rhizosphere temperature might restrict root growth. The net flux of photosynthetic effective radiant energy (PAR) is not considered as a minimum factor, whereas the accumulated growing season heat offers a restriction on production of viable seeds. He did not discuss the possibility of limited nutrient supply, temporary or permanent. The nutrient perspective with possible restrictions and interactions with growth and production of viable seeds in the mountain boreal forests, has not been properly discussed.

A new generation of water and nutrient optimising tests was established in Sweden in 1987, and the growth response is reported by Linder & Bergh (1996). It is evident that the genetic potential of growth in ordinary spruce plantations is very high. The spruce at the northern boreal site Flakaliden was restricted by nutrients as watering did not result in any growth response. The young stands responded to nutrition by tripled stem growth even at this high altitude. At the boreonemoral site Asa the spruce responded to both watering and nutrition and there was a strong interaction between these treatments. A likely explanation is that the site had permanent nutrient deficiency and temporary water deficits in drought periods.

Systematic use of advance growth in the regeneration process

If we consider advance growth in group or shelter-wood systems, the discussed minimum factors will usually become more critical to this compartment than to dominant and codominant trees. Besides, light must be included in the list of minimum sub-factors. Cannell & Grace (1993) have reviewed light competition by detection, measurements and quantification. The physical laws behind irradiance and light interception in forest stands are well known and can be modelled rather properly (Fig.4). Howev-



Equations for light interception for monocultures and mixtures, assuming that light attenuation follows the Beer-Lambert law (after Cannell & Grace 1993)

Monoculture $I_0(1\text{-}\exp(\text{-}K_1L_1))$

Mixture

Codominant $I_0[1\text{-}\exp(\text{-}(K_1L_1+K_2L_2))]$

Below overst. $I_0(1\text{-}\exp(\text{-}K_tL_t))$

Below underst. $I_0\exp(\text{-}K_tL_t)[1\text{-}\exp(\text{-}K_vL_v)]$

I_0, irradiance at the top of the canopy
L, leaf area index
K, light extinction coefficient

Figure 4. Equations for light interception for monocultures and mixtures, assuming that light follows the Beer-Lambert law (Chanell & Grace 1993).

er, the physiological response of different species to shade in an ecosystem, which means their individual competing ability, is more difficult to describe in a simple way and to express in mathematical models. One important feature of successful mixtured and multi-layered stands is the ability of two-sided competition between the species in question. Assmann (1961) has summarised the characteristics of species which can be successfully mixed and grow under two-sided stand competition. He concluded that such species should have different: demand of light, growth rhythm, rooting depth and litter quality.

Conclusions

A major part of the forest research in the Nordic countries has dealt with monocultures. I would like to pin point our meagre knowledge about how main effects and interactions of the minimum factors are creating stress in mixed forests, multi-layered forests and on advance growth in the regeneration process under canopies. The differences between monocultures and the mentioned stand types with respect to water and nutrient cycling, are not so well documented. Such knowledge is necessary to improve the silvicultural methods and to develop proper ecosystem models.

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TEMPERATURE AND RADIATION REGIMES IN SELECTIVE THINNED FOREST STAND

Mikaell Ottosson-Löfvenius



Ottosson-Löfvenius, M. 1998. Temperature and radiation regimes in selective thinned forest stand. New stand types in boreal forestry. Metla, Research Papers 714: 29-32.

The near ground microclimate in a forest is quite different from that in a clear-cut area. The trees exert control on the irradiance and precipitation reaching the ground but also influence the near-ground conditions, such as the temperature and humidity as well as the soil temperature. In particular, the diurnal variation of the near ground temperature is much larger in a clear-cut area than in a forest during clear and calm weather conditions. During clear and calm summer nights, the near ground temperature in a forest is warmer than in a clear-cut area, and during daytime the temperature is colder. This nocturnal "heating effect" of the forest is partially retained after thinning. Therefore, forest regeneration in areas that might be frost exposed after clear felling, should include thinning of the mature stand to produce a shelterwood to serve as frost protection.

Results from earlier studies of the near ground microclimate, i.e. minimum temperature, temperature profile characteristic, net radiation and short wave radiation, related to different single-layer shelterwood stand densities and tree heights, show that thinning of a forest stand produces microclimate conditions that go towards the typical clear cut area conditions. Yet, there is an individual relation between different microclimate variables and stand density variables. In a more or less open multi-layer forest stand, there is a particular interest pointing to the vertical variation of short wave radiation, both intensity and spectral composition (light quality), which may be essential for understanding the growth and response by the plants and remaining trees.

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Introduction

The microclimate within a forest stand is different from that in an open area. The trees exert direct control on the short-wave radiation and precipitation reaching the forest floor but also influence the near ground conditions such as the air temperature, air humidity, wind speed as well as the soil temperature and snow conditions. The effect on the near ground microclimate is related to the stand characteristics, such as stand density, tree height, canopy structure etc. At present, there are indications of a shift in forest renewal and silviculture methods that includes various kinds of thinning op-

erations rather than clear-cut of forest stands. This change of the stand characteristics by thinning will also modify the microclimate conditions.

The main objective of this presentation is to reveal the importance of the near ground microclimate related to thinning. The shelterwood effect on nocturnal radiative cooling and transmission of solar radiation will serve as examples of microclimate modification by various degrees of thinning.

Near ground temperature in selective thinned stands

During clear and calm weather conditions, the diurnal variation of the near ground temperature in a clear-cut area is much larger than in a forest. During the night the near ground temperature in a forest is warmer than in a clear-cut area, and during daytime the temperature is colder. In most cases, the effect of clear cutting on the temperature is regarded as positive for forest regeneration. In certain places, however, problems due to severe and frequent frosts may occur after clear felling. This type of frosts is mainly of the radiative type and tends to occur locally in the terrain during clear and calm nights. Such areas should be devoted with special care and not being clear-cut. Since the nocturnal "heating effect" of a forest is partially retained after thinning, the forest regeneration in such areas, that might be frost exposed after clear felling, should include thinning to produce a shelterwood to serve as frost protection.

The nocturnal cooling during clear and calm weather conditions is radiative in origin and is attributed to the net thermal radiation loss from the ground surface. The nocturnal net radiation (Q_N) is the balance of upward longwave radiation from the surface (R_T), mainly controlled by the surface temperature, and the downward atmospheric longwave radiation (R_A);

$$Q_N = R_A - R_T$$

Near the ground in a forest stand, the downward radiation consists of the portion of R_A that penetrates the canopy and the downward radiation emitted by the trees. Since the radiative temperature of the sky is less than the radiation emitted by the trees, the total downward radiative flux is larger in a forest stand than R_A alone (Reifsnyder and Lull, 1965). Assuming that the upward longwave radiation emitted from the forest floor is constant, a decrease in canopy cover will increase the net loss of radiative energy resulting in stronger radiative cooling near the ground.

The nocturnal near ground temperature is however not a function of radiative fluxes alone. The magnitude of the sensible and latent heat flux, the soil heat fluxes and heat storage of the biomass may be of the same order as the net radiation (Ottosson Löfvenius, 1993). Thus, there is a delicate nocturnal energy balance of fluxes, comparative in magnitude but of different physical modes (radiation, conduction and convection) with different transfer rates.

The near ground nocturnal temperature is higher in a forest stand than on a clear cut area during clear and calm nights and the difference in the near ground minimum temperature between the forest and the clear cut area may be defined as the forest "heating effect". Previous studies show that the shelterwood heating effect is not a function of stand density alone, but depends also on the average tree height, figure 1. It is evident that the shelterwood height is a very important parameter that controls the cooling near the ground. Consequently, with the same view factor, a shelterwood with lower average tree height provide less "heating effect" than a shelterwood with higher trees.

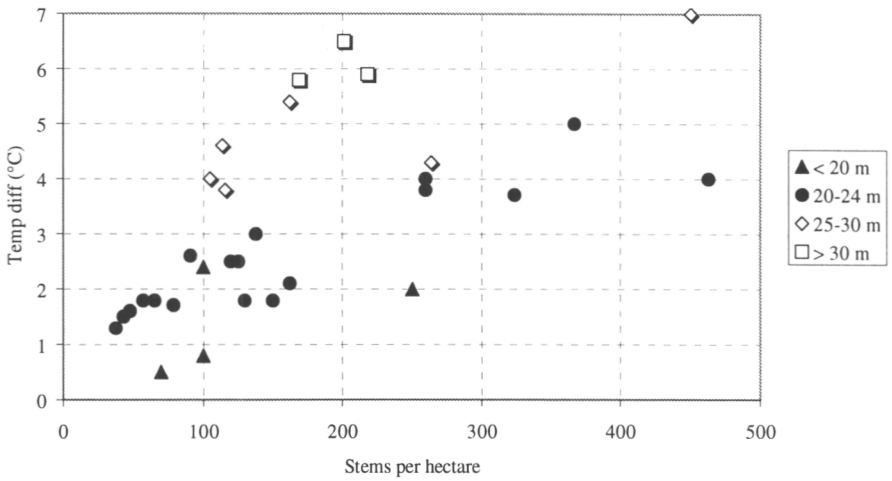

Figure 1. Average near ground minimum temperature difference between forest and clear-cut area (Temp diff) during clear and calm summer nights. Pine and spruce stands separated height classes.

Short-wave radiation in selective thinned stands

The microclimate in a forest stand is largely controlled by the short wave radiation that penetrates the canopy. During days with clear skies the solar radiation displays a mosaic pattern of sunspots and different degree of shading spots on the forest floor. The intensity varies from a few percent of the intensity above the canopy to almost full solar radiation load, figure 2. In addition the absorption, reflection and transmission process in the canopy affects not only the quantity but also the quality of the radiation reaching the below canopy environment.

The intensity and duration of short wave radiation has a significant effect on young coniferous plants that have been exposed to nocturnal freezing temperatures. Plants exposed to high values of irradiance during the days after a severe frost night show more pronounced frost damages than plants exposed to less irradiance. Interactions between low temperature and short wave radiation are suggested to be responsible for the discoloured needles and photosynthetic rate observed on pine and spruce seedlings (Lundmark, 1996, Lundmark and Hällgren, 1987). Hence, in addition to the above-defined "heating effect" of a thinned forest stand, the shading effect may further improve the plant survival rates in areas exposed to severe summer frosts.

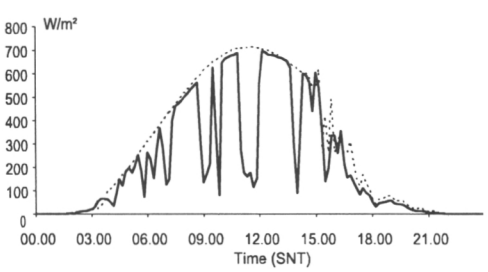

Figure 2. Short-wave radiation below pine shelterwood canopy (density 125 stems per hectare, height 20 meter, solid line) and in a nearby clear-cut area (dashed line). Vindeln (64° 14' Lat N), June 26, 1986.

It is evident that the reduction of short wave radiation below the canopy increases with the stand density. However, the shading effect of a thinned stand increases with lower solar altitude. By this, the daily irradiance below the canopy in a thinned stand is lower at higher than lower latitudes in clear days due to lower solar incident angle. Furthermore, the relative short wave irradiance is larger during cloudy than during sunny conditions, figure 3.

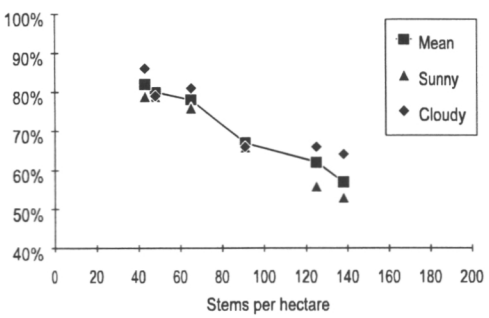

Figure 3. Transmission of short wave radiation in pine shelterwood as function of stem density expressed as percentage of the daily irradiance in an open area. Vindeln (Lat. 64° 14' N) in late August and early September 1985 and 1986.

Discussion

By various reasons, forest renewal involving clear cutting may not be as convenient as before and rather be replaced by different kinds of selective thinning. This short presentation focuses on the importance of the microclimate in selective thinned stands. It has been shown that the temperature and the short wave radiation conditions are close related to the structure and density of the remaining stand after thinning. Results from earlier studies of the near ground microclimate, i.e. minimum temperature, temperature profile characteristic, net radiation and short wave radiation, related to different single-layer shelterwood stand densities and tree heights, show that thinning of a forest stand produces microclimate conditions that go towards the typical clear cut area conditions. Yet, there is an individual relation between different microclimate variables and stand density variables.

The effect of selective thinning on the microclimate should be used intentionally, such as for frost protection, but also for radiation control. However, the trees and plants responses to selective thinning are not fully understood, particularly in the long-term perspective. In a more or less open multi-layer forest stand, there is also a particular interest pointing to the vertical distribution of short wave radiation, both intensity and spectral composition (light quality), which may be essential for understanding the growth and response by the plants and remaining trees.

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NEW SILVICULTURE – A CHALLENGE FOR PHYSIOLOGICALLY BASED GROWTH MODELLING

Annikki Mäkelä



Mäkelä, A. 1998. New silviculture – a challenge for physiologically based growth modelling. New stand types in boreal forestry. Metla, Research Papers 714: 33-38.

Physiologically based growth models derive tree and stand development from the metabolic processes of trees and their interactions with the physical environment. Although these models have recently developed to be more readily applicable to practical questions of forest management, most of them have been built upon the assumption of even-aged, homogeneous stands. Silvicultural methods that follow more closely the natural development of stands act towards increasing heterogeneity of stands, e.g., by favouring natural regeneration and mixed and multilayered stands. If physiologically based growth models are to be used for the prediction of stand development, tree growth and timber quality in these kind of stands, the heterogeneity of stands will have to be incorporated in the models.

The requirements for model building set by the challenge of heterogeneity include the 3-dimensional description of tree distribution, the impacts of the local environment on growth, and the interactions between different species within a plot. While many of these tasks are straightforward, provided sufficient computer capacity, some scientifically more challenging problems remain. One of the key issues in this respect seems to be, understanding the structural acclimation of trees grown in different environments, or plasticity of structure. Empirical research combined with theories of adaptation and acclimation are needed in order to increase our understanding in this matter.

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Physiologically based growth models derive tree and stand development from the metabolic processes of trees and their interactions with the physical environment (Fig. 1). Key processes in these models are those related to the carbon balance of trees, including photosynthesis, respiration, and carbon allocation to the different parts of the tree. Due to their inherent causal structure, these models have been able to describe the essential features of stand dynamics from a minimum set of assumptions (Botkin et al. 1972, McMurtrie and Wolf 1983, Mäkelä and Hari 1986), but recently they have also developed to be more readily applicable to practical questions of forest management (Sievänen 1993, Mäkelä 1997, Mäkelä et al. 1997, Bartelink 1998). However, most of the physiologically based growth models have been built upon the

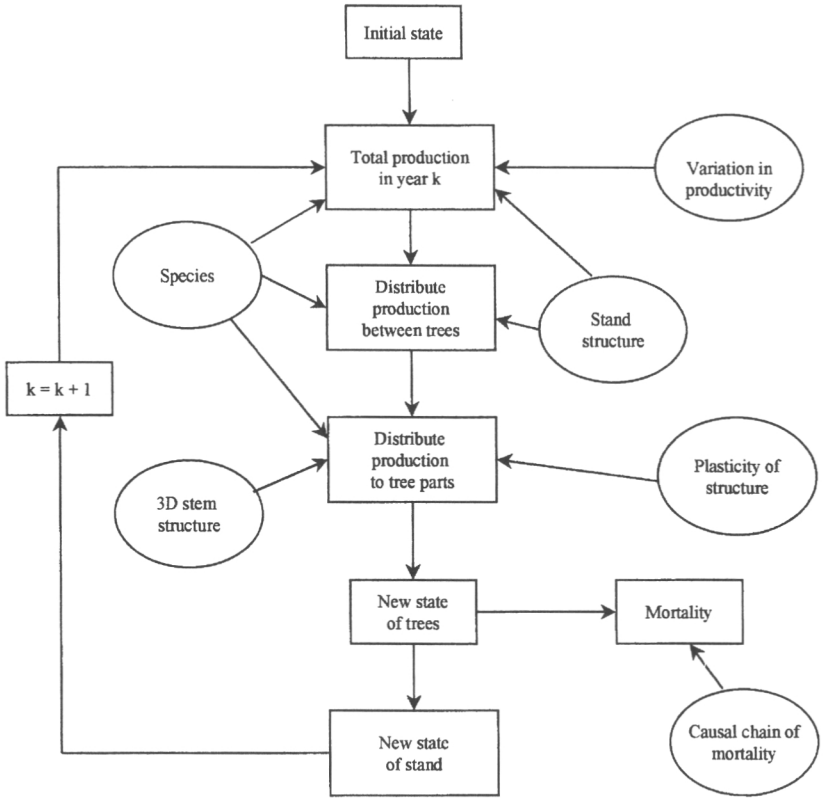

Figure 1. Schematic presentation of stand dynamics in physiologically based models.

assumption of even-aged, homogeneous stands, which has lead to a mean-tree or size class approach with random spatial distribution of trees (Oker-Blom et al. 1989).

There is an increasing trend in forest management to promote silvicultural methods that follow more closely the natural development of stands (e.g. Finnish Forest and Park Service 1994). This involves, e.g., favouring natural regeneration which, in turn, will lead to mixtures of species and multi-storey stands, conducting selection fellings, and retaining decaying wood material in stands to support organisms that depend on dead wood for their survival. All these factors act towards increasing heterogeneity of stands. If physiologically based growth models are to be used for the prediction of stand development, tree growth and timber quality in these kind of stands, the heterogeneity of stands will have to be incorporated in the models.

A number of models have already been developed to deal with the actual spatial distribution of trees (Kuuluvainen and Pukkala 1987, Pretzsch 1995, Franc and Picard 1997). There are indications that the fast increasing computer capacity will soon allow us to use a genuine individual tree approach, with all the tree locations coded over a reasonably sized area, such as one hectare (Perttunen et al. 1996). However, statistical methods will be required to generate and classify probable, non-random

distributions of trees in different types of stand. One of the key questions will be the minimum stand size that can be used as a basis for repetition in the calculations.

The physiologically based growth models are quantified through parameters related to (1) tree and stand structure, and (2) the relationships between the environment and metabolic rates. In most models, only one or two species have been considered. In order to analyse mixed species stands, the parameters will have to be measured for all relevant species. Although this is quite a laborious task, it is straightforward in principle, as model structures in physiologically based models are generic.

The impact of stand structure on growth in physiologically based models is mediated through environmental factors. This is of crucial importance for the dynamics of the model, in particular, when there is a feedback from the local environment to growth. In physiologically based models, this feedback process accounts for the competition between trees. Shading is probably the most thoroughly understood process of intercation, and sophisticated methods have been developed to calculate the passage of light through the crowns and the capture of light energy by the foliage (e.g. Oker-Blom 1986).These have traditionally been extremely time-consuming, but the development of computer capacity has now made it feasible to make these calculations online (Bartelink 1998). Technical methods of model simplification have also been developed (Mäkelä 1990). Soil interactions are more difficult to analyse, but some attempts to look at the development of root systems and root competition in a spatial model have already been initiated (Hauhs et al. 1995). Especially in young stands, it is not so much a question of interactions through the soil, but of an uneven distribution of soil properties, creating a different initial environment for each tree.

The problem that has had the least attention in growth modelling is the feedback effect of the environment on the development of tree structure. It is known that trees are able to acclimatize to different environments by modifying their structure in ways that also affect their metabolic functioning, generally so as to increase their growth rates and chances of survival (Sorrensen-Cothern et al. 1993). In even-aged stands, this *plasticity* of tree structure is manifested mainly by the flexible H/D ratio which can also be seen in the variability of crown ratio (Valentine et al. 1994, Mäkelä and Vanninen 1998). Other acclimations include root:foliage ratios, crown shape, specific leaf area, etc (Weiner 1988, Coyea and Margolis 1992, Gillespie et al. 1994, Deleuze et al. 1996). In a heterogeneous stand where the local environmental variation is wide, the acclimation of structure inevitably becomes more pronounced.

In dynamic models of stand growth, understanding the structural acclimation is very important for three reasons. Firstly, tree structure has an impact on the local environment and hence the driving variables of the other trees. Secondly, the structural characteristics have an impact on the metabolic rates and, through growth allocation, on growth efficiency. Thirdly, the final product, the stems, are formed in the process of structural growth, and their quality as timber is affected by the processes of structural acclimation.

In a summary, understanding the structural plasticity in trees is a key question in our attempts to model and understand better heterogeneous stands which will increase in coverage with the new silviculture. Empirical research combined with theories of adaptation and acclimation are needed in order to increase our understanding in this matter.

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UTILIZATION OF NORWAY SPRUCE ADVANCE REGENERATION IN MULTI-STORIED STANDS –

Presentation of a field experiment with various degrees of overstory removal

Aksel Granhus



Granhus, A. 1998. Utilization of Norway spruce advance regeneration in multi-storied stands. New stand types in boreal forestry. Metla, Research Papers 714: 39-44.

Knowledge about how Norway spruce advance regeneration respond to various degrees of overstory removal under Nordic conditions is, despite recent progress, rather limited. Future research on how pre-release competitive status and various degree of overstory removal affect mortality, growth and resource allocation, should be promoted. In addition, there is a need to evaluate how nutrient competition, water stress and stand temperature affects growth performance and resource allocation in relation to competition for light under various site conditions.

With reference to these questions, the research project «Alternative Forest Management» is presented. During 1993 and 1994, research plots with a variety of silvicultural treatments were established at 9 different sites in SE-Norway. The plots are located in multi-storied spruce stands, on low and medium site indices 4-600 m.a.s.l. The silvicultural treatments involve harvest strengths of 0, 25, 45, 65 and 100 % of basal area. Before treatment, detailed measurements were done on all advance regeneration higher than 0.5 m, involving coordinate mapping and registration of morphological characteristics and increment data. As a part of a Ph.D. project, these research plots will be re-measured in 1998 and 1999, six growing seasons after treatment. The future study will involve analysis of growth performance on an individual tree basis, with emphasis on the interactions between morphological characteristics, nutrient status and microclimate under various overstory densities. In addition, the behavior of advance growth damaged during harvesting operations will be examined, with particular emphasis on the interactions between pre-harvest vigor, mortality and healing of different types of mechanical wounds (green crown reduction, bark and fiber damage, bending etc.).

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Introduction

Physiologically based research on how Norway spruce advance regeneration adapts to various levels of competition and -release has, with some exceptions, until recently been a field of limited concern in the Nordic countries. Outside the Nordic countries,

particularly in North America, the mechanisms involved in the physiological adaptation to changing stand environments have been more thoroughly studied (i.e. Tucker et al. 1987). However, due to the differences in species composition and site conditions, these results can not automatically be transferred to the boreal forests in Fennoscandia.

The problem of maintaining an acceptable production level due to unsatisfactory regeneration and reduction of stand densities was one of the reasons, why selective harvesting methods were abandoned in both the Nordic countries and Central Europe (Ebert 1995, Hagner 1995). However, the low production level frequently associated with such non-clearcut systems can probably to a high degree be explained by wrong adaptations of these silvicultural systems. Nevertheless, these experiences stress the importance of adapting new silvicultural practices in a way that promote establishment and ingrowth of new regeneration, either by artificial regeneration methods or by means of utilizing existing advance regeneration. In this context, the growth response to different levels of overstory removal, as well as the influence of the individual trees, pre-release competitive status, are important questions.

Alternative Forest Management - a research project on the feasibility of «alternative» forestry practice- and regeneration methods

In 1993, the Norwegian forest research institute (NISK) and the Department of Forest Sciences at the Agricultural University of Norway established the research project «Alternative forest management». During 1993 and 1994, nine blocks with various treatments were established in uneven-aged Norway spruce stands. The blocks are established on *Eu-Piceetum myrtilletosum* (bilberry) and *Eu-Piceetum dryopteridetosum* (small fern) site types 4-600 m above sea level in south-east Norway. The site index on the different blocks are ranging from G8 (low) to G15 (medium), based on the Norwegian H40 site index classification system. Each block has three different selective logging treatments (25, 45 and 65 % removal of basal area), as well as four small clear-cut plots of two different size classes (three 25 x 25 m plots and one 50 x 50 m plot), and one control plot. After harvesting, several combinations of soil treatment (no treatment, patch scarification and mounding) and regeneration methods (planting and seeding) were applied to the different plots (Fig. 1).

On the selectively logged and control plots, pre-harvest registrations involved coordinate mapping of all trees taller than 0.5 m, and a more detailed registration of different tree characteristics on all advance regeneration 0.5-3.0 m. Due to this spatial mapping, investigation of growth response and competition can be made on both single-tree basis as well as on stand level. The recorded tree-data for the smaller trees include registrations of height growth, branch growth, and vitality indices such as crown density. In addition, trees were classified according to the morphological classes described by Lesinski & Sundqvist (1992).

These experimental plots will be extensively used in a further study during 1998 and 1999, with emphasis on how understory Norway spruce adapts to various levels of release. A short introduction to some of the actual topics is given in the following sections.

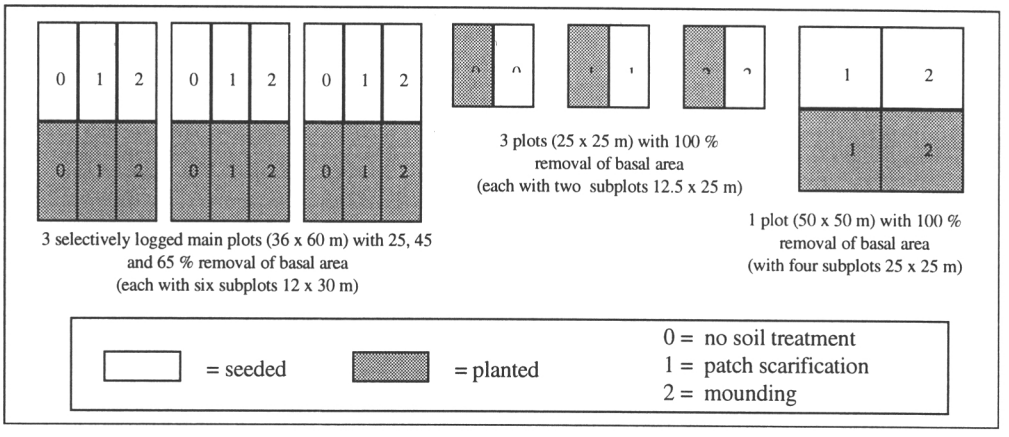

Figure 1. Principal sketch of the block design, showing the logging treatments and the combinations of soil scarification methods (0, 1, 2) and regeneration methods (white = planted, shaded = artificial seeding). In addition to the treatments shown in the figure, each block includes one untouched control plot (25 x 24 m).

Morphological- and microclimate aspects related to growth potential and response to release

For a wide range of shade-tolerant species growing in the understory, including Norway spruce, increased competition is often associated with wide crowns and adjustments of foliar morphology (Greis & Kellomäki 1981, Lesinski & Sundqvist 1992, Niinemets & Kull 1995a, 1995b). From this one might state the hypothesis, that morphological features describing pre-release vigor should be an appropriate way to «quantify» the competition stress affecting individual trees, and hence, the ability (and time required) to adapt to the altered growing conditions after the removal (complete or partial) of overstory trees. However, a serious problem when dealing with overstory competition is, that differences in nutrient and water availability on different sites are likely to affect relative growth performance, even if the light conditions are comparable. If site- and density-dependent variation in nutrient and water availability is an additional growth limiting factor under forest canopies, resource allocation patterns and hence morphological features of the individual tree should be affected, too.

Quantifying the relationships between above-ground and below-ground competition is a tedious and complicated process, where resource allocation patterns can be expected to be influenced by all of the limiting factors. In addition, the spectral quality of light may affect growth. In an experiment with Norway spruce, where both artificially shaded and control trees were fertilized and irrigated for a period of 3 years (Nilsson & Hällgren 1993), the shading treatment resulted in a larger height increment than in the control trees, as well as other changes in resource allocation patterns.

Several investigations on a broad range of conifer species have shown that there is a good correlation between pre-release morphological characteristics of understory trees and their ability to react after overstory removal, as well as upon the time required to respond to the change in growth conditions (Hatcher 1964, Ferguson & Ad-

ams 1980, McCaughey & Schmidt 1982, Oliver 1985, Seidel 1985, Tesch & Korpela 1993). Though there are some exceptions, these studies show that in particular pre-release height growth, initial tree height, high crown ratios and the abscence of logging damages are important factors affecting growth performance after release (McCaughey & Ferguson 1988). Other studies also emphasize the effects of microclimate upon response to release. In a study of Grand fir advance growth, Ferguson and Adams (1980) found that trees growing on cool, moist sites responded better to release than trees on dryer sites.

In the current study, a combination of nutrient analysis and monitoring of temperature and soil water potential on selected plots of different overstory densities will be important supplements. During the 1998 growing season, permanent monitoring of light availability and other microclimate variables will be established.

Effects of mechanical injuries

When releasing advance regeneration from overstory trees, some degree of mechanical injuries can not be avoided (Westerberg & Berg 1994, Fjeld and Granhus 1998). In a study based on the selection harvesting experiment described above, Haveraaen et al. (in press) found that the average injury rate for stems 0.5-3 m showed a high variation depending on the choice of damage criteria when classifying a tree as injured or not. When only counting dead and missing stems, the average injury rate (20 %) was 25 % lower compared with the results obtained when all recorded damages were included (45 %). Therefore, in Norway spruce forests where the amount of regeneration is a limiting factor, the recovery potential of damaged advance growth is important when determining the need for supplementary regeneration treatments.

When examining the recovery potential and growth response of damaged trees, one should have in mind that injured trees probably will show another growth pattern than undamaged trees, due to the introduction of an additional stress factor. This question will be studied in detail in connection with the 1999 revision of the established plots. More specifically, important questions to be answered will be the recovery connected with different damage types (i.e. crown removal, stem leaning and bole wounds) and the effect of the severity of different damage types (i.e. per cent green crown removal etc.). In addition, the effect of pre-release vigor (i.e. morphology, crown volume and height growth), as well as the degree of overstory removal, will be included in the study.

To the authors knowledge, no studies have been done upon recovery potential after damage in Norway spruce advance regeneration. For North American species however, the literature is more abundant (i.e. Gordon 1973, McCaughey & Schmidt 1982, Oliver 1985, Tesch et al. 1993, Ruel et al. 1995). Species specific patterns in survival- and growth response are likely to occur, but as shown by the above sited authors, some measures of pre-release vigor are probably important determinant factors.

Concluding remarks

Future research on how pre-release competitive status and various degree of overstory removal affects mortality, growth and resource allocation, should be promoted. In addition, there is a need to evaluate how nutrient competition and water stress affect growth performance and resource allocation in relation to competition for light under various site- and stand conditions.

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WHEN TO REMOVE SCOTS PINE SEED TREES

Eero Kubin



Kubin, E. 1998. When to remove Scots pine seed trees. New stand types in boreal forestry. Metla, Research Papers 714: 45-54.

The rate of natural regeneration of Scots pine, the abundance of regrowth, and the height growth of the restocking material underneath seed trees were studied in Kuhmo (64°15´N, 29°32´E) during the period 1986-1997. The seed trees were removed one, two, four and eight years after site preparation so that the corresponding numbers of seed crops were shed before their removal.

No pronounced advantage was observed to have been achieved by retaining the seed trees for two, four or eight years instead of one year. The seed crops produced by the longer-retained trees had a minor impact or no impact at all on the regeneration outcome recorded twelve years after the maturing of the first seed crops. On the contrary, prolonged retention of seed trees reduced the height growth of pine seedlings, especially when the seed trees were retained for longer than four years. There were no differences in soil texture or nutrient status to explain the outcome neither did the ground vegetation compete with the pine seedlings. Thus, there is an inconsistency between the aim of achieving regeneration and the new practice of retaining trees to promote biodiversity. More knowledge about the long-term effects of retention trees is needed to support decision makers in practical forestry.

Key words Pinus sylvestris, natural regeneration, boreal forests, silviculture

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Introduction

The interest shown towards natural regeneration of the forests has considerably varied depending on both the trends which have dominated in forest treatment and on the accumulation of research knowledge (Leikola 1986, 1987). The most recent silvicultural recommendations (Luonnonläheinen ... 1994) propose, in the manner of previous recommendations, the application of forest cultivation only when the preconditions for natural regeneration are entirely lacking or there is uncertainty regarding success. In the natural regeneration of Scots pine, the recommendation is to leave 50-150 seed trees per hectare either in small groups or in striplike formations, to clear away trees hampering growth, and to prepare the soil by either disc-trenching or patch-scarification. A further recommendation is to remove the seed trees as soon as sufficient restocking has occurred. The recommendations do not point out how many years the seed trees should be retained and what is considered to be an adequate age of the restocking material. Instead, the recommendations proceed to encourage

landowners to leave seed trees to grow singly or in groups for the sake of the landscape and habitat management.

In practice, the number of seed trees has varied quite widely. When defining different regeneration stands on the basis of tree density and distance between trees, Mikola (1956) proposed 10-50 trees per hectare to be adopted as the number of stems for a sparse seed-tree stand and 50-100 trees for a dense stand. Correspondingly, Heikinheimo (1948) has proposed leaving 25-75 trees per hectare, depending on tree quality and forest site type. The recommendation embodied in the new forestry directive (Luonnonläheinen ... 1994) of leaving as many as 150 seed trees per hectare means a rather high density, as more than 60 trees per hectare has the effect of hampering the height growth of the restocking material, particularly if the seed trees are retained for a long period (Valtanen 1972, 1984). According to Norokorpi (1983), the more seed trees are retained, the sooner they should be removed. Both Niemistö et al. (1993) and Skoklefald (1995) have observed that the height growth of pine seedlings is distinctly impaired the longer seed trees are retained and the closer the seedlings are to seed trees. The formation of gaps around individual pine trees is a phenomenon that was noted very early in Lapland (Aaltonen 1919).

The significance of site preparation to promote natural restocking, has been emphasised since the 1930´s (Tertti 1934, Heikinheimo 1940, Sirén 1948) and in more recent studies it has been observed that site preparation considerably accelerates the process of natural restocking (Valtanen 1984, 1985, Norokorpi 1981, 1983, Jeansson 1995). On the other hand, it has also been observed that retaining seed trees for more than 5-6 years since site preparation has a debilitating impact on the development of the emerging seedling stand and retaining them for longer than 10 years leads to formation of gaps particularly around the seed trees (Valtanen 1984).

The results of many studies indicate that the development of seedling stands is impaired by the lengthy retention of pine seed trees. However, research data on how soon Scots pine seed trees can be removed has been inadequately assessed. The present study on this very subject originated in a practical situation. Staff at the Forestry District of Kuhmo of the Finnish Forest and Park Service had observed that regeneration of pine was very successful if site preparation consisted of disc-trenching and if the seed trees were removed 1-2 years after the regeneration felling. Because no research results were available on such a brief retention of seed trees, four field experiments were established during the years 1985-1986 to clarify the matter. In this report, results obtained in one of the experimental fields in Kuhmo will be presented.

Material and methods

The experimental field (Fig. 1) was established in 1986 on the Lehtoniemi forest holding in Kuhmo owned by Kajaani Oy (subsequently UPM-Kymmene Ltd.). Regeneration felling was carried out in 1984, disc-trenching in the autumn of 1985, and the establishing of the experiment in 1986. The seed trees were retained for one, two, four, and eight years subsequent to soil preparation by disc-trenching. The experimental plots varied between 2½ and 3 hectares in size. The site type of the trial area is that of a dryish upland, mineral-soil site.

Regeneration was monitored in two ways. One was to monitor twice a year, in the spring and autumn, the annual increase in the number of seedlings along the same sampling lines located along the furrows produced by the disc-trencher. The seedling numbers were converted into numbers per hectare based on the proportionate surface

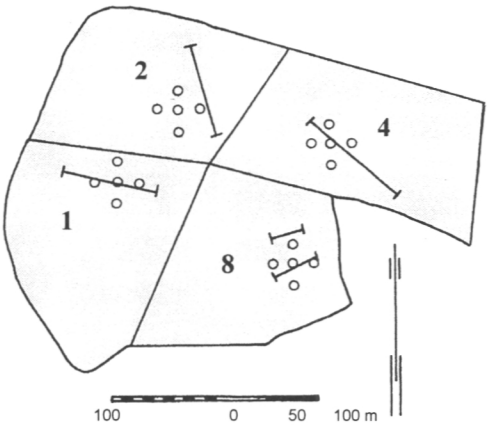

Figure 1. The Lehtoniemi experimental field in Kuhmo. I—I = sampling line in the disc trenched furrows for the annual inventory of pine seedlings. o = circular sample plot used for the inventory of all seedlings in 1994 and 1997. The seed trees were retained for one (1), two (2), four (4) and eight (8) years.

area of the furrows, which was 26.3 % of the total regeneration area. The other monitoring method took place in 1994 following the removal of the longest retained seed trees and 1997 using five one are circular sample plots in each regeneration area where seed trees were removed. The plots were examined for the number of seedlings of each tree species categorised according to prepared and unprepared site as well as measuring the seedling heights. Mineral soil and humus samples were also collected and analysed by using standard methods to get backround knowledge about the particle-size distribution and nutrients.

Results

Restocking in disc-trenched furrows

The baring of the mineral soil had a crucial impact on natural restocking as more than 90% of the pine and birch seedlings were found to grow in the disc-trenched furrows (Table 1). Spruce seedlings grew mainly on non-prepared surfaces, and they had emerged already before the regeneration felling.

The numbers of pine seedlings in the disc-trenched furrows showed immediate post-establishment random variation as soon as all experimental plots had received just one seed crop. However, there was an abundance of seedlings (in excess of 10 000 seedlings per hectare) throughout (Fig. 2). Retaining seed trees for one to two years resulted in only minor additional natural restocking; the same applied to retaining them

Table 1. Seedlings in disc-trenched furrows as per cent of all seedlings and by tree species. 1, 2, 4 and 8 are the retention years of seed trees. The inventory was conducted following the removal of the longest retained seed trees.

Tree species	1	2	4	8
Pine	93.5	97.7	95.2	96.4
Spruce	23.0	0.0	0.0	37.5
Downy birch, seed origin	99.0	98.0	92.9	96.0
Downy birch, vegetative origin	0.0	0.0	0.0	0.0
Silver birch, seed origin	93.4	91.6	100.0	100.0
Silver birch, vegetative origin	0.0	0.0	0.0	0.0
Rowan and willow	58.6	0.0	0.0	0.0

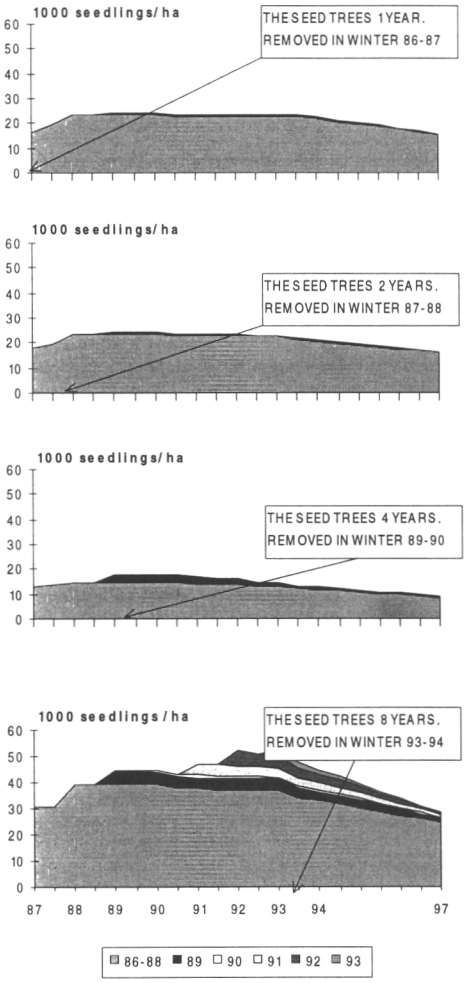

Figure 2. Number of seedlings emerging annually (years 1986-88 combined).

for two to four years. The seedling numbers changed most of all in the experimental plot receiving eight seed crops.

Monitoring of the numbers of annually emerging seedlings showed that the later the seedlings were born after the regeneration felling and site preparation, the less significance the later seed crops (shedding) had from the point of view of the resultant seedling stand (Fig. 3). Thus, new seedling stands would appear to be derived mainly from the seed shed during the first couple of years.

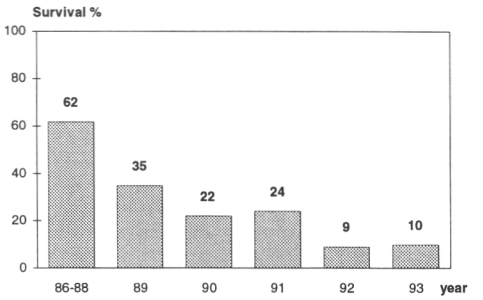

Figure 3. Survival in 1997 of seedlings emerging annually (years 1986-88 combined).

Restocking based on circular-plot inventory

The numbers of pine seedlings observed at circular-plot-based inventories (Table 2) were a little smaller than those obtained when assessing the restocking result along the disc-trencher furrows (Fig. 2). There were quite notable differences between the tree species, but the differences between the various retention times were not statistically significant in the light of the inventory carried out in 1994. Actually, the restocking outcome was fairly even and almost independent of the number of seed crops.

A similar inventory was conducted in 1997 at which point in time three years had elapsed from the previous inventory and the age of seedling stand was 11 years. Clear differences (Table 3) were observed between the experimental plots, especially such that the number of pine seedlings over 1.3 m in height was at its minimum underneath seed trees that had been retained for the longest period.

Seedling height

Seedling height, too, was observed to vary according to experimental plot (Table 4), and the differences were statistically signif-

Table 2. The number of seedlings per hectare observed at circular plot inventory in 1994. 1, 2, 4 and 8 are the retention years of seed trees. The inventory was conducted following the removal of the longest retained seed trees. p = statistical significance.

Tree species	1	2	4	8	p
Pine	14 740	17 080	11 280	16 080	0.31
Spruce	260	320	340	320	0.94
Downy birch, seed origin	6 240	3 060	4 500	1 480	0.06
Downy birch, vegetative origin	860	460	380	180	0.18
Silver birch, seed origin	1 820	1 420	800	960	0.37
Silver birch, vegetative origin	180	0	0	160	-

Table 3. The number of seedlings per hectare in different height classes in 1997. 1, 2, 4 and 8 are the retention years of seed trees. The inventory was conducted three years after the removal of the longest retained seed trees. p = statistical significance.

Tree species	1	2	4	8	p
Pine, >1.3 m	5 580	3 140	1 860	580	0.0001
Pine, 0.3 - 1.3 m	9 920	11 740	8 860	9 820	0.53
Spruce, all seedlings	360	380	560	1 880	0.03
Downy birch, >1.3 m	2 580	1 480	1 920	400	0.02
Silver birch, >1.3 m	1 420	740	540	420	0.03
Other broadleaves, >1.3 m	220	420	520	340	0.40

Table 4. The mean seedling height (cm) in 1994 after the removal of the longest retained seed trees. 1, 2, 4 and 8 are the retention years of seed trees. p = statistical significance.

Tree species	1	2	4	8	p
Pine	52	42	45	20	0.001
Spruce	28	48	28	19	0.011
Downy birch, seed origin	70	70	80	49	0.001
Downy birch, vegetative origin	240	185	216	192	0.036
Silver birch, seed origin	120	88	120	67	0.001
Silver birch, vegetative origin	379	-	-	195	-
Rowan and willow	90	75	99	112	0.066

icant for all tree species. Retaining the seed trees for one to four years had only a minor effect on the mean seedling height as measured at eight years, but retaining the seed trees for four to eight years reduced mean height of pine seedlings by more than 50%. A fall in mean seedling height was also observed with silver birch and downy birch between retention of four and eight years.

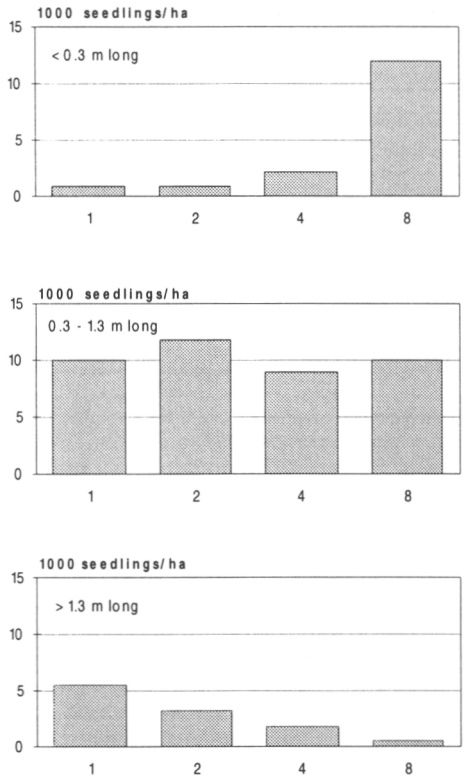

Fig. 4. The height of pine seedlings in different height classes three years after the removal of the longest retained seed trees. 1, 2, 4 and 8 are the retention years of seed trees.

The next inventory, conducted three years later, showed that the differences were still statistically significant on part of the conifers, but not in the case of broadleaves over 1.3 m in height (Table 5). The result was especially evident for pine restocking (Fig. 4). Seedlings below 0.3 m in height were abundant, but seedlings over1.3 m in height were relatively few in number on plots where seed trees had been retained for eight years. There were no big differences in soil texture (Fig. 5) or in soluble or total nutrients (Fig. 6) e.g. between the areas where seed trees were retained one or eight years.

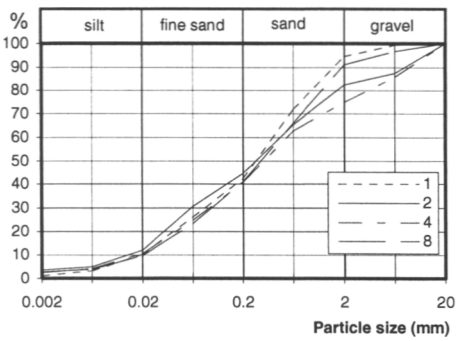

Fig. 5. Cumulative particle-size curves measured from different experimental plots. 1, 2, 4 and 8 are the retention years of seed trees.

Table 5. The mean seedling height (cm) in 1997 by heigh classes three years after the removal of the longest retained seed trees. 1, 2, 4 and 8 are the retention years of seed trees. p = statistical significance.

Tree species	1	2	4	8	p
Pine, >1.3 m	171	163	158	150	0.001
Pine, 0.3 - 1.3 m	76	77	85	60	0.0001
Spruce, all seedlings	52	62	39	17	0.0001
Downy birch, >1.3 m	249	214	222	210	0.06
Silver birch, >1.3 m	250	205	228	216	0.11
Other broadleaves, >1.3 m	161	173	184	176	0.38

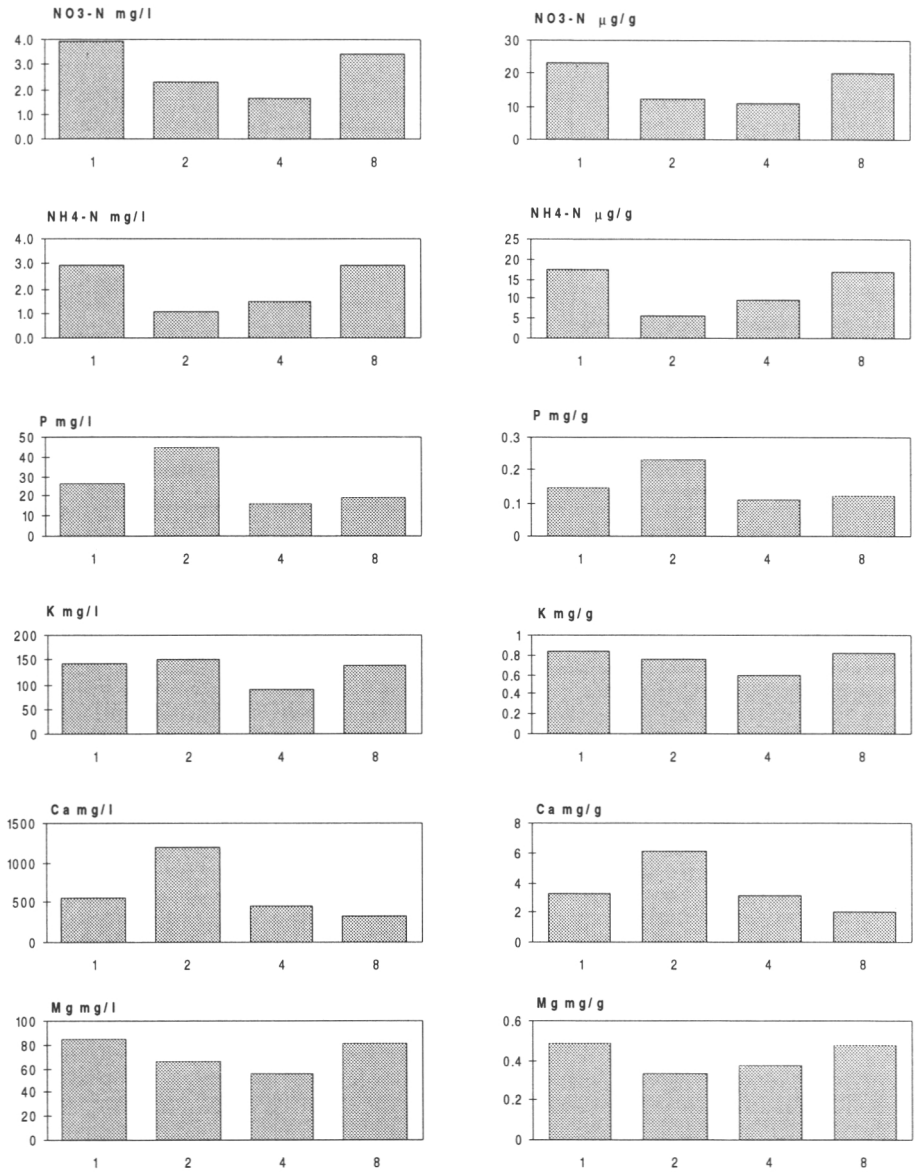

Fig. 6. Soluble (mg/l) and total (µg/g-mg/g) nutrients in the humus layer in 1997. 1, 2, 4 and 8 are the retention years of seed trees.

Discussion

Natural regeneration of pine takes place rapidly, even within one year, in the conditions prevailing during this experiment. No pronounced advantage was achieved by retaining the seed trees for two, four or eight years instead of one year. As observed in previous studies (Kinnunen and Mäki-Kojola 1980, Valtanen 1984, 1985, 1988), the bulk of the seedlings grew in the prepared soil.

The greater number of annually emerging seedlings died, the more time had elapsed between seedling emergence and regeneration felling and site preparation, re-

spectively. The result that a new seedling stand would appear to be derived mainly from seed shed during the first couple of years is interesting, and no previous observations of equivalent detail on this phenomenon exist.

When the seed trees were retained for between four and eight years, the impaired height growth of pine seedlings was quite evident when comparing the outcome to plots from which the seed trees were removed after one, two or four years since the regeneration felling. There were no statistically significant differences in the fraction of fine particles or nutrient content of the soil between the experiment plots. Also, the mean seedling height of the birch declined between four and eight years of seed tree retention.

As height-growth measurements were not conducted each year, it is not possible to indicate when exactly growth started to decline. However, this result is analogous with the observations of Valtanen (1984), according to which retaining seed trees for more than 6 years impairs the development of seedling stands. This effect may make itself felt even earlier. Lehto (1956) observed that even a drastically thinned overstorey to a large extent prevents seedling growth, and he drew attention the role of the competition among seedlings at the root level as an impediment to development. In accordance with the current silvicultural recommendations, the role of retention trees on regeneration sites should, indeed, be considered in relation to regeneration, biodiversity and landscape viewpoints.

On the basis of the results obtained in the present study, the removal of pine seed trees is recommended to be carried out within 1-4 years in conditions prevailing on dryish upland mineral-soil sites, unless one wishes to leave them on the site for biodiversity or landscape reasons. In that case prolonged retention of seed trees reduces the height growth of pine seedlings. However, the preconditions for rapid, natural regeneration are the availability of a quantitatively and qualitatively adequate seed crop and the carrying out of site preparation. The presence of seedlings should be ensured by means of a reliable inventory before removing the seed trees.

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STRUCTURE AND DYNAMICS OF AN OLD-GROWTH CONIFER FOREST ON THE RISING BOREAL COASTLINE

Johan Svensson



Svensson, J. 1998. Structure and dynamics of an old-growth conifer forest on the rising boreal coastline. New stand types in boreal forestry. Metla, Research Papers 714: 55-62.

It is obvious that a paradigm shift is occurring in forestry, towards practices that favour diversity and long-term ecosystem sustainability, and where the principles of management are developed on a firm knowledge base of natural processes. However, forested ecosystems that could potentially be used as models for understanding of the natural processes, i.e. pristine or long-term naturally developing ecosystems, are rare in the Nordic boreal zone. Furthermore, analyses of natural succession and dynamics need to be derived from an identification and description, in time and space, of a starting point from which the processes are originated.

Along the Gulf of Bothnia, the coastlines are rising due to isostatic rebound, and new land is continuously being added to the coast. The ecosystems that colonize the emerging land are experiencing a primary succession including pedogenesis. Coastal forests can be found that have had little or no disturbance by man. In some instances, newly raised land becomes commonly owned by the inhabitants of a village, in other cases the new land is located on isolated areas, on islands or far from settlements, or on private land where the owner has chosen not to harvest.

These forests present an excellent opportunity to examine natural succession and dynamics, and to classify stages of structural development. The ongoing land uplift provides the time-sequence needed for the successional and dynamic approach. The highest rate, 9 mm annually, occurs along the coastal area on the northern part of Västerbotten and the southern part of Norrbotten. The known rate offers the possibility to age any particular spot by measuring its elevation above sea level. The moraine, less exposed shores are especially relevant to use for scientific exploitation, since these sites are quite productive with a rapid and extensive vegetation colonization and succession.

A study conducted at the coast in the vicinity of Umeå, Västerbotten, reveales that it is possible to find sites with up to at least 300 years of undisturbed forest development, resulting in a dense, old-growth spruce (*Picea abies*) forest that contains all the attributes from initial establishment to natural secondary regeneration in tree-fall gaps.

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Introduction

The paradigm shift moves forestry towards practices that favour diversity and long-term ecosystem sustainability, and the principles of management are developed on a firm knowledge base of natural processes, i.e. disturbances, succession and dynamics (cf. Grumbine 1993, Franklin 1994, Schlaepfer et al. 1994). However, forested ecosystems that could potentially be used as models for understanding of the natural processes, i.e. pristine or long-term naturally developing ecosystems, are rare in the Nordic boreal zone (Nord 1994). Furthermore, analyses of natural succession and dynamics need to be derived from an identification and description, in time and space, of a starting point from which the processes have originated.

Along the Gulf of Bothnia, the coastlines are rising due to isostatic rebound, and new land is continuously being added to the coast. The ecosystems that colonize the emerging land are experiencing a primary succession including pedogenesis (Ericsson 1981, Cramer 1985, Verwijst & Cramer 1985). The ongoing land uplift provides the time-sequence needed for the successional and dynamic approach. The highest rate, 9 mm annually, occurs along the coastal area in the northern part of Västerbotten and the southern part of Norrbotten (cf. Okko 1967, Ehlert 1982). The known rate offers the possibility to age any particular spot by measuring its elevation above sea level (Carlsson et al. 1990, Starr 1991). The less exposed shores with morainal deposits are especially relevant to use for studies, since these sites are quite productive with a rapid vegetation colonization and succession to dense forest (cp. Ericson & Wallentinus 1979). In spite of the fact that most of the coastal forests are relatively young, the old-growth forests than can be found contain several rare and threatened species. This is owing to considerable amounts of dead wood (Suomi et al. 1997).

Scope of the paper

In this paper, some of the structural features of an old-growth spruce forest on the Västerbotten coast will be described and discussed. The main problem that is elucidated is whether it is possible to find forests that have had no disturbance by man and that represent a time-sequence long enough to cover the essential stages of forest dynamics. Further, if it is possible to use such forests as reference plant communities for understanding of the natural processes, i.e. the ecological fundaments for new forestry principles.

This paper deals with some of the results from a PhD-project entitled "Primary Succession and Dynamics in Virgin Forest Ecosystems on a Rising Boreal Coastline", funded by the faculty of Forestry, SLU and by Stiftelsen Oscar och Lili Lamms Minne.

Study site and methodology

A study has been conducted at the coast in the vicinity of Umeå, Västerbotten province northeast Sweden. The data, presented and discussed here, is from one plot, 30 x 35 meter, 1050 m², on a former island in the inner archipelago of Sörfjärden Bay (63°49'N and 20°41' E). This plot is one of three plots in this study area on islands of different age. In addition, 17 transects covering the vegetational gradient from the sea shore into the forest are included.

In the plot, all elements 0.5 m and higher, and logs 5 cm in diameter and larger, have been located and recorded. Elements

Table 1. Element density [no/ha], basal area [cm²/ha] at 1.3 m for live, declining and recently dead elements and at root collar for snags, logs and stumps, and stem volume [m³/ha] (n = 1207).

	All species	Spruce only
Element density	11.500	9.100
Basal area (1.3 m)	45.4	45.3
Basal area (root neck)	26.0	5.4
Stem volume for live and declining	365	364
Stem volume for snags	24	8
Stem volume for logs	52	31

are regarded as woody stems that are distinct at the ground surface. These may have originated as seedlings or as vegetative shoots. The latter is very common for most woody species under these conditions. The elements were separated into 23 different categories, including 6 height-classes of live, declining and recently dead, and 5 categories of old dead elements such as snags, logs and stumps.

Age has been detemined for randomly chosen 173 of 219 live and declining spruces 2 cm (DBH) and larger. The cores were taken at 0.25 m above ground.

The plot represents land that is between 100 and 300 years old, completely dominated by Norway spruce (*Picea abies*). However, the oldest parts of this land emerged from the sea at a stage with higher exposure. The land uplift has changed the surroundings since then. Since the colonization of woody plants, especially spruce, is delayed in more exposed sites (cp. Ericson & Wallentinus 1979), we can not expect a 200 year spruce development, but rather a 125 to 150 year development. Presently, the forest structure is heterogenous, dense and old-growth like and contains all the attributes from initial spruce establishment to natural secondary regeneration in gaps that have arisen from the death of dominating trees. No traces of human-related disturbances have been detected.

Preliminary results and discussion

The density of the forest can be described by density of elements, basal area and stem volume. Some basic data is given in Table 1. The total dominance of spruce is obvious, except for the dead wood component. Nevertheless the proportion of dead spruce wood exceeds 10 % of the total spruce wood component. Other woody species present are grey alder (*Alnus incana*), rowan (*Sorbus aucuparia*) and juniper (*Juniperus communis*), of which the first two species build up a considerable proportion of the total dead wood component. These three species occur frequently in earlier successional stages on the rising coastlines, but are replaced by spruce on more elevated land (Ericson 1980, Cramer 1985).

Table 2. Vertical distribution of spruce elements [no|ha] (n = 904).

Height-class (m)	Live	Declining	Recently dead	Total
1: 0.5 - 1.3	1640	890	2420	4940
2: 1.4 - 2.9	1280	520	370	2170
3: 3.0 - 5.5	410	90	70	560
4: 5.6 - 10.9	280	120	20	420
5: 11.0 - 16.0	120	70	0	190
6: 16.5 - 22.0	280	50	0	320
Total	4000	1730	2880	8610

The vertical distribution of spruce elements is presented in Table 2. It is obvious that a very large proportion of the live, declining and recently dead elements are present in the lower height-classes. Thus, the height distribution shows a inverse J-shaped pattern, the median spruce is 1.2 m high and the average 2.7 m. The maximum height is 22.0 m. Also the diameter distribution shows the same pattern, where the median spruce is 1 cm DBH and the average 3.5 cm. The largest live spruce is 53 cm DBH and the largest dead spruce 63 cm at root collar. An obvious dynamics is going on amongst the lower height-classes, but also in the higher classes some 10 % of the trees is declining or dead.

The age distribution shows almost a normal distribution (see Fig. 1). The median spruce is 42 years old and the average 48. The oldest live spruce is 106 years. There are some more or less obvious peaks in the age distribution, with an interval of almost 20 years. The long intervals can partly be explained by good seed crop years, which can occur at intervals of 6 to 13 years in average in these parts of the boreal zone (Sarvas 1968, Koski & Tallqvist 1978, Leikola et al. 1982) and partly by the necessity of good establishment conditions that coincide with the good crop (Junttila & Skaret 1990).

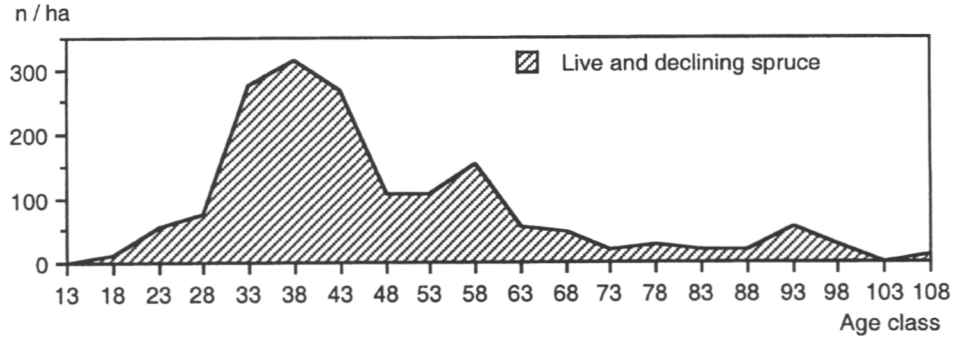

Figure 1. Age distribution of spruce aged at 0.25 m above ground [no|ha] (n = 173).

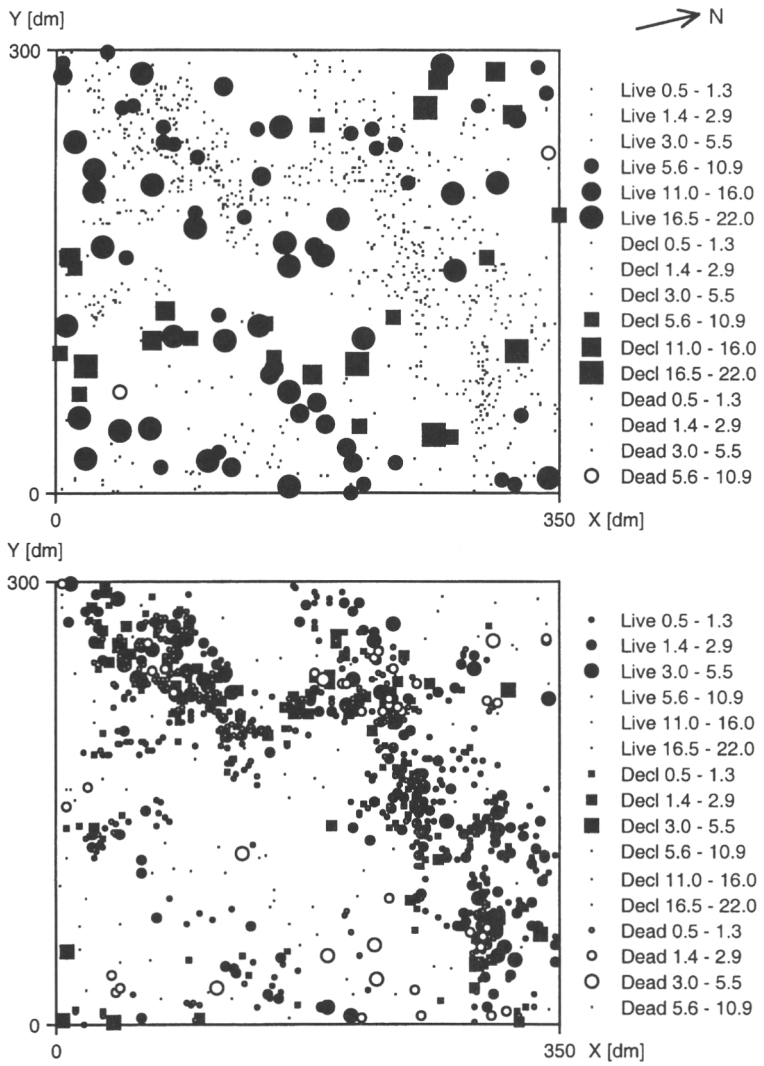

Figure 2. Spatial and vertical distribution of live, declining and recently dead spruce (n = 904). The above plot-graph shows the top three height-classes, and the below the three lower.

Figure 2 shows the spatial and vertical distribution of spruce. Elements in the top three height-classes, encompassing the top three quarters of the stand height (> 5.5 m), show a random distribution, but elements 5.5 m and less show a contagious distribution, almost perfectly filling up the openings left by the bigger trees.

This can also be revealed by the use of the coefficient of dispersion, the variance/mean ratio (Meyer 1933) (see Fig. 3). When the ratio is close to 1 the distribution is random, when it is less than 1 it is regular, and when it is more than 1 it is contagious. Here, a marked difference between the two low height-classes and the ones above is obvious. Height-class 3, elements 3.0 to 5.5 m, can be regarded as intermediate. In this fig-

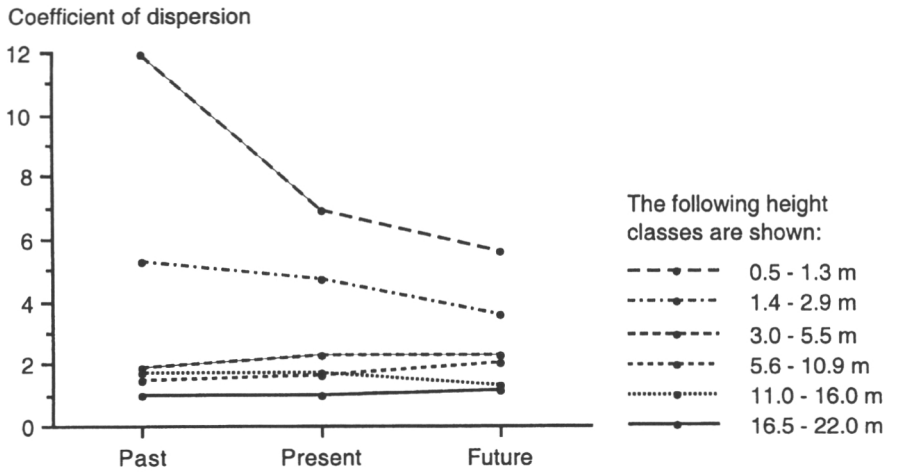

Figure 3. Coefficient of dispersion for different height-classes of spruce. The interpreted time sequence: Past structure = recently dead + declining + live elements; Present structure = declining + live elements; Future structure = live elements (n = 904).

ure a interpreted time-sequence is introduced (see figure text). Then, the most obvious change is occuring among elements less than 3.0 m high, where severe competition results in outdying of trees and a trend from contagious to random distribution. Of course, during this time-sequence some migration of elements to the next height-class should be regarded.

Conclusions

Based on the structural features of a forest on the rising coastline of Västerbotten, northeast Sweden, it is concluded that forests can be found that have had no disturbance by man, and that represents a time-sequence long enough to cover the essential stages of spruce dynamics. A survey (report in prep.) reveals that a high proportion of the private owned land is pristine or old-growth like with only small-scale man-caused disturbances (low intensity, scattered). Frequently, narrow zones of young to middle-age untouched spruce forests can be found. Older untouched stages are not so common, but do exist. These long-term and undisturbed successional sequences represent an excellent opportunity to examine natural succession and dynamics, and to classify stages of structural development of old-growth forests.

In some instances, newly raised land becomes commonly owned by the inhabitants of a village, in other cases the new land is located on isolated areas, on islands or far from settlements, or on private land where the owner has chosen not to harvest. We should remember that the inhabitants of coastal villages in the past, were fishermen and small-scale farmers. They were not depending on the forest for their economic life. They were depending on their forests mainly for small-scale harvesting for fuel wood and other purposes.

One main disturbance factor that has to be mentioned, is domestic grazing. This land-use clearly has affected the coastal forests over vast areas. But still, we can find forests that have had only minor grazing impact in the past, or an impact equivalent to the present one by wild animal browsing.

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FOREST MANAGEMENT AND THREATENED SPECIES

Erkki Annila



Annila, E. 1998. Forest management and threatened species. New stand types in boreal forestry. Metla, Research Papers 714: 63-70.

Starting from European ministerial conference in Strasbourg in 1990 the biodiversity has been one of the most important issues in the international discussions of forest management in this decade. Although the consequences of the management of the boreal coniferous forests have not been as dramatic as in tropical rainforests, it has been found that populations of some species have declined and even disappeared in commercially exploitted forests.

Some countries e.g. Finland, Sweden and Norway, have listed the threatened species. In Finland, the total number of species is about 50 000, and one half of them has been estimated to live in forests. So far the number of species threatened by forestry, including peatland drainage, is about 900. This means that 3,6 % of the forest species has been endangered by forest management. In Sweden and Norway the figures are about the same.

More than one half of the threatened forest species is occuring in special habitats. These habitats are called keybiotopes because they are crucial to many species. About one quarter of the threatened Finnish species, especially vascular plants and mosses, are living in the herb-rich forests. In Sweden, the southern decidious forest contains the most threatened species. Nevertheless the forest fires have been rather common in the past, relative few species (about 2 % of the threatened species both in Sweden and Finland) are endagered by efficient fire control.

One third of the threatened species is dependent on dead wood and hollow trees. Dead wood is especially important for fungi and invertebrates like insects, as well as for cavity nesting birds and small mammals. When dead wood is excluded, less than 10 % of the threatened species is occuring in old natural or seminatural forests.

Although several new silvicultural practices have been introduced, relative little has been discussed how much the survival of threatened species can be improved with the new measures like tree retention, keybiotopes, dead wood etc.

About one third of the Finnish threatened species is very rare. Most of these species have been found only once or a couple of times in Finland, mostly in Åland or in the south-western part of the country. It is highly questionable whether the populations of these species can be increased with any measures.

Another third of the species is rare or unsufficiently known. There is no excact evidence of the decline of the species. It is not known whether the species were more common before large-scale forest management was started. It is likely that the decline of the species can be prevented with renewed silvicultural methods.

The rest of the species was more or less common at the time when relative large forest areas were still in natural or seminatural state. There is good reason to believe that the living conditions of the species will be gradually improved.

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Background

It has been known for a long time that species have became extinct as a result of human activities. The ecological importance of species disappearance gained concrete form when tropical rain forests started to be exploited commercially. After clear cutting, rain forest has often changed into a completely different type of ecosystem. Although the consequences of the management of boreal coniferous forests have not been as dramatic as those of rain forests, the populations of some species have declined and even disappeared in commercially exploited forests.

The biodiversity of the boreal forests is based on the relatively large variation in space and time. It is relatively easy to understand the variation between different site types: each biotope has its own composition of plant species, depending on the site factors. The range of variety in the animal kingdom, and in fungi and microbes is mainly regulated by the vegetation, primarily by the trees.

What is much more difficult to understand is the variation over time, i.e. successional diversity. The problems are mainly caused by the long time period, usually stretching for hundreds of years, which is needed for complete passage of the succession process from open ground to old-growth forest. Depending on the succession stage there may be totally different types of forest on similar sites. Because forest management in most cases interferes with forest succession, people consider that the forest ecosystem is irreversibly changed by man.

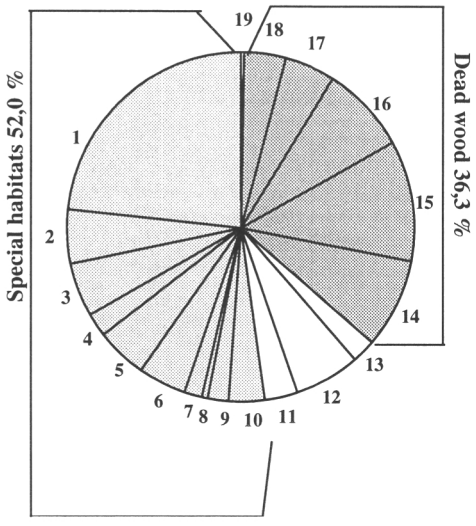
Threatened species

During the past few decades the populations of certain species living in forests have decreased to such an extent that they are now considered endangered or threatened. The relative and total numbers of the more common species have also changed (Kouki 1994), but the species which are in danger of disappearing are more evident when evaluating the effects of modern forestry. Although the proportion of threatened forest species is so far low, and the boreal forest ecosystem in the Nordic countries is not yet threatened, it is clear that a number of species will gradually disappear if wood production is the only criterion taken into account.

Some countries e.g. Finland, Sweden and Norway (Komiteamietintö 1991, Ehnström et al. 1993), have listed their threatened species. In Finland, the total number of species is about 50 000, one half of which are estimated to live in forests. So far the number of species threatened by forestry, including peatland drainage, is about 900. This means that 3,6 % of the forest species are endangered by forest management. In Sweden and Norway the figures are about the same. Considering the heavy cuttings and other practices employed by modern forestry, the figure is amazingly low. Compared with the situation in the tropical rain forests where forest cuttings have often resulted in the total disappearance of an ecosystem, it is clear that the methods used in our forests are not in complete contradiction with the natural dynamics and succession of the forests.

Key biotopes

More than half of the threatened forest species occur in special habitats (Fig. 1). These habitats are called key biotopes, because they are crucial to many species. About one quarter of the threatened Finnish species, especially vascular plants and mosses, live in herb-rich forests. In Sweden, the south-



Special habitats:
1. Herb-rich forests 23,4 %
2. Quercus forests 4,8 %
3. Meadows 5,2 %
4. Eskers 2,0 %
5. Rocky slopes 4,7 %
6. Eutrophic mires 4,6 %
7. Spring surroundings 1,6 %
8. Riparian zones 0,6 %
9. Herb-rich forest mires 1,9 %
10. Mires 3,2 %
11. Seminatural forests 3,2 %
12. Natural forests 6,2 %
13. Burnt areas 2,0 %

Dead wood:
14. Coniferous 8,5 %
15. Broadleaved 10,9 %
16. Coniferous/broadleaved 8,0 %
17. Old Populus 4,8 %
18. Quercus/ulmus etc. 3,9 %
19. Old living trees 0,3 %

Figure 1. Distribution of the Finnish species threatened by forest management according to habitat.

ern deciduous forest contains the greatest number of threatened species (Berg et al. 1994). The other key biotopes are *Quercus* forest, forest meadows, eskers, rocky slopes, spring surroundings, riparian zones and certain types of mire.

Most key biotopes are situated on moist sites. The conditions on these sites are rather stable and have rarely been changed by catastrophic disturbances like forest fire or storm damage. This has resulted in the species becoming more specialized than those in areas that are relatively frequently subjected to disturbances. The rotation period of managed forest ranges from 70 to 120 years, and in northern parts of the region even 150 years, regardless of the forest site type. The rotation time in natural forests varies considerably depending on the water conditions of the site. Pine forests on dry sites have been burnt by forest fires at average intervals of 50 years (Zachrisson 1977). In contrast, the time between fires on moist sites has been several hundred years. In commercially exploited forests eutrophic mires, spruce swamps, wet meadows, riparian zones, rocky slopes etc. have often been altered by clear cutting or ditching to such an extent that certain species can no longer survive on such sites. Because such sites are often located at considerable distances from each other, some species have difficulties in finding a new place to live and breed in when their original habitat has changed too much.

The best way to maintain the species assemblage in the key biotopes is to leave these habitats in a completely natural state. However, they can be managed by selective cuttings only in order to maintain the prevailing conditions, for instance the light conditions in herb-rich forests. Forest conservation should be concentrated on moist sites where the natural rotation is longer than that in managed forests. In actual fact, it is a rather unnatural situation to keep a pine forest on a dry site for longer than 120 years. It has been reported that some dry

heaths are currently considerably more fertile than earlier. One reason for this may be that they have not burnt for a long time, and litter and humus have accumulated in the soil.

One crucial point is how close to each other the keybiotopes should be in order to ensure that the species and populations maintain contact with other populations. Because key biotopes are sporadically distributied in a natural environment, most species have a good ability to spread from one habitat to another. For instance, the spores of the root rot fungus (*Heterobasidion annosum*) can easily spread for hundreds of kilometers (Kallio 1970, Stenlid 1994) even though its fruit bodies are located in the soil beneath the tree roots. On the other hand, some insects living in dead wood can hardly move more than a few kilometers (Økland et al. 1996). All potential key biotopes should be left out of the sphere of commercial forestry in the future, regardless of their present state. The role of small habitats, key biotopes, has been underestimated in conservation biology.

Dead wood

One third of the threatened species are dependent on dead wood and hollow trees. Dead wood is especially important for fungi and invertebrates like insects, as well as for cavity nesting birds and small mammals. From the biodiversity point of view, aspen (*Populus tremula*) is the most valuable tree species. Because aspen causes many problems in forest regeneration and forest protection, it should preferably be saved as small stands whenever possible. These separate stands could be treated like key biotopes.

The most striking difference between managed forest and natural woodland is in the amount of dead wood, especially coarse woody debris, i.e. snags and logs of large diameter. In natural old-growth forests this component often amounts to more than 100 cubic meters of dead wood per hectare and, after a catastrophic disturbance such as a forest fire or heavy storm, it may rise to much higher levels (Peterken 1996). Dead wood has been one of the most widespread (in space and time) and richest resource in the forests. Its role in coniferous forests is greater than that in deciduous forests. In general, much less dead wood accumulates in broad-leaved stands than in coniferous stands: the input rates are slower and decay is faster. It is therefore easy to understand that many species in coniferous forests have become adapted to utilizing dead wood as food and shelter. The decay and disintegration of a large dead conifer may last for more than 100 years. During this period a wide range of insects and fungi, for instance, can utilize the decaying wood (Ehnström & Walden 1986).

Modern forestry, often called the Scandinavian model, is largely based on two or three thinnings before the final cutting. Achieving a higher yield is not the only reason because it is also important to maintain a high level of forest hygiene. About one third of the total amount of timber produced during the whole rotation - about 150 cubic meters per hectare - is harvested in thinnings (Vuokila & Väliaho 1980). Most of the trees cut in thinnings are weak, dominated or dying individuals, i.e. the major source of the dead wood in the early successional stages of the forest. In managed forests the amount of dead wood is usually less than 10 cubic meters per hectare (Martikainen et al. 1996). According to studies made in spruce stands in Finland, dead wood starts to accumulate when the trees reach an age of 30 years (Isomäki 1995). In the absence of thinnings the amount of dead wood increases to 60 cubic meters per hectare during the next 30 years.

Attempts to increase the amount of decaying wood are in contradiction with the aims of wood production. However, if the survival of species dependent on dead wood is to be ensured, then it is necessary to increase the amount of decaying wood. Individual dead and dying trees can be saved and some living trees left to grow and gradually decline. Tree retention in regeneration cutting areas is already a common practice. Retaining trees in groups or small stands seems to be more reasonable than to leave solitary trees which are susceptible to wind. Furthermore, dead wood will gradually accumulate in key biotopes if these habitats are left completely untouched. Considering the spreading ability of saproxylic species, suitable dead wood should be located at a distance of one or two kilometers.

Forest fires

Although forest fires were rather common in the past, relatively few species (2 % of the threatened species) are endangered by efficient fire control. The figure is the same in Sweden (Berg et al. 1994). One explanation for the relatively low number could be that several species which originally lived in burnt areas can survive in clear cut areas (Bakke 1996). Ahnlund & Lindhe (1992) found 31 threatened species on a clearcut area containing snags and logs, and 27 species on burnt areas of different age.

Old-growth forests

When dead wood is excluded from the characteristics of old-growth forest, less than 10 % of the threatened species occur in old, natural or semi-natural forest. It would appear that the conditions in mature commercial forests from the age of 70 years onwards are rather similar to those in natural old-growth forests if there is sufficient decaying wood. Some birds need fairly large areas of natural old-growth forest (Virkkala et al. 1994), but most threatened plants, fungi and invertebrates can probably survive in relatively small habitats such as key biotopes.

In conclusion, there are three main reasons for the decline of species: heavy exploitation of key biotopes, effective and selective thinnings, and a short rotation period on most sites. However, there are also many forest practices which have only a very marginal effect on decreasing biodiversity. Because the reasons for species decline are often more or less unclear, almost all the forest practices employed by modern forestry have been considered harmful to forest biodiversity.

Clear cutting

Clear cutting is one of the practices which has been strongly criticized. However, open ground is extremely important for the forest fauna and flora. In the Yellowstone National Park, for instance, the number of species in recently burned areas was greater than that in the preceding mature forests (Taylor 1973). The total number of plant species is the highest in the early stages of growth, and the lowest when the old tree generation starts to decline (Sirén 1955). Some insect groups and spiders favour open ground, whereas wood-rotting fungi seem to be more specialized to old-growth forests. Generalist species utilize almost all the successional stages, whereas most specialist species seem to breed only in either the early successional stages or the mature and old-growth stages. Species diversity tends to be lowest in the sapling and pole stage.

When attempts are made to promote threatened species by changing management practices, all species should be taken

into consideration in order to ensure some other species do not become threatened. If, for instance, selective cutting were to be used instead of clear cutting on normal forest land, the forest diversity will decrease. In northern Sweden, for instance the abundance of wood-rotting fungi is still rather poor in old-growth forest even one hundred years after selective cutting (Bader et al. 1995). It is dead wood of large diameter which is needed, and there will never be enough if we regularly remove all the large trees. Selective or gap cutting in commercial forests is an alternative on the most fertile and moist sites where natural regeneration is sufficient.

Efficiency of new practices

Relative little has been discussed about how much the survival of threatened species can be improved by means of new forestry practices. About one third of the Finnish threatened species are very rare (Fig. 2). Most of these species have been found only once or a couple of times in Finland, mostly in the Åland Islands or in the south-western part of the country where there are *Quercus* forests and other southern broad-leaved tree species such as *Acer, Ulmus, Tilia, Fraxinus and Corylus*. It is difficult to draw any definite conclusions about possible declines when only a few findings are available. These threatened species occur on the northernmost edge of their distribution. They are more common in southern latitudes or eastern longitudes. In the northern climatic and geological conditions they are threatened by natural events. It appears to be very difficult to make them more numerous. The extremely rare species are, of course, often very vulnerable.

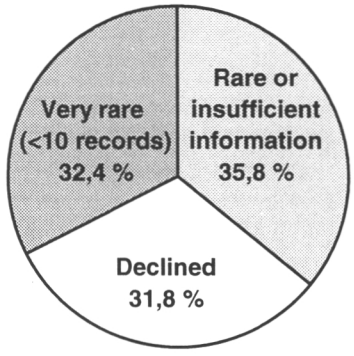


Figure 2. Occurrence frequency of the species threatened by forest management in Finland.

One third of the species are rare or insufficiently known. There is no exact evidence of a decline in these species. It is not known whether the species were more common before the start of large-scale commercial cuttings. However, a decline in these species could probably be prevented by means of reformed silvicultural methods.

All of the other species were more or less common at the time when relatively large forest areas were still in a natural or semi-natural state. This catecory includes disappeared, endangered and vulnerable species. It has been demonstrated that management practices are the primary or secondary cause for the species becoming threatened. There is good reason to believe that when the conditions they require gradually improve, the populations of these species will recover.

Overall, a relative large amount of information is available about the qualitative aspects of improving the living conditions of threatened species and preserving biodiversity in managed forests. However, the quantitative aspects are, in most cases, more or less obscure, especially on the landscape level. More research and experience are needed to resolve these problems.

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THE INFLUENCE OF SILVICULTURAL MANAGEMENT ON BIODIVERSITY IN THE HERB LAYER OF DANISH BEECH FORESTS

Jørgen Bille-Hansen



Bille-Hansen, J. 1998. The influence of silvicultural management on biodiversity in the herb layer of Danish beech forests. New stand types in boreal forestry. Metla, Research Papers 714: 71-78.

The public community shows an increasing concern for the biodiversity of managed forests as opposed to natural forests. In Denmark, where only patches of natural forests have been preserved, we are left with a limited knowledge of the species composition and the interrelating processes in natural forests. As a consequence Danish research initiatives have focused on either the study of dynamics in the small natural forest or near natural forests, as opposed to managed forest, or the study of forests subjected to different management intensities. In the framework of an interdisciplinary research initiative, "Man, Landscape and Biodiversity", a series of projects concerning herb layer vegetation in beech forests have been planned or initiated.

- One long-term study has focused on the vegetation changes in the same mature beech stands from the early 1920's to mid 1990's. One of the main results, so far, was that the new species were more tolerant for light and equally adapted to forests and disturbed substrates, which indicate that the main flora response was to management, thinnings and other disturbances.
- In another study we followed the vegetation changes through a rotation. The thicket phase was recognised as the most critical phase for determining the species composition in mature beech stands.
- We are in progress of studying the effect of different methods of cultivation on the species composition. The methods applied in practice, which may include chemical treatment and soil preparation, could have a profound influence on the species composition especially in the first part of a rotation. This method of cultivation is, in our study, opposed to natural regeneration in gaps.

Focus will be on our main aims and hypotheses, as well as the current results.

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Introduction

The natural deciduous forest cover in Denmark belongs to the nemoral vegetation zone. Beech (*Fagus sylvatica* L.) and oak (*Quercus robur* L.) are important overstory species in the semi-natural forests in most parts of the country. In the last nearly 200

years they have been managed as high forest. The typical silvicultural system used in these even-aged homogenous stands is the shelterwood system. The natural regeneration is usually initiated by scarification and shelterwood thinnings in years with beech seed masts. In the years following regeneration regular thinnings of the stands are applied through the forest cycle almost until harvesting at a stand age of c. 110 - 120 years. Soil disturbances are frequent due to the use of heavy machinery in the management operations. In the last decades reports on changes in the forest floor vegetation have been attributed to acid atmospheric deposition. However, in other studies on herb layer vegetation both in conifers (Liu and Bråkenhielm 1996), as well in deciduous (Brunet et al. 1996), it was found, that species diversity was not significantly influenced by acidic atmospheric deposition. The changes observed were explained either as a consequence of natural processes or as a result of management (Brunet et al. 1996, Liu and Bråkenhielm 1996). Management including cutting, which results in increased light flux to the forest floor and soil disturbances, has an increasing effect on species number, although the increase is mainly by shade intolerant ruderals (Gove et al. 1992, Kjellson 1992). Canopy gaps with intact soil conditions have been found to undergo only small floristic changes, here are the existing species favoured by a relative higher light flux (Ehrenfeld, 1980). It has been shown, that the soil seed bank may become depleted, if a long period without fellings occur (Harris and Kent 1987). A traditional forest cycle in beech with natural regeneration is shown on Fig. 1.

The primeval forest of Denmark is not existing. The forest area reached a minimum in 1805 A.D., where less than 3% of the total area was made up of forest. The decrease in the forest area took pace during Medieval and Early Modern times (Fritzbøger 1994), it was profoundly influenced by traditional rural woodland management, like pannage, pasture, coppicing, etc. The different management types were

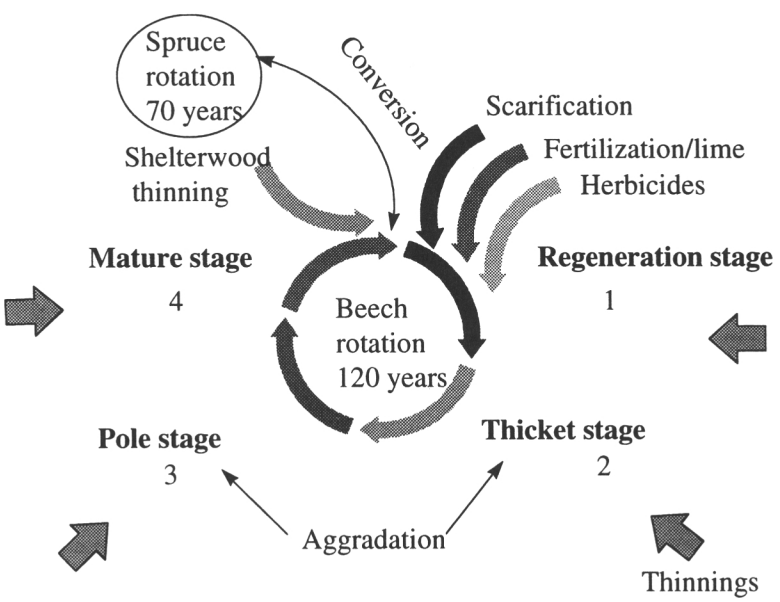

Figure 1. A traditional forest cycle for beech in Denmark.

often intermingled, thus making up a mosaic of different management types. In the early 19th century the remaining forests, where enclosed, and only used for wood production. Since that time the forest area has increased to its present day level of c. 12%. Then, the forests in Denmark are heavily influenced by man. Around half of the forests are exotic conifer plantations, and only an area of about 1% of the total area of Denmark originate from pristine forest (The National Forest and nature Agency, 1994). The forest cycle of pristine or near-nature forest has been investigated in Suserup forest, in relation to structure, mensurational dynamics (Christensen and Emborg 1996, Emborg et al. 1996), historical justification (Fritzbøger and Emborg 1996) and distribution of soil nutrients to former land use (Vejre and Emborg 1996). No account of the forest floor vegetation has been attempted. From other studies of deciduous forest it is known, that some herbaceous plants are able to survive for extended period of time. It is however an open question, if the present day distribution of herbaceous plants as such, viz. the vegetation, can be taken as pointer for the vegetation dynamics of pristine forests. On the contrary the vegetation could be in a transition between the Medieval- early 19th century rural forest management and a pristine forest. The near-nature forest cycle as described from Suserup forest is depicted on Fig. 2.

Research initiatives, objectives, hypotheses.

In the framework of an interdisciplinary research initiative, "Man, Landscape and Biodiversity - Boundaries in the Landscape", where agronomists, jurists, philosophers, historians, economists, foresters, so-

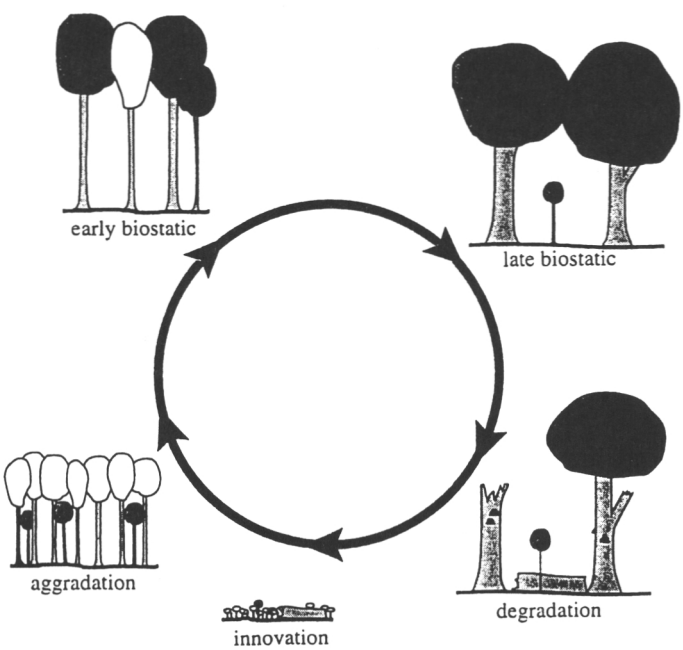

Figure 2. The near-nature full forest cycle, duration c. 280 years, as described from Suserup forest. (Christensen and Emborg 1996).

ciologists, zoologists and botanists have merged and in conjunction will try to elucidate the barriers and the short cuts laid down by the nature as well as the community for increasing the biological/ecological diversity in 3 parishes. These parishes have been selected as an workshop area reflecting the whole country, although in a small scale.

The main objectives/hypotheses connected to forestry for ongoing and planned research:

1. **Floristic continuity over one to several rotations: New or old woodland.**
   A prerequisite for the occurrences of primary woodland species is a continuous forest cover of several hundreds of years age (Hermy 1994).
2. **Vegetation changes through a rotation.**
   Could stages in a managed forest cycle itself be an obstacle to the occurrences of certain species, e.g. the light conditions. A higher light intensity at the forest floor would promote non-woodland species and lead to, that more competitive species would replace the primary woodland species.
3. **Management operations, e.g. intensity/frequency of thinnings.**
   Vehicle traffic in conjunction with management operations makes a disturbance of the forest floor. Primary woodland species are not adapted to this kind of disturbances, which in turn leads to competitive disadvantages. Plants adapted to disturbed substrates, as ruderals, will gain a competitive advantage over the primary woodland species. The light conditions at the forest floor are interrelated to management operations through the thinnings, which in turn effect the microclimate and perhaps recruitment from the seed bank (through increased light and/or disturbances of the forest floor).
4. **Previous conversions of forest compartments from one species to another; e.g. Beech → Norway spruce → Beech.**
   Woodland species have only a limited seed bank. A conversion to conifers will lead to disarmament of germinative capabilities of the seed bank.
5. **Method of cultivation/regeneration.**
   Cultivation is important in creating discontinuities. The kind of cultivation is considered important, meaning if it is with or without application of herbicides and scarification.
6. **Grazing by deer.**
   Grazing by deer will promote plant species, e.g. grasses, which are adapted to withstand browsing. Then, a heavy population of deer could promote vegetation changes not seen in nature near forests.

How far are we in meeting our objectives

1. An analysis of historical records on forest structure and continuity based on maps and records from 1770's and to present day has been initiated. Only two forests in the workshop area have such a long record.
2. In a study of 20 beech stands from the regeneration stages to old growth forest the number of species in one sample plot per stand was analysed. The sample plots, 50m x 50m, were chosen to represent the stands as adequate as possible. The vegetation was recorded in 20 subplots in each plot (Johansen and Bille-Hansen 1998). The frequency and cover of all vascular plants were estimated, but only the number of species in relation to stand age is shown on Fig. 3.
3. Management operations.
   Our study of the effect of forest management on herb layer vegetation was a repetition of studies from the 1920's and 1950's on the same 11 stands. In the 1920's the plots were of an age of 81 years in average (54 years (2 stands) to 132 years old).

Measurements of the environmental parameters in the 1923-sampling were done with state of the art methods of that time. No attempt has been done to repeat these analyses. Instead environmental conditions were described by using indicator values, 'Zeigerwerte', for vascular plants (Ellenberg et al. 1992). These values indicate the ecological optimum with respect to a certain environmental condition, such as light, temperature, moisture, pH, nitrogen supply, and for a given species its favoured sociological association, e.g. its main occurrence in vegetation type. For each condition the indicator values range from 0 to 9, moisture from 0 to 12. High and low values reflect high and low demand. Mean indicator values were calculated for each plot based on presence/absence data (Ellenberg et al. 1992, van Dobben 1993, Diekmann 1995, Hannerz and Hånell 1997) and for the DCA-analysis (Fig. 4) on the frequency data set (frequency sensu Raunkiær 1909, 1912 and 1916).

Species richness

In all but one plot the number of species has increased since the 1920s (Table 1). So, the trend during the eight decades was towards a more diverse herb layer vegetation ($P < 0.004$ paired t-test). The number of species has increased by a factor 1.3 to 4.3. Plot DE makes up an exception, in that almost the same number of species has been recorded at both occasions. This does not imply, however, that the same species have been re-sampled, for plot DE seven species have disappeared in the intervening years and eight species have been registered de nova.

There has been found no relation between the original species number and the number of new species occurring in 1990s, neither has there been found a relation between stand age, stem number or basal area and number of species in 1990s. By contrast, focusing on the new species recorded and the change in stem number between the

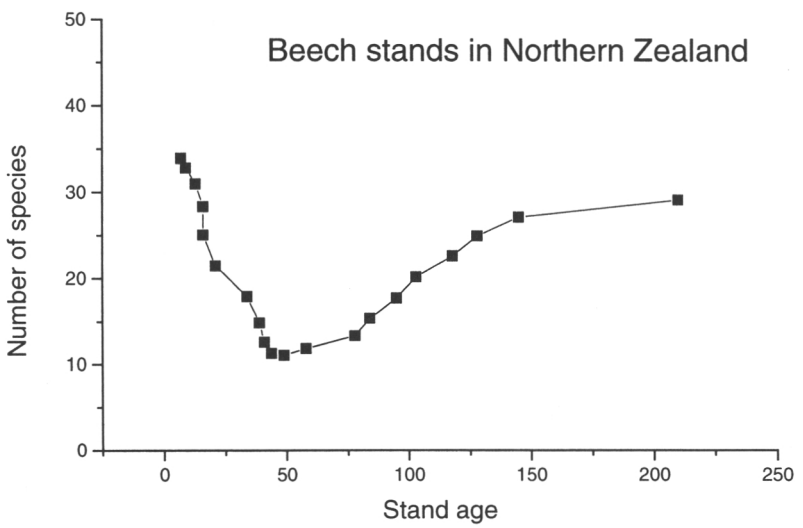

Figure 3. The average number of species in 20 subplots from the 20 beech stands, Hareskoven.

Table 1. Number of species in the plots in 1995 and number of new species and not re-recorded species in relation to the 1923-investigation.

	DD	DC	DF	BL	Q	R	K	M	DE	DEx	LN
No. of species in 1995	18	19	18	25	23	32	31	46	23	37	52
No. of species in 1923	4	10		9	7	23	24	15	22		
Increase in species no.	14	9		16	16	9	7	31	1		
Not re-recorded	0	0		1	2	6	7	1	7		
No. of new species	14	9		17	18	15	14	32	8		
% Species exchange	350	90		189	257	65	58	213	36		

mensurational characterisation in 1920s respective 1994 a significant relation appears. The additional number of species found in 1990s increases by decreasing stem number on the plots. This relation could imply, that the species number is influenced by management operations and/or light. The amount of light reaching the forest floor is among other parameters, dependent on the leaf area index which in turn has a relationship to the basal area, (Waring et al. 1982). There was a strong tendency to a negative relationship between the number of additional species and the difference in basal area between the mensurational characterisation in 1920 and 1994, $P< 0.053$.

Fig. 4 represents the result of a DCA-analysis (detrended correspondence analysis) of both the species and the stands (a mean indicator value for the stands) the most important influence on the vegetation the last 70 years has been from light, which has increased at the forest floor due to thinning operations. By contrast the influence from pH, judged from the indicator values, shows no development in time, but stretches the points from rich to poor localities (y-axis, Fig. 4). So, the general trend was away from the typical woodland species adapted to shadow to the present day vegetation, with more light-demanding species and ruderals. In conclusion, the main triggering factors have been thinnings and forest floor disturbances caused by modern machines.

At present we have only initiated small pilot projects under these headings, however these topics are on our schedule for the years to come.

Where are we going

What kind of forest vegetation is the goal, or do we have more than one goal?

It is clear, that in a country like Denmark, where forests have been heavily influenced by man for hundreds of years. It could be problematic to define a biological sound reference for forest successions.

Primary forest species are dependent upon forest continuity and have a competitive disadvantage at increased light intensities. On the other hand, Danish forests have been rather open and intermingled with pastures and arable fields, at least from Medieval to Early modern time. Then, plant species and other organisms adapted to the open forest environment are less suited for the pristine-type of forest. In selecting one type of forest as the genuine one, we can put ourselves between two chairs. The preliminary solution to the problem could be a mosaic-type of forest, either on a stand level or higher level.

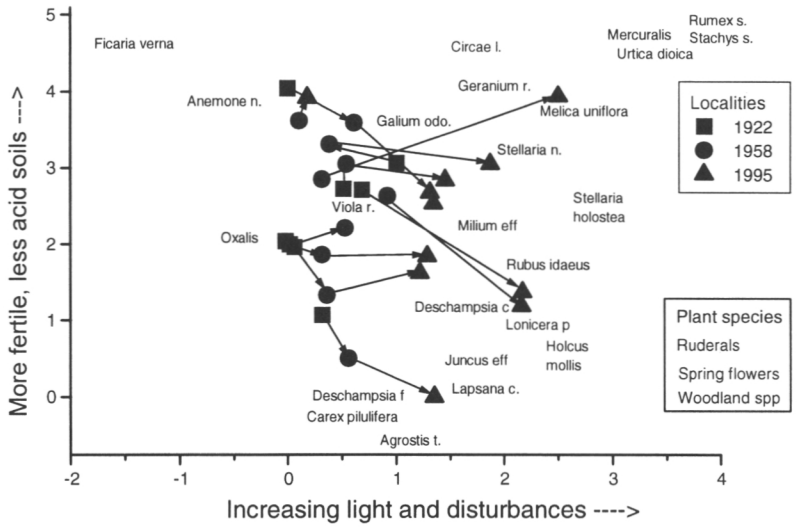

Fig 4. DCA-analysis of indicator values from species, mean values from stands, based on frequency data. The x-axis represents light and disturbances, whereas the y-axis represent more fertile, less acid soils.

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BIOTIC ZONATION – BIODIVERSITY – FOREST RESERVES

Alf Bakke



Bakke, A. 1998. Biotic zonation – biodiversity – forest reserves. New stand types in boreal forestry. Metla, Research Papers 714: 79-82.

Intensive modern forestry may be the most important factor for the decline of certain animals and plants in the Nordic countries. The objectives for management in new stand types must therefore be to maintain the natural biodiversity. However, the species richness varies considerably between the different subdivisions of the boreal forest of Fennoscandia with a decreasing number of species from south towards north. The southern zones, in particular the hemiboreal zone, also called boreonemoral zone, which have the highest number of threatened invertebrates, have been heavily exploited by man during the past five to six centuries and need most care and consideration. Red Data Lists are valuable basis for our knowledge on vulnerable species. Such lists should be worked out for each of the biotic zones and each zones need their special guide-lines for an ecologically thoughtful silvicultural management. Forest reserves with ancient forest may serve as reference areas.

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Background

Several papers from the Nordic countries blame the intensive forestry for being the most important single cause of the decline of certain species of animal and plants. Different forestry activities, like forest renewal and management, changes of tree species ratios, change in age structure and reduction of decaying wood in forest are the main causes. Rassi & Väisänen (1987) postulate that forest management in Finland has led to the disappearance of almost one-third of the species that have disappeared, mainly because they have lost their habitats due to logging operations. This is an alarming and serious message which may be true for part of the boreal forest but hardly for the entire Nordic boreal forest area. However, the statement has been of great value in order to wake up the forestry for a more careful utilisation of the forest land. The objectives for biodiversity in new stand types must be to maintain the natural biodiversity in the forest by a more careful harvesting and management, but not to creat a higher diversity, the goals are not to build a zoological or botanical garden.

Biotic zonation of the boreal forest

The boreal forest of Fennoscandia can be divided into four subdivisions. The most accepted scheme is that by Ahti et al. (1968), which identified the *hemiboreal, southern, middle* and *northern boreal zone* mainly based on large-scale differences in tree species composition.

The species richness varies considerably between these different subdivisions of the boreal forest with a decreasing number of species from south towards north. Threatened species tend to be congregated towards the south of Fennoscandia.

Southern zones

The hemiboreal zone, also called boreonemoral zone, is characterised by the presence of temperate deciduous tree species like *Quercus, Tilia, Ulmus* and *Fraxinus* mixed with conifers on more poor soil. The south boreal zone is characterised by scattered occurrence of the same deciduous trees and a dominance of conifers. The hemiboreal mixed forest of southern Scandinavia is assumed to be the richest in birds in Europe (Nilsson 1992) and includes «hot-spots» of insect diversity in northern Europe (Väisänen & Heliövaara 1994). In this zone we have the highest number of threatened invertebrates.

Most of the forest in the hemiboreal zone in Fennoscandia is heavily exploited by man during the past five to six centuries for timber export, mining, charcoal production, house-building and for firewood. The larger trees in the oak forest disappeared and with them the habitat for many beetle species. The only way to retain the natural fauna in mixed stand of deciduous and coniferous trees is to permit some trees of all species, gathered in small stands, to grow old, die by themselves and to be left for decomposition by insects and fungi.

Middle and northern zones

The middle and northern zones have a conifer dominance, with *Betula* and partly *Populus* as the main deciduous species. In these zones a large number of insects are confined to old-growth stands. Many saphroxylic beetles and midges occur exclusively in a very old spruce stand. Threatened noctuid moths of the genus *Xestia* mainly occur in old slow-growing spruce forests with an abundant growth of pendant lichens. The larvae feed on common plants, but lichens seem to be necessary as camouflage for both larvae and adults.

Red Data Lists

Our knowledge on vulnerable and threatened species has advanced during the recent years and biologists have gathered the information in Red Data Lists in each of the Nordic countries. A common list for the Nordic countries has been approved by the Nordic Council of Ministers. The accumulation of data gathered through these lists is our best basis for further work also in establishing guidelines for silvicultural management.

However, there is a lot of work to do to analyse and describe the species composition associated to the natural stands in the various zones of our boreal forest and to study their habitat requirements and fundamentals for their survival.

Forest reserves - reference areas

Forest reserves which have been left untouched for at least a tree generation may be the best area to start in order to get the best information on the fauna and flora composition which are natural to the biogeographical zone. Knowing the species and their habitats we may be able to take their requirement into consideration during the management of the stand.

Beetles dependent on dead wood, bark and associated fungi, e.g. saproxylic beetles have been studied by several scientists in the Nordic countries for nearly hundred years. They represent one of the largest groups contributing to the biodiversity in the forest and have therefore been in focus in the discussion on how to protect vulnerable species threatened by modern forestry.

Sampling of saproxylic beetles has been done in several forest reserves in Fennoscandia:

- Pyhän-Häkki national park in Central Finland (Biström & Väisänen 1988, Väisänen, Biström & Heliövaara 1993)
- Kolari, Finnish Lapland (Siitonen 1994)
- Marsholm in Lake Möckeln, Småland, southern Sweden (Nilsson & Baranowsky 1993)
- Birtjärnsberget, Dalarne Central Sweden (Baranowski 1980)
- Fiby urskog , Central Sweden (Lundblad 1950)

This winter I finished a study in a forest reserve in the hemiboreal zone in Telemark in southern Norway (Bakke 1998). I concentrated on beetles depending on dead wood. The forest, which was protected in 1916, is a mixture of Norway spruce and several species of deciduous trees and is characterised as very close to a primeval forest. We found 335 species of which 68 are assumed to be threatened or rare in Fennoscandia, 50 are on the Red Data List in Sweden and suggested for a similar list in Norway.

Conclusions

- Biodiversity and composition of threatened and vulnerable species vary between biotic zones of the boreal forests. Some management measures will be the same all over, but due to the difference in the natural tree composition each of the biotic zones need their special guidelines for an ecologically thoughtful silvicultural management.
- Forest reserve with ancient natural forest or stands with primeval forest are assumed to contain the biodiversity pattern of the biotic zone. They may serve as reference areas.
- Each single threatened species needs to be carefully studied to find the fundamental requirement for its existence.

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WIND AND OTHER ABIOTIC RISKS TO FORESTS

Heli Peltola



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Forest damage by wind, snow and fire are a continuing cause of economic loss in managed forests. For example, in 1990 one hundred million cubic metres of forest were blown down in the course of one night as a storm swept over Europe. At least four million cubic metres of timber are damaged by snow each year. In regard to fire damage, between 1980 and 1988, for example, 585 000 hectares of forests were burned down on average each year in the EU member states. Currently, wind and snow damage are the most significant threats to forestry, especially in northern and middle Europe, whereas fire damage is most problematic in southern Europe. In the above context, this paper will concentrate especially on the risks associated with wind and snow damage.

Reducing this huge problem largely depends on managers of forest resources making appropriate silvicultural decisions to minimize the risk of damage. However, the main problem is that the silvicultural knowledge needed to make these decisions is generally not systematically available. This is the situation, although our understanding of the many elements of the damage processes has substantially advanced in recent years.

The information available for planning longer-term risk assessments need thus be brought together by combining knowledge on climate (topographic and forest influences), tree/stand characteristics and site characteristics, as regard risk of damage. In this context, mechanistic models of tree stability can be used to describe the mechanism of damage, because they can define the causal links between the factors affecting the risk. Furthermore, mechanistic models combined with climate and stand inventory data can be used to to map the probability of damage, as will be demonstrated in this paper. In this context, GIS tools provide a range of modelling capabilities ranging from the evaluation of analytic expressions over a spatial domain to wind flow modelling and techniques for analysing features at different scales and resolutions. On the other hand, because forest resources and their economic significance vary a lot by country and geographical region, as do the silvicultural practices applied, generic tools are needed to assess the silvicultural risks, i.e. these tools being modified depending on country-specific special needs.

Keywords wind damage, snow damage, fire damage, forest management, silvicultural risks

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Introduction

Forest damage by wind, snow and fire is a continuing cause of economic loss in managed forests. In Europe, the scale of the problem in monetary terms amounts to hundreds of millions of FIM each year. In 1990, for example, one hundred million cubic metres of forest were blown down in the course of one night as a storm swept over Europe (Doll 1991a, 1991b; Wanderler and Gunter 1991). At least four million cubic metres of timber are damaged by snow each year (Valinger and Fridman 1995). In regard to fire damage, between 1980 and 1988, for example, 585 000 hectares of forests were burned down on average every year in the EU member states. Currently, wind and snow damage are the most significant threats to forestry, especially in northern and middle Europe, whereas fire damage is most problematic in southern Europe.

Between 1975 and 1985, late-autumn storms blew down a total of over eleven million cubic metres of timber in Finland; on a single day, 26th October 1985, four million cubic metres of timber were blown down. This amounted to approx. 7% of the average annual timber harvest of 55 million cubic metres, and it had an approximate value of FIM 100 million (Laiho 1987, Metsälehti 1985, Savolainen et al. 1994). In some areas of Finland, snow damage is almost an annual event, but in others its frequency varies a lot. On average, the limit of low and moderate damage risk has been exceeded every 5 years in southern Finland and every 3 years in the north-eastern Finland (Nykänen et al. 1997). Recently, climatological factors (wind, snow and frost etc.) have decreased the quality of forest stands over an area of 1.1 million hectares, which corresponds to 5.6% of Finland's forest area. (Metsätilastotiedote 1996).

In Northern Europe, wind and snow damage are serious threats to managed forests, because they result in loss of timber yield (Quine et al. 1995). The economic impact is particularly severe in fast-growing, semi-mature forests, i.e. each year of additional growth can bring substantial increases in total timber volume, tree size and value. Both wind and snow damage reduce the yield of recoverable timber and increase the costs of unscheduled thinnings, leading to disturbances in planned forestry management. Furthermore, broken and uprooted trees left unharvested can lead to detrimental insect attacks on the remaining stand because of increase in the amount of breeding material (Ravn 1985, Schroeder and Eidmann 1993). In Norway, during the period 1971-81, there were severe outbreaks of the spruce bark beetle (*Ips typographus*) that caused damage to an equivalent of five million cubic metres of timber following an extensive windblow (Bakke 1989).

Concern over global climate change has also highlighted uncertainties concerning the factors governing risks of abiotic damage and the future magnitude of such damage. Reducing this huge problem largely depends on managers of forest resources making appropriate silvicultural decisions to minimize the risk of damage. The main problem is that the silvicultural knowledge needed to make these decisions is generally not systematically available. This is the situation despite advances in our understanding of many of the elements involved in the damage processes of wind, snow and fire in recent years.

The information available for planning longer-term risk assesments now need to be brought together by combining our knowledge on climate (topographic and forest influences), species characteristics, silvicultural treatment, and site characteristics (soil and vegetation) as regard risk of damage by wind, snow and fire. It would be possi-

ble to integrate components from tree/stand to regional level in regard to risks by wind, snow and fire and thereby produce a unified risk model utilizing GIS. This paper will concentrate especially on the abiotic risks associated with wind and snow damage, which are most significant abiotic risks in northern Europe.

Factors affecting abiotic damage risks associated with wind and snow

Several studies have been conducted on the subject of wind- and snow-induced forest damage, and their results indicate how the properties and position of tree stands are related to the frequency and extent of damage (Fig. 1). According to these studies, stand and ground characteristics (e.g. tree and stand characteristics, tree species, soil type, stand management) set the critical windspeed and/or snow loading at which damage will occur (e.g. Persson 1972, 1975, Rottmann 1985, Lohmander and Helles 1987, Valinger et al. 1993, Solantie 1994, Nykänen et al. 1997). The local wind and snow conditions, and extremes of climate and topography determine how probable such a windspeed and/or snow-loading is. Vast differences have been found in the risk of wind and snow-induced damage between regions/locations differing in exposure and as regards the interaction between climatological and topographic factors with consequent damage to forests (Quine 1995).

The risk of wind- and snow-induced damage is greatest in stands adjacent to newly clear-cut areas and within newly thinned stands, i.e. especially if stands not previously thinned are thinned heavily (Alexander 1964, Neustein 1965, Laiho 1987, Lohmander and Helles 1987, Peltola 1995, 1996a, b, Stacey et al. 1994, Gardiner et al. 1997). The reason for this is that following thinning, wind is able to penetrate deeper into the stand canopy with a subsequent increase in the wind load imposed on trees, while dense stands dissipate incoming winds (Lohmander and Helles 1987, Stacey et al. 1994, Peltola 1996a, 1996b). Furthermore, thinnings increase the trees' susceptibility to damage, because the branches of adjacent trees in unthinned stands tend to dampen the oscillation of swaying trees, and furthermore, there is less interlocking of root systems in thinned stands (Peltola 1996a, 1996b). On the other hand, although the probability of damage has been found to increase with increase in relative thinning volume (Kolstock and Lockow 1981, Lohmander and Helles 1987), it decreases with the time since the last thinning. This is because the trees capacity to resist dynamic wind loads increases because of the decrease in the height to diameter ratio of trees after thinning, and also because of the increase in the root mass and strength of the roots (Laiho 1987, Lohmander and Helles 1987). Thus, trees are exposed to maximum risk during the first few years after thinning (Lohmander and Helles 1987).

Despite the possibility of a short-term increase in risk of damage caused by wind and snow following forest management actions, these are of primary importance, because they allow the forest owner to exercise control over the growth and properties of trees. Similarly, the total timber yield (pulpwood, sawtimber) over the rotation is closely related to management. In southern Finland, about 40% of the total cutting removal from Scots pine stands over a rotation of 100 years is obtained from thinnings, which substantially increase the total supply of timber to the forest based industries (Kellomäki and Kolström 1993). Because of risk of damage, the stand properties, especially at the margins of forest clearings,

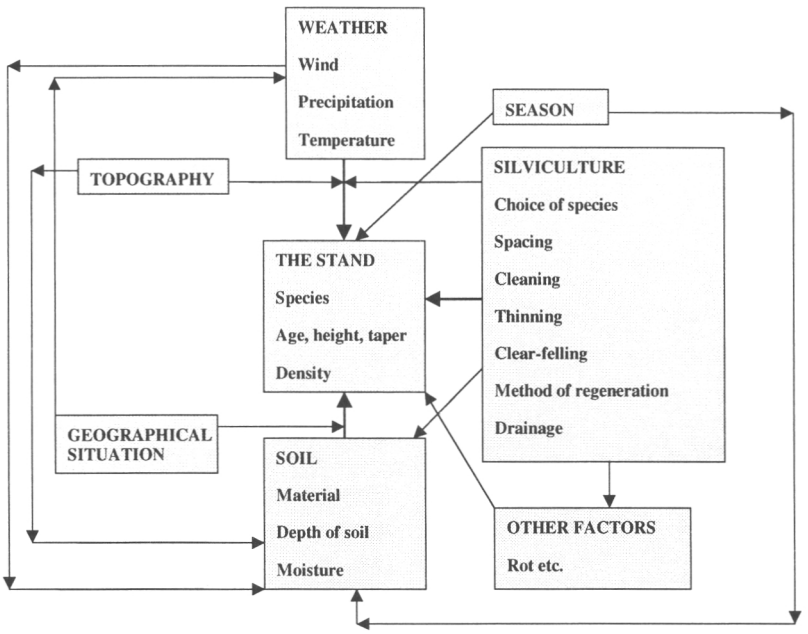

Figure 1. Factors affecting the risk of wind- and snow-induced damage.

are important to forestry practitioners concerned with the effect of thinning practices on losses due to wind and snow damage. The most basic issues in the planning of gaps as clear-felled areas and the related management of the margins of such areas are, how a gap or a hole in an otherwise undisturbed stand affects the speed and direction of local windflow, and how the wind hits the windward margins of clearings (Peltola 1996b). On the other hand, even within a single stand, trees experience different wind and snow loads depending on their size, stand density and position in the stand, but also depending on the gap size upwind from the stand edge (Gardiner 1994, 1995, Stacey et al. 1994, Gardiner and Stacey 1995, Peltola 1995, 1996a, 1996b, Peltola and Kellomäki 1993, Peltola et al. 1993, Gardiner and Peltola 1998, Gardiner et al. 1997).

Since the early 1960s, the frequency of strong winds has increased in Finland, especially during the period of unfrozen soil conditions; this has happened presumably due to the changing climate (Solantie 1986). At the same time, the total growing stock in Finland's forests has increased, making the structure of the forest ecosystems more prone to wind and snow damage, i.e. intensive thinnings and clearcuts applied as the main method of timber harvest have produced more vulnerable forest edges (Neustein 1965, Persson 1972, 1975, Laiho 1987, Lohmander and Helles 1987). In the future, the changing climate may alter the patterns of windblow by forcing the wind belts of the middle latitudes northwards (Schneider and Rosberg 1989). Consequently, this may lead to increase in windspeed and in the frequency of strong winds (Easmus and Jarvis 1989), which in turn may increase the risk of wind- and snow-induced damage. Especially in northern latitudes, these risks can be enhanced because of the potential decrease in the length of

time that the soil is frozen and in the anchorage of trees under a more humid and warmer climate. The subsequent damage is most probable between late autumn and early spring; i.e. during the windiest months of the year (e.g. Meteorological Yearbooks of Finland 1961-90, Peltola et al. 1998a).

Modelling abiotic risks

Recent works dealing with wind and snow damage have focused on either single tree level and/or a single damaging agent, or they have been generalized in the light of national level statistics of damage occurrence. Sophisticated classifications are already available for fire damage, but these require testing and tailoring to European conditions. For example, only a few forest-fuel maps exist despite the fact that these are crucial in predicting fire behaviour. An understanding of the processes and patterns of damage can be put to use in mitigating these threats. In regard to wind and snow damage, the scale of damage is a single tree, the risk of which damage can be influenced by stand management, for example. However, when dealing with fire damage, the important scale is the stand-level approach. However, the thing all these damage agents have in common is wind, which is the direct cause of wind damage, but wind can also enchance the risk of snow damage through additional wind loading, and wind can also increase the spreading of fire.

Some logistic and mechanistic models have been developed for risk assessment in connection with wind and snow damage (see Peltola and Kellomäki 1993, Peltola et al. 1998a, 1998b, Gardiner and Peltola 1998, Valinger and Fridman 1997a, 1997b). These models can serve as tools in the risk assessment of wind- and snow-induced damage to single trees/stands by predicting the probability and/or critical windspeed and/or snowloading which causes trees to be uprooted or broken under a range of silvicultural conditions.

Logistic models (based on site variables such as altitude, latitude, and longitude, and tree variables such as tree form) can be used to classify the overall susceptibility of forest stands growing on specific sites to being damaged by snow and wind (see Valinger and Fridman 1997a, 1997b). The resultant classification can then be used as a guide to forest management and to minimize future damage and costs in forestry. Forest managers differ in the level of risk they are prepared to bear or accept. The models can, therefore, become valuable tools when managing forests in a sustainable way, and thus meet the demands of increasing concern about the environment (Quarrie 1992). However, these models cannot be used to predict catastrophic snow- and winddamage events.

However, mechanistic models, providing the mechanics of wind- and snow-induced dynamic forces on trees by predicting the probability and/or critical windspeed at which trees are uprooted or broken (Fig. 2), in conjuction with the model for turbulent windflow, allow one to study how the properties of wind and snow and trees affect the mechanisms of damage in various stand management regimes (see Peltola et al. 1998b). This is because high windspeed and/or extreme snow loading are responsible for wind- and snow-induced damage. Thus reasonably realistic models for forest aerodynamics would provide a way of estimating the passage of wind through gaps and the wind- and snowload imposed on trees. Models relating canopy structure to turbulent wind conditions could offer opportunities for defining thinning standards for achieving optimum stability on a particular site. All this is possible, especially if data on the frequency and occurrence of strong winds and snow extremes

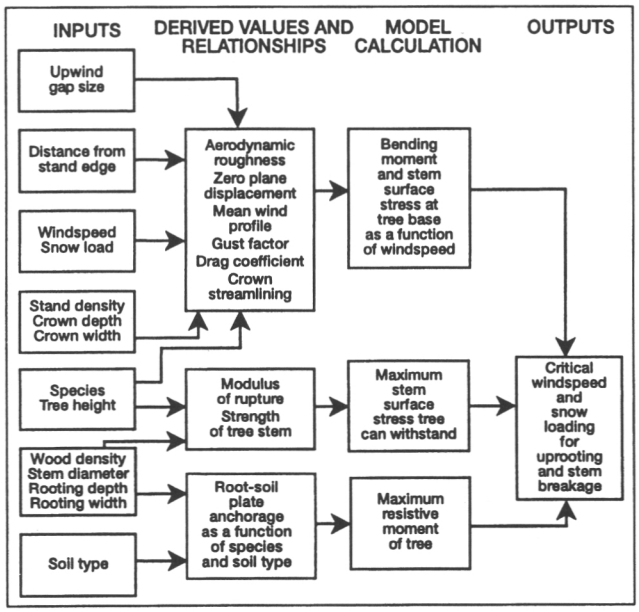

Figure 2. Diagram of possible inputs, relationships and outputs of the mechanistic model (see Peltola et al. 1998b).

are available. In addition, models including the interactions between windflow and topography can improve predictions by making it possible to identify specific parts of forested areas subject to particular levels of risk of being damaged.

Mechanistic models, thus, offer simple tools for assessing the risk of wind- and snow-induced damage to trees. They can be used to predict the critical combination of snow load and windspeed at which trees are broken or uprooted (Fig. 3), and to estimate the probability of damage over a range of silvicultural situations, provided that the probability distribution of long-term extremes in wind and snow conditions on the site are known. In other words, they could be used to evaluate the risks likely to arise from the application of given forest management measures (see Peltola et al. 1998b).

Such models could also be linked to the growth and yield tables (see Fig. 4) or alternatively those models predicting available growth and yield. This would thus make it possible to assess the risk of wind and snow damage to individual stands in different stages of tree or stand development, based on critical windspeeds and snow loads and the long-term probability distribution of extreme wind and snow conditions on the site. The use of growth and yield models in this context would also enable the evaluation of the influence of wind and snow loading on trees and stands growing under different exposure conditions brought about by forest management measures (e.g. thinning), and the evaluation of risk while optimising tree or stand growth and yield. However, mechanistic models as well as logistic models should be used with reservation beyond the circumstances for which they have been developed and validated.

Figure 4 shows an example of stand level risk assessment, where mechanistic mod-

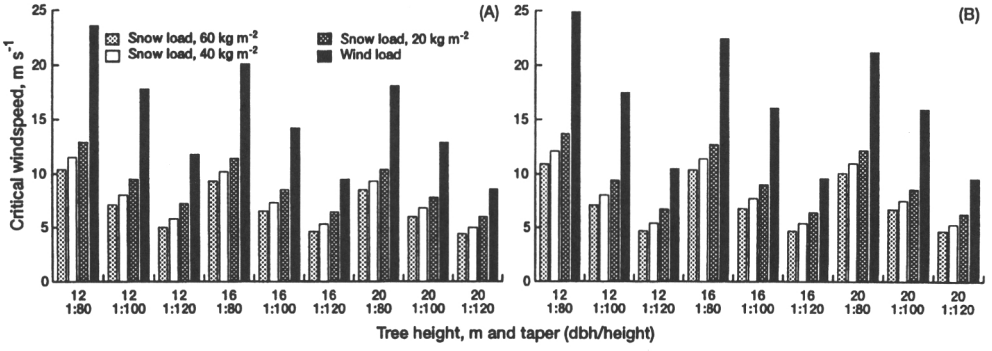

Figure 3. Example of critical windspeeds (mean windspeed per 10 min) for wind and snow damage of Scots pine at stand edge conditions under wind and/or snow loading: (A) uprooting, (B) stem breakage (Peltola et al. 1998b).

el developed by Peltola et al. (1998b) is combined with growth and yield table data available for unmanaged and managed stands in Southern Finland and local wind climate data (windspeed distribution) for risk assessment in terms of critical windspeeds for uprooting of trees and annual probability of occurence of those windspeeds (e.g. at location of Helsinki). This example provides an example of overall risk during rotation (long term effects of stand management), but does not predict the immediate change of risk affected for example by thinning.

Integration of component models from tree/stand to regional level for risk assessment

To minimize future damage, we need detailed information on the factors affecting the risk of damage and on how to minimize the probability of damage. Tools for integrating the knowledge available have been developed rapidly in recent years. Thus, it is now possible to link the damage identified (remote-sensed or ground-based) to stand data to explain the pattern of damage, or to link stand data to models describing the mechanism of damage for risk assessment. In both cases, a Geographic Information System (GIS) can manage the data and produce flexible output accessible to forest managers. Such usage can be complemented by the use of artificial intelligence techniques, e.g. expert systems, rule-induction, and decision-trees, to allow the integration of images, thematic spatial data, and ecological and spatial models. For example, mechanistic models of tree stability can be combined with climate and stand inventory to map wind and snow risk. Similarly, a fuel-hazard knowledge-base and ecological models of tree growth can be coupled with remote-sensed data to map fire risk.

Mapping risks is one way to detect areas prone to damage, but forest management at a regional scale may call for more detailed probability estimates. The now presented modelling approaches (e.g. logistic and mechanistic models) can be used by decision makers as a step in the selection of

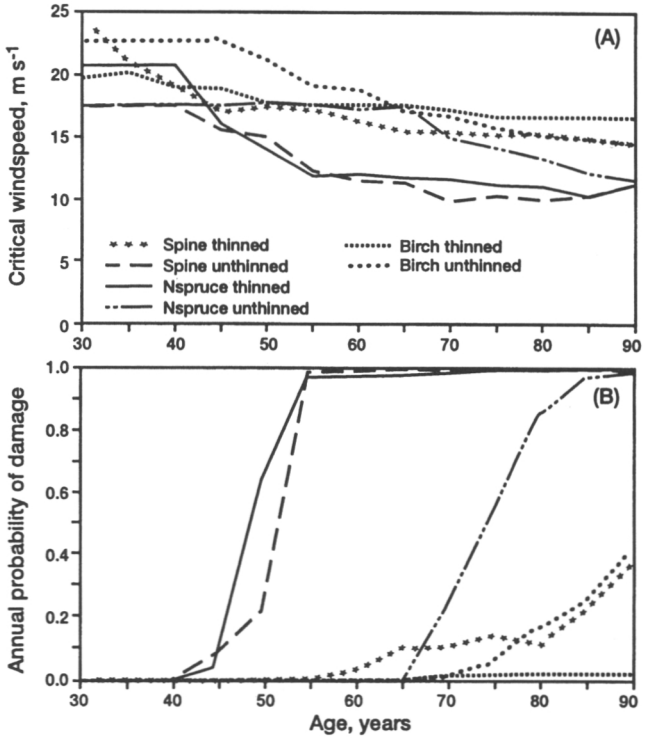

Figure 4. Example of critical windspeeds (average windspeed of 10 min) and probabilities of wind damage of unmanaged and managed Scots pine, Norway spruce and birch stands (see Kellomäki and Peltola 1998).

silvicultural method for a specific site. Risks can be calculated at different scales, provided appropriate input variables are available. High probability values indicate that forestry operations must be performed with great care and avoiding treatments known to promote damage.

The silvicultural practice most likely to exacerbate damage (e.g. wind and snow damage) is thinning. Forester managers can base their initial decision to thin on risk models. Then, if the decision to thin is taken, great care is needed, as damage can still occur in relatively low-risk areas. Also, the combination of heavy thinnings and fertilisation, repeated fertilisation, and retention of seed trees for natural regeneration, would have to be abandoned on high-risk sites (e.g. Laiho 1987, Hirvelä and Hynynen 1990). On low-risk sites, more intensive forest management can be permitted. As the tree models show the damage probabilities for specific sites, they can be used regardless of the present stand.

The information needed for planning longer-term risk assesments can be brought together by integrating components from tree/stand to regional level (even to national level) (Fig. 5), i.e. by combining knowledge on climate (topographic and forest influences), species characteristics, silvicultural treatment, and site characteristics (soil and vegetation) as regards risk of damage by wind and snow.

Figure 6 shows an example of regional-level risk assessment, where a mechanistic model of tree stability is combined with a regional level airflow model to simulate local wind climate, and with a geographical database of stand inventory data, i.e. to map risk of wind damage (see Fig. 5). Furthermore, annual average windspeed statistics (mean windspeed of 10 min) are used to map the probability of critical windspeeds at the location. The highest probabilities are to be found in stands actually damaged. However, also others, non-damaged stands are identified. This is done because the assumption in computations is that all the stands would be at the margins of forests (stand edges of clear-cut areas), which however was not the case. Thus, these stands could be identified as being potential risk areas if new forest edges are created (see Talkkari et al. 1998).

Similarly, Figure 7 shows another example, where logistic models (based on tree, stand and site characteristics) are combined with stand inventory data to map wind and snow damage risk at the national level in Sweden. High-risk areas are to be found in the westernmost parts of northern Sweden

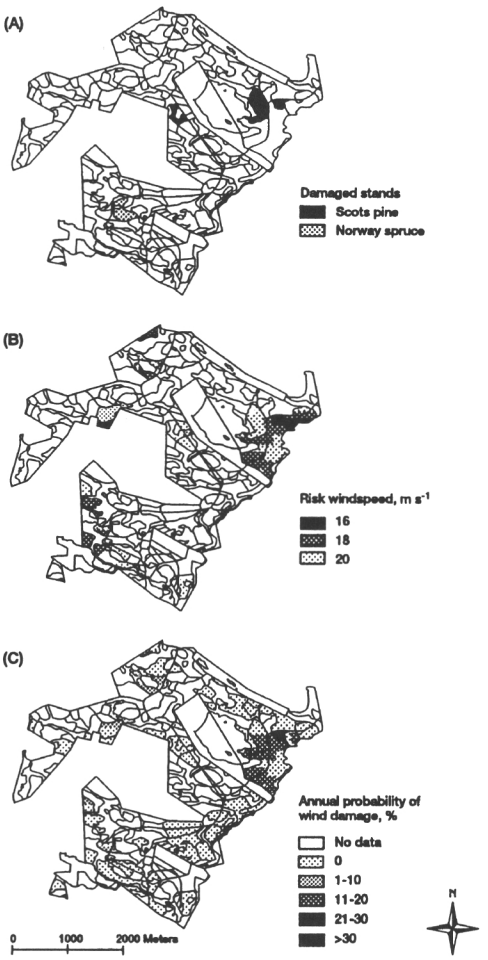

Figure 6. Example of maps of (A) actual damage, (B) risk areas and (C) probabilities in Finnish test area at Hyrynsalmi (north-eastern Finland) at different windspeeds (mean windspeed of 10 min) using stand inventory data (mean tree height, mean diameter at breast height, stand density) (see Talkkari et al. 1998)

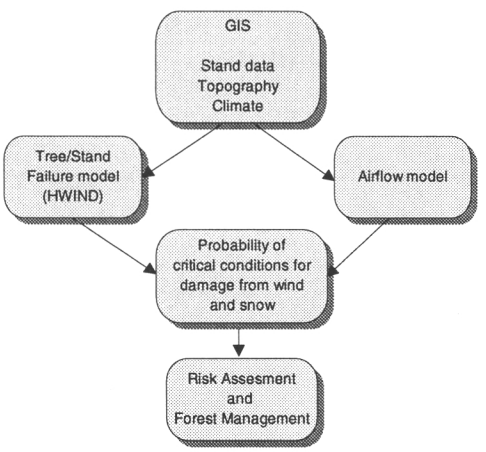

Figure 5. Layout of integration of component models (see Talkkari et. al. 1998).

and in the nortwestern and mid-southern parts of central Sweden. The low risk areas, on the other hand, are concentrated to the eastern parts of central Sweden and to the northeastern parts of northern Sweden (Valinger and Fridman 1997b).

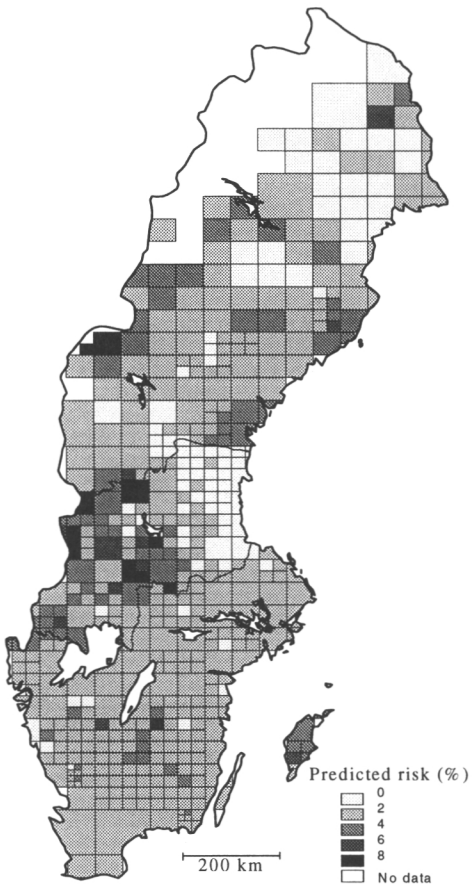

Figure 7. Example of probability of damage (%) caused by snow and wind for all species (Scots pine, Norway spruce and birch sp) using logistic models based on tree, stand and site characteristics (Valinger and Fridman, 1997b).

GIS tools provide a range of modelling capabilities from the evaluation of analytic expressions over a spatial domain to wind flow and fire spread modelling and techniques used in analysing features at different scales and resolutions. The quality or availability of proper input data is, of course, a concern identified in the integration of the component models. Assessing the results and identifying the lessons to be learnt is not easy because of the contribution of both quality of data and validity of model impact. Stand variability, both in tree characteristics and site conditions, remains very difficult to treat in models constructed on the basis of mechanical treatment of individual trees. Despite these limitations, it is clear that component models, as mentioned above, can be used to define silvicultural strategies - but this must be done for a specific situation as attempts to produce one-off, widely applicable regimes are doomed to fail.

Discussion

The forest industries throughout Northern (and middle) Europe are influenced by the risk of wind damage, in places, to forests with the added effects of snow (thus also of snow damage). On the other hand, forests in Southern Europe are especially vulnerable to being damaged by fire. Improved vulnerability assessment can be readily implemented by foresters, who at present rely either on crude empirical methods or their own professional experience. It is thought to be likely that the economic returns from improved rotations and better economic forecasting will more than compensate for the cost of implementing preventative measures.

In the future, more detailed knowledge is needed by foresters in silvicultural decisions in relation to the risk of wind, snow and fire damage, i.e. to derive long-term silvicultural strategies for managing forests to reduce the impact of abiotic risks such as wind, snow and fire damage, while obtaining the best possible wood quality. The integration of model components summarises an understanding of the factors increasing the probability of forest damage

at different scales. The information available for planning longer-term risk assesments needs, thus, to be brought together by combining knowledge on climate (topographic and forest influences), species characteristics, silvicultural treatment, and site characteristics (soil and vegetation) as regard risks of wind, snow and fire damage. It would be possible, as demonstrated above, to integrate components from tree/stand to regional level in regard to risks of wind, snow and fire damage and produce a unified risk model utilizing GIS. On the other hand, because forest resources and their economic significance vary a lot by country and geographical region, as do silvicultural practices, generic tools are needed to assess the silvicultural risks of wind, snow and fire damage, i.e. these tools being modified for each countries depending on special needs.

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GREEN TREE RETENTION AND PARASITIC FUNGI OCCURRENCE

Per Hansson



Hansson, P. 1998. Green tree retention and parasitic fungi occurrence. New stand types in boreal forestry. Metla, Research Papers 714: 97-100.

The possibility that the modern clear-cuts with small shrubs and larger shelter trees, will be less exposed to epidemics of parasitic fungi than the traditional large plantations is discussed briefly.

The effect of different structures of regeneration areas on the vegetative growth of snow blight (*Phacidium infestans*) is tested. Groups of five 50 cm high Scots pine (*Pinus sylvestris*) seedlings are planted in different environments on a modern regeneration area with "green tree retention": within 2-5 m high birches, spruces, Scots pines, on a small clear-cut, and under fresh logging slash. Results will be recorded after snow melting 1998.

Preliminary data from a field study in northernmost Sweden in September 1997, indicates that the number of Scots pine seedlings is somewhat lower under than just outside the crown projection of seed trees. Under the same trees, the proportion snow blight infected seedling was significantly lower than outside the crown projection. Quicker snow melting in connection to stems penetrating the snow surface, might be the explanation.

A second field study from the same area indicates that there are less pine seedlings within the logging slash from seed trees removed in late autumn. The proportion snow blight infected seedlings within the logging slash did not, however, differ from that outside the slash.

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Is it possible that modern clear-felled areas with a lot of shrubs and shelter trees left after harvest, will be less exposed to epidemics of parasitic fungi than traditional plantations?

There are mainly three species of parasitic fungi that from time to time cause mortality in regenerations of Scots pine (*Pinus sylvestris*); snow blight (*Phacidium infestans*), *Scleroderris* canker (*Gremmeniella abietina*), at dry lichen heaths, also the northern pine canker (*Lachnellula pini*) may kill trees. After fire a fourth pathogen, *Rhizina* root rot (*Rhizina undulata*), may cause extensive mortality. Regenerations of Norway spruce (*Picea abies*) in the northern boreal forests usually are much less affected by pathogens. In the northernmost areas there might be some mortality caused by the spruce snow blight fungus (*Lophophacidium hyperboreum*). Since snow blight is the most severe parasite on the indigenous Scots pine in the northern boreal forest zone, I will focus on that pathogen in this paper.

Many Swedish foresters still remember the recommendation by Wretlind (1948) which was supported by Björkman (1948) to make large "clean" clear-cuts in order to reduce the risk of snow blight attacks. Less known is that Björkman actually placed shelter-wood practice side by side with large clear-cuts. One reason why the hypothesis about large clear-cuts has been so long-lived, might be the fact that this recommendation coincided with the mechanisation of harvest practices within larger forest companies. In Norway Kaasa (1971, 1973) made contradictory observations, namely that the damage by snow blight was worst on large clear-cuts in different parts of Norway. Some of his results were recorded after a winter with an extreme ice-crust above a 2 m deep snow, which enhanced the development of the snow blight fungus. Furthermore, the climate in Norway is more maritime than the climate in the interior parts of northern Sweden, where Björkman made his studies.

Professor Björkman made an excellent work on the biology of the snow blight fungus. Björkman based his conclusions on the regeneration practice of his time. Today's "green tree retention" is different from the forest types existing on that time. We think it is adequate to look further into the snow blight problem. We think it is important to study the snow itself. However, recommendations to practical forestry concerning silvicultural measures has to be done after traditional field experiments with equal plant material in different forest types.

Since the phenomenon of "green tree retention" still is rather new, no experimental comparisons between the occurrence of parasitic fungi in traditional monocultures and in more heterogeneous regenerations, have been made so far.

To increase the knowledge about the occurrence of parasitic fungi on the new regenerations, associate professor Margareta Karlman and I, laid out an inoculation experiment last autumn, where we study the damage by snow blight in groups of five Scots pine seedlings (H=50 cm), planted on a clear-cut with "green tree retention". Ten groups were planted in each of five different environments: in 2-5 m high retained birches (1), spruces (2), pines (3), and, on a clear-cut part, with (4) or without (5) fresh late autumn logging slash laying over the seedlings. In each group the central pine was inoculated with snow blight infected needles in October 1997. The fungal infection on these seedlings will be recorded after the snow has melted in May 1998.

Last September I made a field trip in northernmost Sweden (N Pajala) and studied a recent outbreak of snow blight in that area. This minor epidemic broke out after the snowy winter of 1993/94. I found that the disease occurred scattered and was severe only in repeatedly unsuccessful natural regenerations at pure pine sites.

Data from 50 pair-wise comparisons of circular plots (r=2 m) indicate that the number of pine seedlings is somewhat lower under, than 5 m from the stem of seed trees (Fig. 1a). Under the same trees, the proportion of snow blight infected seedlings was significantly lower than outside the crown projection (Fig. 1b). This is probably because of the quicker snow melting around the stem of seed trees.

Data from another field study in the same area indicates that there are significantly less pine seedlings within than outside the logging slash from seed trees removed in late autumn (Fig. 2a). However, from the same 50 pair-wise comparisons, the proportion of snow blight infected seedlings within the logging slash did not differ significantly from that outside the slash (Fig. 2b). Seed tree removal in late autumn (October-November) means that green needles are covered by snow, which according to Björkman (1948) leads to a potential threat

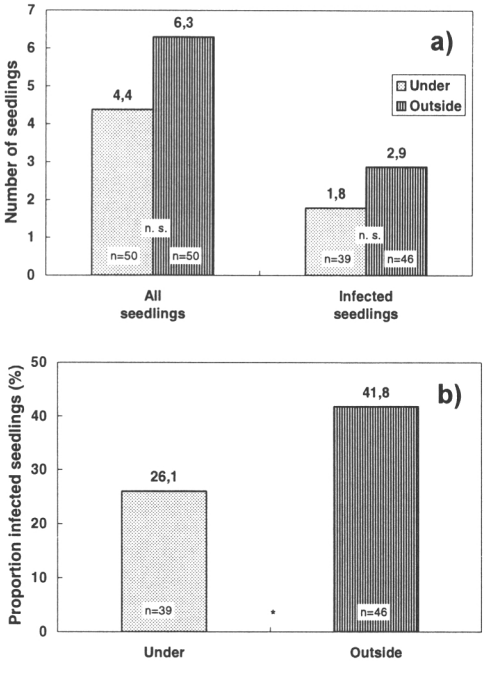

Figure 1. a) Total number of Scots pine seedlings and number of seedlings infected by snow blight (*Phacidium infestans*), and b) proportions of infected seedlings under and outside the crown projection of seed trees in Pajala September 1997.

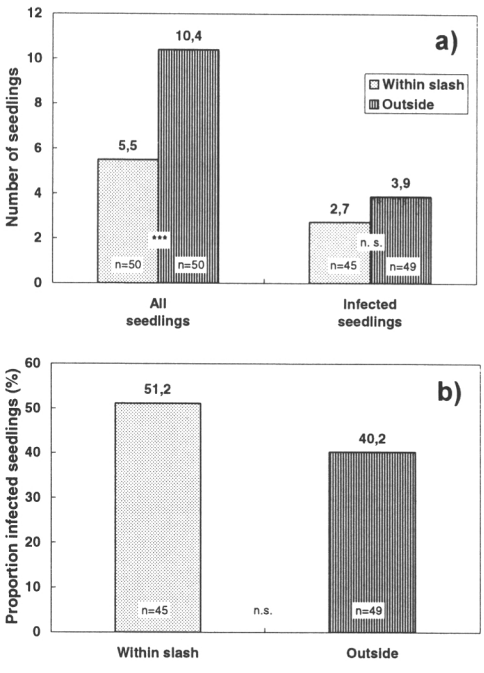

Figure 2. a) Total number of Scots pine seedlings and number of seedlings infected by snow blight (*Phacidium infestans*), and b) proportions of infected seedlings within and outside logging slash from seed trees removed in late autumn. Data from Pajala September 1997.

from snow blight – these needles are suitable substrate for the fungus. If there are only some infected seedlings under the slash, the snow blight mycelium will use the green needles on the slash as a substrate for nutrients and as a vector for spread to healthy seedlings standing within the slash. Despite the lack of significance in my study, it is probable that Björkman's conclusion is valid, since the actual number of seedlings was significantly lower in the slash and the tendency in the proportions points in the same direction.

The expected uneven height distribution of young Scots pines after "green tree retention" might be a source of some uncertainty, since the snow blight in that case probably will survive longer, and therefore may cause severe damage. Here is additional research needed.

Concerning the introductory question, it is well known among forest pathologists, that severe epidemics of parasitic fungi in northern Scandinavia started to occur in connection with the use of large clear-cuts and following plantations of Scots pine in the 1950s and 60s. The history has shown that the situation may become worse if too southern provenances of the native conifers (Dietrichsson 1968; Kurkela 1984) or even totally new exotic conifers such as lodgepole pine (*Pinus contorta*) are planted in

large monocultures (Karlman et al. 1994; Hansson 1996). From this point of view the "green tree retention" at today's clear-cuts – resulting in uneven-aged and mixed conifer and deciduous stands – probably will reduce the risk of epidemics of parasitic fungi.

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SPREAD OF FUNGI FROM NATURAL TO MANAGED FORESTS – A POTENTIAL RISK?

Iben Margrete Thomsen



Thomsen, I. M. 1998. Spread of fungi from natural to managed forests – a potential risk? New stand types in boreal forestry. Metla, Research Papers 714: 101-104.

In Denmark practically all forests have been influenced by man. Thus, there are no original natural forests. However, the Danish Forest and Nature Agency has developed a strategy for the state owned forests directed at creating forest areas which will approach the natural state. Most of these forest areas are or will be adjacent to areas managed for production or recreative purposes. A large part of the stands has beech as the main tree species. One of the most important wood-destroying fungi in beech is the polypore *Fomes fomentarius,* which produces white rot. *F. fomentarius* enters living trees through wounds, typically the broken ends of large branches containing heart wood. However, the fungus can live saprophytically in dead trees for many years, producing its perennial fruitbodies on both standing and fallen trees. The spore production takes place from March till December, with a major peak in April/May and a smaller peak in September/October. *F. fomentarius* is common in old stands, and it plays a major role in the degeneration of beech trees in old untouched forests. *F. fomentarius* is an example of a fungus whose presence in natural or untouched forest stands may have an impact on nearby managed beech stands. This is based on the assumptions 1) that the risk of colonization of wounds on standing trees is dependent on a certain spore load in the air, and 2) that increased numbers of spore sources will lead to higher spore concentrations, at least in the nearby environment. Plans are underway for a project aiming to assess the second issue. This includes determining "background" spore loads both within and outside forests and spore counts at various distances from local spore sources. The aim of the project will be to ascertain whether spore concentrations are significantly increased in relation to spore source numbers and how far away any such increase may be detected (dependent on prevaling wind directions and other weather factors).

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Introduction

In Denmark practically all forests have been influenced by man. Thus, there are no original natural forests. However, in an effort to create forest areas which will approach the natural state, the Danish Forest and Nature Agency has developed a strategy for the state owned forests (Anon. 1997). According to this "natural forest strategy", a natural forest must be descended from the original forest by direct seeding, i.e. no

planting or sowing of non-local stock have taken place. Untouched forest are areas that have not been influenced by management actions such as thinnings for a long period, the longer the better. The strategy aims at preserving natural forest areas, especially those which have been left untouched, and appointing more areas to be left untouched or to be managed by old methods such as coppicing. In appointing natural and/or untouched forests, larger areas were given high priority. Such areas had to be at least 25 ha, and the average was 136 ha. These areas constitute about 85 % of the areas chosen in the "natural forest strategy". The rest of the appointed areas are smaller, isolated stands or forest edges. In addition, the strategy recommends the retention of 3-5 old broadleaves pr ha when rejuvenating the stands in the managed forest areas.

The predominant tree species of the natural and untouched forest areas are beech and oak, other broadleaves being e.g. birch, ash, lime and alder. Old conifers such as Scots pine, fir, larch and even Norway spruce may also be included (Anon. 1997). Most of the appointed forest areas are or will be adjacent to areas managed for production or recreative purposes. One aspect in relation to the "natural forest strategy" is whether such areas will have an impact on nearby managed forests. This includes the possible spread of both fungi and insects. The general attitude is that within one or two years a tree's death the ensuing populations of insects and fungi will not be a threath to nearby stands. On the contrary, it is expected that leaving trees to degenerate and die naturally will increase the numbers of rare insects and fungi which depend on the presence of old wood.

Beech and tinder fungus

Beech constitutes the main tree species in many of the selected stands. One of the most important wood-destroying fungi on beech is the polypore *Fomes fomentarius* or tinder fungus. *F. fomentarius* enters living trees through wounds, typically the broken ends of large branches containing heart wood. It produces a severe white rot, starting in the heartwood but gradually invading the sapwood untill the bark is reached and killed (Koch 1985). Fruitbodies may be produced on the still living tree, but the fungus can live saprophytically in dead trees for many years, forming its perennial fruitbodies on both standing and fallen trees. In Denmark, spore production of *F. fomentarius* takes place from the end of March till December, depending on weather conditions. The spore production has a major peak in April/May and a smaller peak in September/October (Bjørnekær 1938). *F. fomentarius* is common in old stands, and it plays a major role in the degeneration of beech trees in old untouched forests (Koch 1985).

F. fomentarius is an example of a fungus whose presence in natural or untouched forest stands may have an impact on nearby managed beech stands. This is due to its capability of acting as a wound parasite on living trees as well as persisting and proliferating on dead trees. The idea of tinder fungus as a potential problem is also based on the assumptions that 1) the risk of colonization of wounds on standing trees depends on a certain spore load in the air, and that 2) increased numbers of spore sources will lead to higher spore concentrations, at least in the nearby environment. None of these points seems to have been elucidated by research so far. To illustrate the spore production capacity of *F. fomentarius*, Buchwald (1938) found that one large fruitbody was capable of producing between 78 and 139 million spores pr cm^2 pore surface pr 24 hours.

Planned project

Plans are underway for a project aiming to assess the second issue. This includes determining "background" spore loads both within and outside forests and carrying out spore counts at various distances from local spore sources. The aim of the project will be to ascertain whether spore concentrations are significantly increased in relation to spore source numbers and how far away any such increase may be detected (dependent on prevaling wind directions and other weather factors).

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ECONOMY IN THE SHORT AND LONG PERSPECTIVES –

Economic analysis of different silvicultural systems

Lauri Valsta



Valsta, L. 1998. Economy in the short and long perspectives – economic analysis of different silvicultural systems. New stand types in boreal forestry. Metla, Research Papers 714: 105-114.

Even-aged stands or plantations have been the most common stand type in forest economic research. This is not surprising because the majority of active silviculture in traditional forestry countries has been based on the even-aged management system. Parallel to the 'normal forest' concept of even-aged forestry, the sustainable diameter distribution of uneven-aged stands has a considerable research history. The advent of more flexible stand management principles, sometimes labelled 'any-aged' management, calls for more careful economic analysis of stand management options.

It is usually assumed in even-aged management that the economic analysis of one rotation can be done without any dependence to a previous or subsequent rotation. The lack of distinct rotations and vulnerability to improper cuttings cause uneven-aged economics to be much more sustainability oriented. To avoid 'forest mining', the value of a regime can be determined only subject to some sustainable stand structure in the long run. A general investment model covers the different silvicultural systems.

The uneven-aged structure calls for the following problems:

A optimal static steady state structure and harvest (no reference to a present stand)
B optimal static steady state structure is attained after a given number of time periods and harvests (conversion period)
C optimal dynamic steady state is attained after an optimal conversion period with a given number of time periods and harvests

A few key observations on uneven-aged management can be stated: The equilibrium structures for static (A, B) and dynamic (C) steady states may be different. The value of C is greater than A or B because C is a less constrained regime. The longer the conversion period in B, the higher the value. The steady state in C is often such that only the smallest and largest diameter classes are harvested. The conversion from an initial stand to the steady state may exhibit a pulse over time in the diameter distribution. When the economics of different silvicultural systems are compared, the analysis needs to cover the value of the ending inventory (the value of a steady state) and the costs and revenues during the conversion period and the invested capital as land and growing stock.

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Introduction

Revised goals for silviculture due to sociological and environmental changes have brought a greater variety of stand types under consideration in forestry. This development calls for research in biological, technological and economic aspects of "new stand types". The economic research on "new stand types" is very dependent on the biological and technological research and requires a solid quantitative basis. However, the basic economic questions are important to understand when establishing biological and/or technological experiments and data collection.

Looking back into history, the so called "new stand types" appear partly as reincarnations of old forestry when the existing stand types varied greatly and included two-storied, coppicing silviculture (Carlowitz 1713), even-aged and uneven-aged silviculture as well as various other selection methods depending on the demand for different timber assortments in different regions.

Even-aged stands or plantations have been the most common stand type in forest economic research. This is not surprising because the majority of active silviculture in traditional forestry countries during the last two centuries has been based on the even-aged management system. The area of selection forests in their principal region, Central Europe, is estimated to amount only for 450 000 ha (Schütz 1994).

Parallel to the 'normal forest' concept of even-aged forestry, the sustainable diameter distribution of uneven-aged stands has a considerable research history (see, e.g., Schütz 1994, Kenk 1995). The advent of more flexible stand management principles, sometimes 'any-aged' management, calls for more careful economic analysis of stand management options.

It is customary to assume in even-aged management that the rotations are separable, i.e., the economic analysis of one rotation can be done without any dependence to a previous or subsequent rotation. It is well known that in practical forestry these dependencies exist, most notably when natural regeneration is used. However, the scarcity of data in relation to the variability of conditions in decision making makes this type of analysis rather inefficient and research results not widely applicable. The lack of distinct rotations and vulnerability to improper cuttings cause uneven-aged economics to be much more sustainability oriented. To avoid 'forest mining', the value of a regime can be determined only subject to some sustainable stand structure in the long run.

When assessing the net returns from a management system, the even-aged silviculture naturally leads to considering the whole rotation, otherwise the results bare little or no significance. In the case of uneven-aged or any-aged systems, the time frame especially in empirically based studies is important. If the stand is in an equilibrium condition, a few decades may be long enough a time horizon. If the stand is in transition, the required time frame may be much longer and the amount of capital invested as growing stock becomes a key factor of profitability: both the level of and changes trough time of capital do matter.

Economic setup

A general framework for computing economic value defines how to identify the costs and revenues used. Among the options for quantities and prices, this paper concentrates on the quantities. Looking at the quantities side, a comparison of silvicultural systems may be based on:

- ideal/optimal silvicultural regime determined for the whole rotation starting from stand establishment,

Table 1. Financial items when computing net revenues for different silvicultural systems.

Entry	Even-aged	Prolonged regeneration[1]	Uneven-aged
Initial investment	Bare land Regeneration	Bare land Residual mature trees Regeneration	Bare land Standing stock
Revenues and costs during calculation period	Thinnings Final harvest Silviculture costs	Thinnings Regeneration cuts Silviculture costs	Selection cuts during transition to equilibrium Silviculture costs
Value of end inventory	Discounted value of future rotations (equals bare land value)	Discounted value of future rotations, (bare land value not available)	Discounted value of equilibrium selection cuts

[1]Rotation starts when the first regeneration cuts have been done

- silvicultural guidelines for adaptive management (target initial density, target basal area after thinning), or
- unique optimal management regime subject to the measured/observed state of the stand at some time

It should be noted that the optimum solution in the last case may be variable and depend on stand state.

Different silvicultural systems require different entries when computing net revenues. Table 1 shows main entries for three silvicultural systems: even-aged management, prolonged regeneration (also, irregular shelterwood system), and uneven-aged management.

It should be noted in the row concerning 'Initial investment' that the value of the standing stock in uneven-aged forest needs be considered as an investment. This is often neglected and uneven-aged management is favored due to low investments in regeneration compared to even-aged management. If the value of standing stock is not considered an investment in uneven-aged management, then the revenue from clear-cutting the previous stand should be included in even-aged management.

Bare land value is not available for prolonged regeneration (or irregular shelterwood) system as the consecutive rotations overlap. Rotation length may, however, be defined.

The basic management decisions for uneven-aged management (adapted from Hann and Bare 1979) in a stand-level analysis are:

1. The optimum, sustainable diameter distribution (trees/ha in each diameter class) for a given stand type. This definition also establishes the optimal stocking level and maximum tree size. The decision has often been divided into questions of optimum distribution, optimum stocking level and maximum tree size although they should be considered simultaneously.
2. The optimal species mix for a stand. The even-aged structure is often managed in stands that have more than one species, such as the Norway spruce-Silver fir mixture in the mountainous areas of Central Europe (Schütz 1994).

3. The optimal cutting cycle length.
4. The optimal transition strategy from the present stand to the optimum sustained diameter distribution, defined by items 1-3.

The any-aged management problem includes the uneven-aged management problem as a subset. However, the general any-aged management system may not necessarily contain equilibrium systems but may contain a cyclical management system. Planting activity may also be part of an any-aged system.

The general economic model

The frameworks for economic analyses of different stand types are not necessarily equal. The even-aged management economics are typically based on rotation based analysis, often referred to as the Faustmann approach (Faustmann 1849). With uneven-aged management, long-run steady-state harvesting has been the prevailing assumption.

Customarily, uneven-aged management is supposed to be performed without planting of seedlings. The 'new stand types' or 'any-aged management' may well involve planting in some years. Also differing from uneven-aged management, a steady state structure may not be an ultimate goal at all in the new stand types. As a result, neither the even-aged nor the uneven-aged management economic frameworks are appropriate. Rather, a kind of combination of the two traditional approaches could be applied.

The stand management problem for all stand types can be formulated as a general investment model (Haight 1987, Valsta 1993) in discrete time for an infinite time horizon using state variables $\mathbf{x}(t) \in \mathrm{IR}^m$, cutting variables $\mathbf{u}(t) \in \mathrm{IR}^n$, and a planting variable $v(t) \in \mathrm{IR}$. Let t take values 0, 1,... . The optimization problem becomes:

$$J(\mathbf{x}_0) = \max_{\mathbf{u}(t),v(t)} \sum_{t=0}^{\infty} g(\mathbf{x}(t),\ \mathbf{u}(t),\ v(t))\ \frac{1}{(1+r)^t} \qquad (1.1)$$

subject to:

$$\mathbf{x}(t+1) - \mathbf{x}(t) = \mathbf{f}(\mathbf{x}(t),\mathbf{u}(t),v(t)),\ t = 0, 1, \ldots \qquad (1.2)$$

$$\mathbf{x}(0) = \mathbf{x}_0 \qquad (1.3)$$

$$\mathbf{u}(t) \in U_t,\ t = 0, 1, \ldots \qquad (1.4)$$

$$v(t) \in V_t,\ t = 0, 1, \ldots \qquad (1.5)$$

where:

$g(\mathbf{x}(t), \mathbf{u}(t), v(t))$ = return function (revenue or cost when performing control $(\mathbf{u}(t), v(t))$ on state $\mathbf{x}(t)$, g: $\mathrm{IR}^m \times \mathrm{IR}^{n+1} \rightarrow \mathrm{IR}$)

r = (decimal) interest rate

$\mathbf{f}(\mathbf{x}(t), \mathbf{u}(t), v(t))$ = state equation, $\mathbf{f}$: $\mathrm{IR}^m \times \mathrm{IR}^{n+1} \rightarrow \mathrm{IR}^m$

$\mathbf{x}_0$ = the given state of the stand at the beginning of the control

U_t, V_t = the feasible control sets at time t

It can be shown (Haight 1987) that the uneven-aged and even-aged management problems are special cases of this general investment model. Solving problem (1) analytically is usually not possible due to nonlinearity and magnitudes of m and n. Numerical solutions require that the problem (1) is approximated by a finite time horizon modification. Depending on the application, a terminal condition for $\mathbf{x}(T)$ may be set or the stand is completely harvested in the final period T (see Haight and Getz 1987).

Uneven-aged economics

Development of methodology

Economic studies on uneven-aged management may, naturally, be either empirical *ex post* studies based on recorded development and associated costs and revenues, or model based *ex ante* studies where alternative developments are simulated and evaluated financially. The principal geographical area for the long-term empirical studies has been Central Europe and, especially, the mountainous areas of the Alps (Schütz 1994). Because of the very long time periods required in the empirical studies, statistically valid experiments that would involve both even and uneven-aged management plots, are difficult to find.

Kenk (1995) reviews the Central European literature on conifer dominated, uneven-aged forests. He points out that several factors affecting the economics need to be assessed: volume yield, size distribution (recovery of assortments), wood quality, logging and road network maintenance, investments in silviculture including game control. Many of these factors are not so important when alternatives within a management system are compared but may become significant when comparing across management systems.

Contrary to empirical studies, model based studies can easily accommodate long time periods. Two major categories of stand development models have been used: matrix models and individual-tree models. The matrix models have a longer tradition but individual tree models have become the standard in growth modelling and, hence, have wider applications. Individual-tree models can further be divided into distance-dependent and distance-independent models. The spatial information used in the former group is potentially valuable but has not become in wide use.

Among the matrix models, the linear uneven-aged stand models follow the Leslie matrix approach (Leslie 1945). Nonlinear uneven-aged stand models relax the linearity assumption but otherwise have usually the same structure (Getz & Haight 1989).

Among the linear models, an early contribution to model based uneven-aged management studies is by Usher (1966). In a Leslie matrix framework, Usher develops a matrix model for Scots pine in Scotland. He further mathematically defines the properties for sustainable and optimal harvesting related to his (linear) model form.

Boungiorno and Michie (1980) develop a linear programming based model that has dynamic (i.e., stand state dependent) ingrowth functions (in linear form). Their model was used to determine jointly the optimum harvest, residual stock, diameter distribution and cutting cycle for a sustained yield system. Advantages included the reliability and ease of finding optimum solution due to the LP model. The obvious disadvantage is the restriction to linear models.

Adams and Ek (1974) present a nonlinear programming solution to uneven-aged management. Their model allows for nonlinear state transition equations. They analyze both the equilibrium distribution and the transition strategy (from a given initial

distribution to the equilibrium in a specified time).

Haight, Brodie and Adams (1985) developed a discrete-time, optimal-control model for uneven-aged management. This model was solved by a gradient method providing an efficient and capable algorithm. The optimization model was combined with the Adams and Ek (1974) stand simulator and optimum equilibrium stand structures were developed for different management objectives. This model was further developed and linked to other growth models: Haight (1987) for Hann (1980); Haight and Monserud (1990a, b) for Wykoff et al. (1982); Haight et al. 1992 for Wykoff et al. (1982) with extension to multiple forest outputs.

Principal problems

Based on the findings in Adams and Ek (1974), Adams (1976) and Haight (1985), we may summarize the basic *uneven-aged* management questions on optimal resource control as the following alternative problems:

A optimal static steady state structure and harvests (no reference to a given stand)
B optimal static steady state structure and, conditioned on it, a set of optimal harvests during a conversion period of given length
C optimal dynamic steady state as attained after an optimal conversion period of given length

One could argue that a further problem would be one where also the length of the conversion period is optimal. However, this is a trivial question as the optimal length of conversion is infinite.

In problem B, one must first solve for the optimal steady state structure (problem A). Then, giving the steady state structure as a terminal condition, the optimal conversion strategy is determined.

A Optimal static steady state structure and harvests

This problem may be called the traditional uneven-aged economic problem. Depending on the growth model assumed, linear or nonlinear programming can be used to determine diameter distributions and cutting lengths that maximize the net revenue (Adams 1976, Buongiorno and Michie 1980, Martin 1982). Also, marginal production rules may be specified for the optimal equilibrium diameter distribution (Chang 1981, Hall 1983). Chang (1981) parallels the static uneven-aged stand value with the Faustmannian land value of even-aged management.

B Optimal static steady state structure and a set of optimal harvests during a given number of time periods (conversion period)

As existing stands seldom are at the equilibrium steady state condition, the conversion from an existing stand structure to the equilibrium structure is an important problem. Given the initial condition and the terminal condition (the equilibrium structure determined in A), linear or nonlinear programming can be used to solve for the optimal conversion strategy (Adams and Ek 1974, Michie 1985). In that, the length of the conversion period and cutting cycle (time between cuts) are important factors.

Inherent in the thinking of this approach is that the steady state is independent of the conversion. A parallel in even-aged management would be the case where the policy for the ongoing rotation is determined separate from the subsequent rotations for which the optimum rotations starting from bare land are applied.

C Optimal dynamic steady state as attained after an optimal conversion period of given length

In this problem, the conversion and equilibrium harvests are solved simultaneously. The result also gives the equilibrium diameter distribution. The objective function value is the sum of the net returns of conversion and equilibrium stages. As Haight (1985) observed, the present net worth of problem C is greater than that of problem B. Interestingly, the value of harvests of the equilibrium stage may be higher in problem B but the value of harvests during conversion stage in problem C more than offsets this difference. The nonlinearities in growth and economic models may explain why it may be optimal not to converge to the static equilibrium of problem B.

Haight and Monserud (1990b) found that, depending on the initial stand structure, different types of management regimes may be optimal for the same species/site. This result was obtained using an any-aged management model where both even-aged and uneven-aged regimes were allowed, as well as all combinations of them. Also, changes in the objective function could change the management system for the same initial stand.

Key observations

In summary, the key observations about the relations between the different problems of uneven-aged management are:

- The equilibrium structures for static (A, B) and dynamic (C) steady states may be different.
- The optimum value of C is greater than of A or B because C is a less constrained regime.
- The longer the conversion period in B, the higher the value.

The steady state in C is often such that only the smallest and largest diameter classes are harvested (bimodal harvest). For linear growth dynamics, at most two size classes are harvested in the optimum regime (Getz 1980).

The conversion from an initial stand to the steady state may exhibit a pulse over time in the diameter distribution.

Any-aged economics

The any-aged management problem may be solved using the general investment model (1). In present day research work, the greatest problems are often encountered in lack of or reliability of the biological models for regeneration, mortality and growth in any-aged stand structures. Also, logging costs and tree values computed by models based on standard even-aged stand structures may be erroneous.

Probably the most thorough model based study on any-aged management is by Haight and Monserud (1990a and 1990b). The forest they used provides for both white pine plantations and mixed-conifer, naturally regenerated stands. One of the questions they analyzed is the effect of decision criteria (the objective of management) on the optimal silvicultural system. With a maximum present value objective, the optimal silvicultural system was uneven-aged management with multi-species structure. When maximizing volume yield, two silvicultural systems were advantageous: either even-aged plantation management with white pine or shelterwood regeneration for mixed-conifer stand. The latter produced sequences of semi-uneven-aged structures with some 30 years or more spread of ages in the stand, due to gradual natural regeneration in the mixed-conifer stand. Large trees are removed in a cycle of approximately 80 years (an estimate of rotation, as well).

Conclusions

When alternative silvicultural systems are discussed, the question often asked is which of the systems is optimal. It is expected that there is no universal, correct answer to this question. More relevant problems are restricted to certain site types and tree species combinations.

The established setting on comparison between even- and uneven-aged management systems was to compare the value of an even-aged system computed in Faustmann (1849) tradition to the value of a static steady state uneven-aged system (e.g., Chang 1981) where the marginal value growth equals the discount rate. Later, Haight (1985) and Haight and Getz (1987) have shown that the static steady state is inferior to a dynamical steady state when the revenue function is not a linear combination of the harvest level.

The review of some existing literature shows that there are several choices on how to compute the value of uneven-aged management. This emphasizes that comparisons between the well defined silvicultural systems even- and uneven-aged management have to be made with care. The comparison is even more complicated with any-aged management. Attention should be paid on:

- What are the costs and revenues during the principal time period compared?
- What is the value of the ending inventory (note that an immediate clear cut value may be less than a discounted value of future net returns)?
- What is the sum of the two items above?

One should also note that the economically justified comparison is based on the optimum regimes of each management system. If these regimes have unequal risks or probabilities, they should be taken into account.

Comparisons between different silvicultural systems are often reported without reference to the considerations presented above. Moreover, economic analyses may even neglect the capital invested in growing stock as can be seen in Schultz (1993), Schütz (1994) and other references in Kenk (1995).

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OPTIMISING THE PRESENT VALUE OF THE FOREST

Mats Hagner



Hagner, M. 1998. Optimising the present value of the forest. New stand types in boreal forestry. Metla, Research Papers 714: 115-126.

Liberich is a forest management system in which trees of high potential value are liberated by thinning of mature trees, and open gaps are closed by planting, provided advance growth is deficient. Trees are harvested when their present value culminates. When neighbouring trees compete, removal of trees has to be done in a way that will maximise the present value of the group of interacting trees.

An estate holder should keep his products, the logs, stored alive, on root, until a customer is willing to purchase.

A computer model for evaluation of net revenue for single trees over time has been developed. It gives the value at roadside, with costs for harvest and enrichment planting subtracted, and the interest rate if retained. The intention is to use this program as an aid in the forest.

Discussion touches on productivity, genetics, risks, and economy
Keywords selection system, forest management, thinning, planting, enrichment, liberation, wood quality, economy, interest rate, present value
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Background

All selection systems have one thing in common. Trees to be removed have to be separated from those retained. Anyone trying to decide what trees to harvest and what trees to retain, quickly realises that a multitude of considerations have to be made.

Professional foresters are aware of price differences on wood from various tree species and, like any farmer, they want to optimise revenue by growing the most valuable crop in plantations. They also understand that selective systems necessitate more elaborate tree harvesting methods.

Selection systems have historically been introduced as "desperate actions" in which anything of value has been harvested. Residual stands have been left with few trees of poor quality. This is often referred to as "creaming". In many parts of the world education of foresters involve warnings for selection systems because scientific studies have proven that "creaming" hampers the long-term revenue.

The selection system presented here, "Liberich", is active and aims at optimising the present net value of the estate. It incorporates not only liberation thinning but also enrichment planting (Hagner 1995, Hagner 1996).

The economic reasoning has much in common with that of Kuper (1994).

The method has been tested in a series of 12 field tests in Sweden, established in 1989-1993, and the results are very promising (Jäghagen et al 1997).

Principles for tree selection

The system for tree selection presented here with an example assumes a polycyclic forestry. This means that harvesting of mature trees is carried out many times during the rotation age of a single tree. At present monocyclic systems are mostly used in Sweden and Finland: mature trees are harvested just once during the rotation age of one tree, and the forest is managed in stands of equal age. In polycyclic forestry there is no such thing as a stand. The smallest unit is the group of close standing interacting trees. The next larger unit is the forest estate.

In polycyclic forest management there is probably no single task of greater importance for the short and long-term revenue than the selection of trees to be harvested or retained. Hence, the person selecting trees should be very well trained and he should have ample time at his disposal.

To simplify the presentation in this paper, one group of two interacting trees is discussed. When dealing with only two trees there are only four possible choices: harvest both, retain both, take number one or take number two. When dealing with ten trees the number of alternatives is $2^{10} = 1024$. Fortunately, intuition can be used to reduce the number of realistic alternatives drastically.

Trees to be harvested in the polycyclic system described here, are those that have obtained an economic maturity. This means that the rate of interest (ROI) of the tree net value (at roadside) falls below an acceptable level. This occurs when the tree has grown to full size. It also occurs when the tree is attacked by centre rot, making the value decline. Very limited growth rate is also reducing the rate of interest.

As trees are competing with their neighbours and interacting, the choice of tree for harvest must consider also the reaction of surrounding trees. Accordingly, the thinning should be performed so that the present net value of the group of interacting trees is maximised.

The acceptable ROI should be set by the forest owner and is unique for each harvest. He has to adjust the ROI in accordance with his economic alternatives. In a surplus situation, ROI will be equal to what he will obtain by placing money in the bank: today about 3 %. In another situation, when the alternative is to take a loan for a high rate, ROI should be equal to that alternative.

One interesting question is whether the long-term income profile of the forest owner should influence the choice of ROI.

In the computer model TREE, the cost for planting is included. This option is used if an open area without acceptable natural regeneration is caused by tree removal. This is named "enrichment planting". A drastic reduction of stand density increases the mortality among seedlings and trees in the residual stand. Important reasons to this are e.g. exposure to snow, wind, sun, insect, and game browsing. Flushes of ground vegetation may further reduce the establishment of new regeneration from tree seeds. Altogether this means that a drastic reduction of stand density usually has to be followed by an intensive planting, enrichment planting.

Practical guide for tree selection

Before the selection starts, ROI has to be fed into the field computer. In addition, current timber prices have to be entered, as well as costs for felling, terrain transport and enrichment planting. All these factors will be used when calculating the value increment, in per cent, for groups of trees.

At the work, the person selecting trees has to consider each spot of ground he passes and secure optimal productivity everywhere. However, generally, optimal productivity must include not only woody products but also multiple use, nature conservation and historic relicts.

In order to explain the way to reason, one example is illustrated in figures 1, 2 and 3, and data are given in table 1 and 2. The two trees number 9 and 10 are considered. If not released, tree no 9 will probably die after about 45 years.

Estimate the present net value and its culmination in time (Fig. 2, Appendix 1). For the small pine, no 9, if it is suppressed, the culmination is 20-40 years from now, and after 70 years if it is released by removal of no 10. For the taller pine, no 10, the culmination is 30 years from now.

Also estimate the net value per m^3 over time (Fig. 3). If released, tree no 9 reaches 582, while no 10 never reaches more than 370. No 10 has already obtained 75 % of the net value/m^3, while no 9 has reached just 2 %. The potential value increase of no 9 is great.

The group of two trees should be handled so that the present net value of the group is maximised. Four alternatives ex-

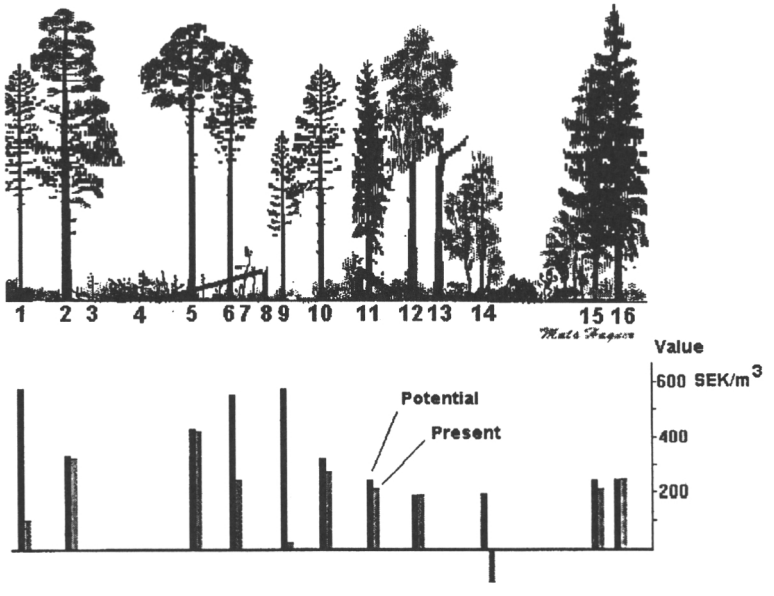

Figure 1. A northern boreal forest of a type commonly exposed to clear cutting. Under each tree the potential net value per m^3 at roadside is illustrated.

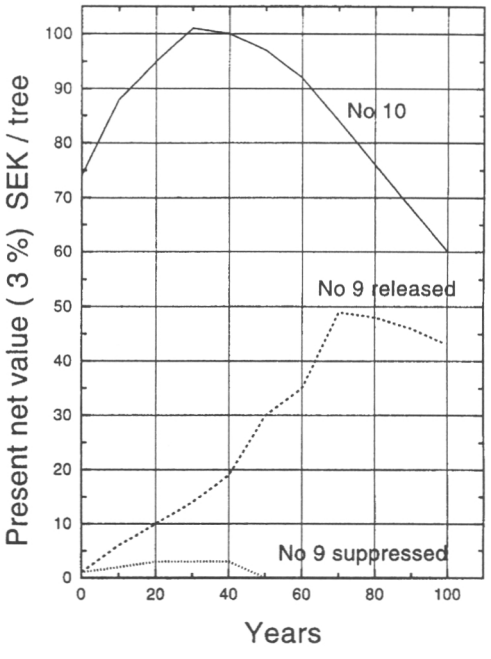

Figure 2. The present net value, base 3 % interest rate, for trees number 9 and 10 in figure 1. If not released it is assumed that tree number 9 dies after 45 years.Economic model TREE.

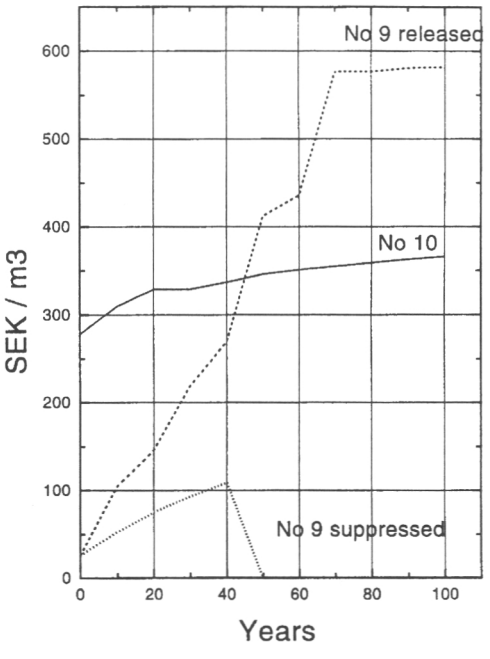

Figure 3. Net value/m^3 at roadside for trees number 9 and 10 in figure 1. If not released it is assumed that tree number 9 dies after 45 years. Economic model TREE.

ist. A maximum value of the group can be figured out by comparing these alternatives (Table 2). For such estimates, growth and vigour of each tree has to be described for each separate alternative.

This method also gives a correct result when small trees of low potential value compete with bigger trees of higher value. It also works in cases where big trees have to be retained to prevent branching of smaller trees.

Small trees with a negative present net value should be removed provided that they are present in much higher numbers than necessary to replace trees harvested later. Competition for water and nutrients is directed not only from big trees towards smaller, but also in the opposite direction.

Simple rules for tree selection

The above rules give the scientific background for tree selection. For simplification the following criteria can be used:

** Harvest trees that have obtained great value and do not appear to grow fast.

** Save trees of high potential value, if they seem to be growing well.

** Harvest big trees if they are detrimental to smaller trees with much higher potential value.

** Harvest diseased or damaged trees, also when they are small

** Remove advance growth growing in very high densities.

To follow the above rules, it is necessary to know the time span to next harvest.

Table 1. Data on single trees in figure 1. Interest rate and net values are estimated by use of model "Tree" (Appendix 1). Species: *Pinus sylvestris* (s), *Picea abies* (a), *Betula pendula* (b). Diameter at breast height (Dbh). Quality of first, second and third saw log, grades: best(s), second(o), third (v), fourth (p). Interest rate if retained 10 years (Int. %). Net value at road side, for whole tree (Net/tree), per cubic meter (Net / m^3). The number of years until the culmination of present net value, when an interest rate of 3 % is used (Future, 3 %, Cul yr). Assumptions: All trees had constant annual ring: 1.5 mm. No need for planting. Harvesting costs adjusted to selective cutting, intensity 50 % of volume.

No	Spec	Dbh cm	Height m	Quality	Current			Future, 3 %			
					Int. %	Net/ tree	Net/ m^3	Cul yr	Dbh cm	Net/ tree	Net/ m^3
1	s	12	13	s o v	8	8	105	60	30	390	577
2	s	30	20	v v v	3	221	327	10	33	298	334
3	s	0	1	-	-	-	-	-	-	-	-
4	a	0	1	-	-	-	-	-	-	-	-
5	s	25	18	o v v	4	159	418	20	31	319	428
6	s	20	16	s v o	8	42	243	50	35	585	554
7	s	0	1	-	-	-	-	-	-	-	-
8	s	-	-	-	-	-	-	-	-	-	-
9	s	9	11	s o v	21	1	26	70	30	390	577
10	s	22	17	v v v	5	74	278	30	31	244	329
11	a	22	17	o o v	5	59	217	30	31	190	250
12	b	25	18	p p p	3	75	194	10	28	102	199
13	b	-	-	-	-	-	-	-	-	-	-
14	b	8	11	p p p	in.	-3	-114	70	29	112	201
15	a	22	17	o o v	5	59	217	30	31	190	250
16	a	30	20	o o v	3	173	251	0	30	173	251

Table 2. Present net value (SEK/tree) estimate for a group of trees in Figure 1. In this case the two trees no 9 and 10 are included in the group. Four possible combinations exist. Years from now to harvest is given within brackets. When no 9 is suppressed the annual ring is assumed to be 0.4 mm and when released 1.5 mm. Tree no 10 assumes to have an annual ring of 1.5 mm. The conclusion is that total clearing gives the lowest value and the highest comes from a retention of no 9 and a harvest of no 10.

Group Sum	Tree no 9		Tree no 10	
	Retained	Harvested	Retained	Harvested
104	3(40)	-	101(30)	-
102	-	1(0)	101(30)	-
123	49(70)	-	-	74(0)
75	-	1(0)	-	74(0)

Theoretical example

It might be of interest to show what the long term handling of the forest in Figure 1 will be if this system of tree selection is carried out for 80 years (Figure 4a, b, c, d). Assuming the same volume is harvested in Clear cutting system (monocyclic), economic evaluations presented elsewhere (Hagner 1996) gives an impression that the present net value of the forest estate could be increased in the range of 100 % if Liberich was used instead Clear cutting.

Discussion

Annual volume production of the estate

There is a risk that Liberich, which produces stands with a mixture of tree sizes, lowers general volume productivity of the forest. In the estimates above, it was assumed that the different types of management mentioned do not affect long term volume productivity. There are scientists (Elfving & Tenghammar 1995) who state that a stand dominated by formerly suppressed trees is less productive than stands in which trees have been able to grow fast from the beginning. There are also many investigations indicating fair productivity after thinning from above (Kallin 1926, Näslund 1942, Vaartaja 1951, Lindman 1984, Bergan 1985, Eriksson, 1986, 1992, Nilsen 1988, Nilsen & Haveraaen 1982, Axelsson & Eriksson, 1986, Kalela 1986, Hynynen & Kukkola 1989, Skoklefald 1989, Lundkvist 1989, Elfving 1990a, 1990b, Fries 1990, Lähde, Laiho, Norokorpi & Saksa 1991, Mielikäinen & Valkonen 1991, Eriksson & Kyrkjeeide 1992, Kuper 1994, Jonsson 1995, Pettersson 1995). This is an important but complicated question that cannot be fully answered until our research series has been followed up for many years ahead.

Knowledge about tree selection

In a selection system like Liberich, proficiency of the person selecting trees is important (Vuokila 1982). If he marks trees randomly, net revenue will certainly be far from optimal. If he marks trees to obtain a maximum short-term income, a negative selection is done, as the most valuable trees will be removed. Trees of low potential value, e.g. non-commercial species, trees with damaged or knotty stems, might be retained for future harvests.

Negative genetic selection for growth rate

Attention must be paid to the negative genetic selection that might occur if suppressed trees are used. In Swedish forests, trees emerged mostly after a forest fire, and close standing trees sometimes were sown the same year. Trees with a genetically inferior growth rate were suppressed by their neighbours. Hence, a commonly held opinion is that emergent trees are of a superior genotype. The variation caused by other factors seems however to dominate.

Positive genetic selection

The tree selection described earlier is directed towards removal of low quality trees. The result is an increasing share of trees with a favourable morphology, i.e. trees with straight stems and thin branches. As the heritability of these features among conifers is high, the Liberich system might comply a positive genetic selection for morphology.

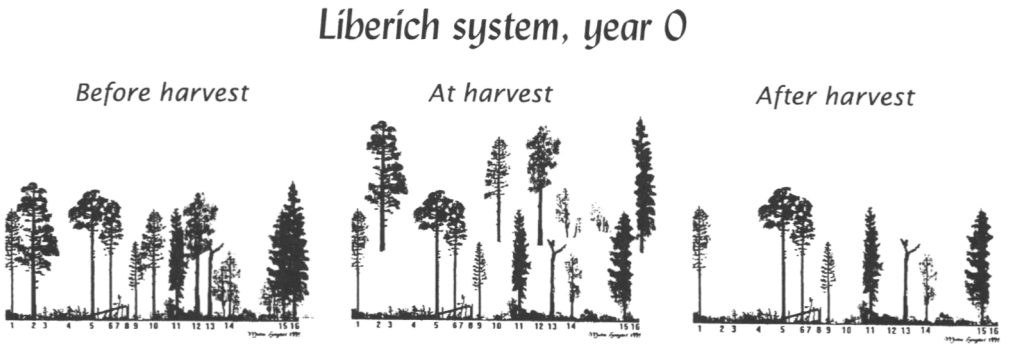

Figure 4a. A selective harvest according to the principles of Liberich.

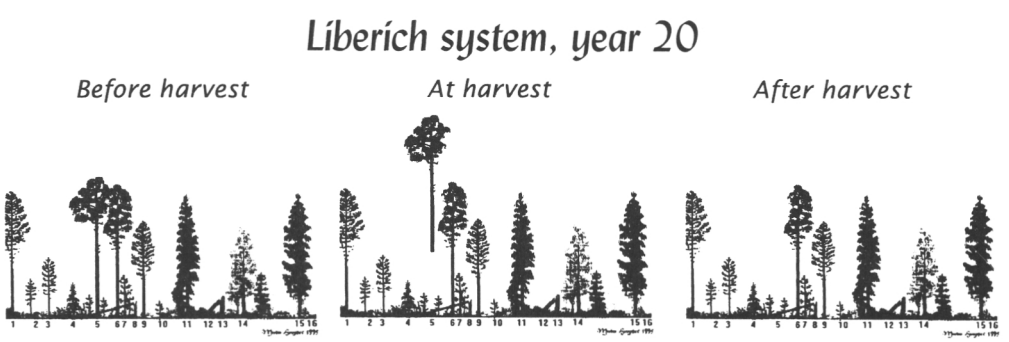

Figure 4b. A selective harvest according to the principles of Liberich.

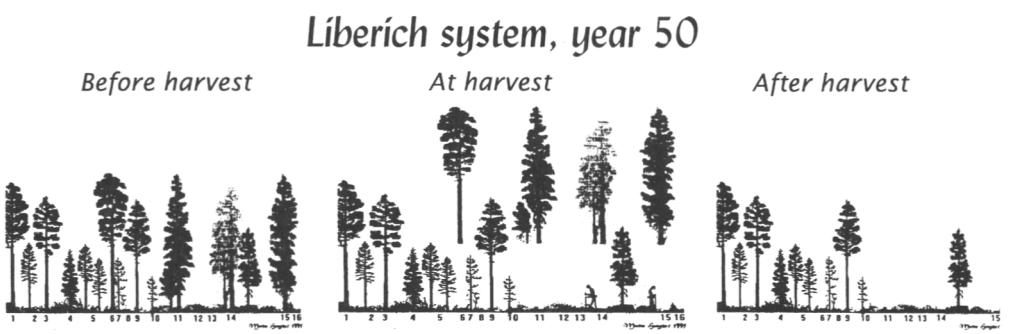

Figure 4c. A selective harvest according to the principles of Liberich. There is a need for enrichment planting at the right hand side of the plot.

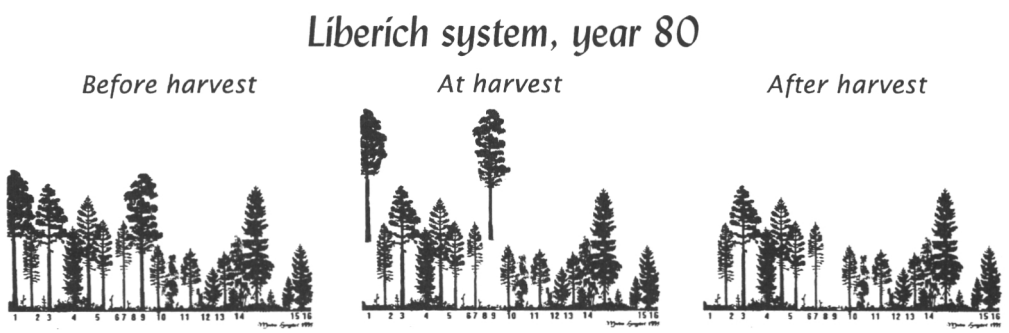

Figure 4d. A selective harvest according to the principles of Liberich.

Liberation without enrichment

There is a risk that some estate owners use the harvesting system described, without combining it with enrichment planting. Investigations have shown that the seedling bank normally does not provide total coverage of regeneration except for a few sites. Such sites are moist, rich sites, and poor lichen heaths. The most common sites in Sweden, characterised by *Vaccinium myrtillus* and *Vaccinium vitis idaea*, do not normally contain regeneration covering all the area. If a selection system is used on such sites, without consideration to the seedling bank, the stands will turn open and productivity will fall. In addition, the high revenue that can be reached on such sites mostly involves some pine, and the natural regeneration of that species is often too scarce (Petrini 1934).

Economy

Two features, tree size and wood quality (Fig. 5) chiefly explain the favourable economy of Liberich. Big trees give logs that are better paid per m^3. With increasing tree size costs for felling, delimbing, cross cutting and terrain transport are reduced. As planting costs have a square relationship to tree size, while volume and prize have a cubic relationship, costs for planting are also lowered with tree size.

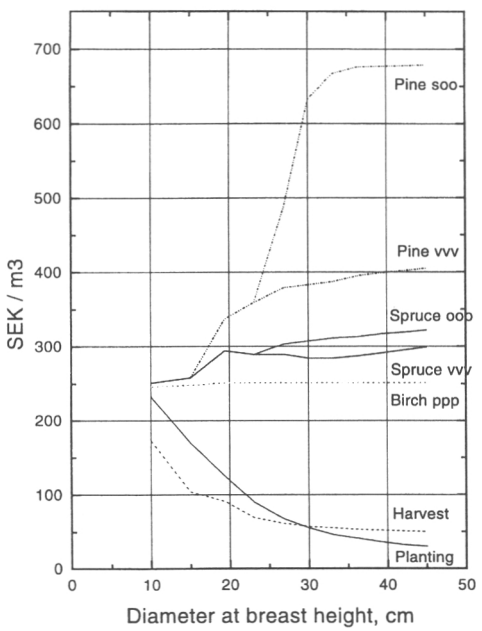

Figure 5. Value of wood from trees of different species and qualities. Costs for harvest: felling, bucking and terrain transport (Harvest). Cost for enrichment planting (Planting). *Pinus sylvestris* (Pine), *Picea abies* (Spruce), *Betula pendula* (Birch). Quality of first, second and third saw log, grades: best(s), second(o), third (v), fourth (p). Economic model TREE.

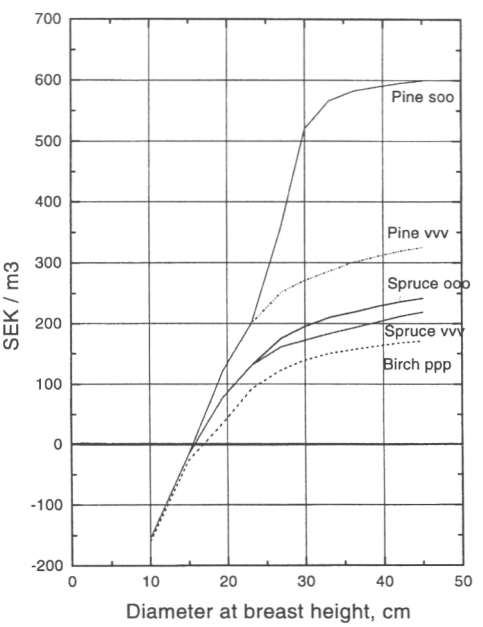

Figure 6. Net value of wood from trees of different species and qualities after deduction of costs for harvest: felling, bucking and terrain transport, and for planting. *Pinus sylvestris* (Pine), *Picea abies* (Spruce), *Betula pendula* (Birch). Quality of first, second and third saw log, grades: best(s), second(o), third (v), fourth (p). Economic model TREE.

The drawback of Liberich is related to higher harvesting costs as all operations have to be carried out inside a stand, where trees must not be damaged and where soil should not be disturbed or compacted (Hagner 1992, Dale, Kjöstelsen & Aamodt 1993, Persson 1993, Fjeld 1994).

If the planting and harvesting costs are deducted from the income, trees with a diameter less than 15 cm do not seem to give any profit at all (Fig. 6). Against this background it seems puzzling that clear cutting in northern Sweden is carried out where average dbh is close to 20 cm.

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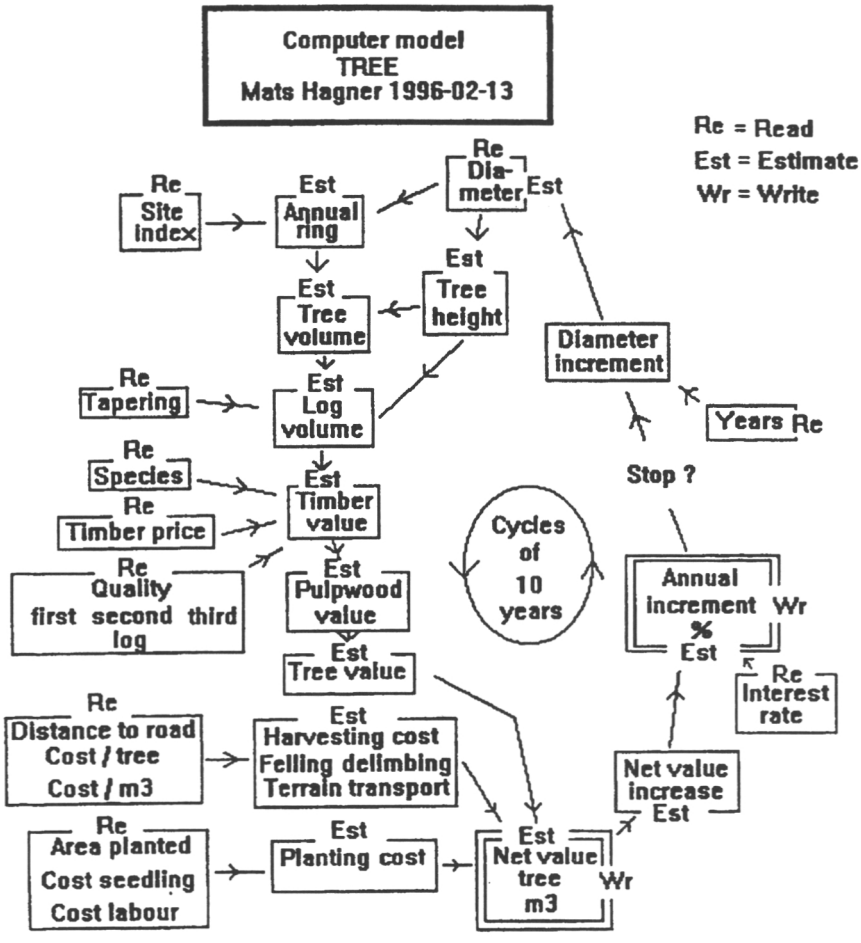
Appendix 1.

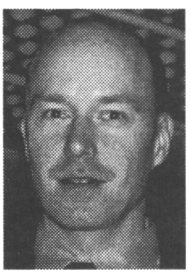


Computer model TREE which estimates the value of the standing tree and, if desired, subtracts costs for harvesting and enrichment planting. The model also considers growth of single trees and repeats the above values for every decade. Finally it gives the present net value for the tree at road side.

Harvesting costs are based on results obtained in the experimental series Liberich. One portion is a fixed cost per tree and the rest related to the tree volume. Planting cost is related to a circular area around the tree with a radius 0.2 x tree height. So far, the costs are not related to the distance to road.

ECONOMY OF GROWING TWO-STORIED MIXED STANDS

Sauli Valkonen



Valkonen, S. 1998. Economy of growing two-storied mixed stands. New stand types in boreal forestry. Metla, Research Papers 714: 127-132.

A birch overstory reduces the height and diameter increment of spruce seedlings only very little if its density is kept at a relatively low level. Consequently, growing a birch overstory of natural volunteers up to sawlog or veneer log dimensions seems to be an attractive option for the management of spruce plantations. A set of models describing individual tree growth in spruce stands with birch overstories was constructed and used for growth and yield simulation in a previous study. In this study, models for stand structure and post-release development were added. The model set was combined with a stand level growth and yield model set for middle-aged pure plantations into a simulator enabling the assessment of the whole rotation. A preliminary economic analysis was performed. Results indicated that growing a birch overstory is very profitable in a young spruce stand compared to its early removal. Analysis for optimal birch management regimes is under way.

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Introduction

Overstories of birch (admixture *(Betula pendula* Roth., *B. pubescens* Ehrh.) have traditionally been used to provide shelter for young spruce (*Picea abies* (L.) Karst.) plantations against night frosts, which can be a very serious problem at certain sites (Leikola 1976, Leikola and Rikala 1983, Hannelius 1978). A birch overstory reduces the height and diameter increment of spruce seedlings only very little if its density is kept at a relatively low level (Thamm 1988, Mielikäinen and Valkonen 1995). Price for good quality birch logs is very high in Finland, and pulpwood currently brings a good price too. Consequently, growing a birch overstory of natural volunteers up to sawlog or veneer log dimensions seems to be an attractive option for the management of spruce plantations. Additionally, a part of the overstory birches could possess remarkable potential for structural enrichment when retained over the whole spruce rotation or beyond (Franklin et al. 1997).

A set of empirical models describing individual tree growth in spruce stands with birch overstories was constructed and reported in a previous study (Mielikäinen and Valkonen 1995). Results of that study were introduced with a few simulation examples. They indicated that the production of birch greatly exceeded the loss in spruce growth in all cases included in the demonstration

runs. Economic calculations and optimisation of the treatment regimes were left to be done in the future. The purpose of this paper is to introduce preliminary results from the economic calculations that have now commenced.

Material and methods

Three model sets were used in the simulation.

1. The individual tree distance independent empirical models of Mielikäinen and Valkonen (1995) describe the development of spruce plantations with a well developed birch overstory. The data set included 31 stands from Southern Finland on relatively fertile upland sites. Stand parameters at measurement for spruce varied as follows: 15≤T (age)≤47 years, 640≤ N (density) ≤2950 ha^{-1}, 2.7≤ H_{dom} (dominant height) ≤11.7 m. The birches were larger, (11.7≤H_{dom}≤23.8 m), and more or less older (17≤T≤76 years) than the spruces. The data consisted of 406 spruce and 66 birch sample trees.

2. Since released stands were not represented in the data, a model set for pure plantations with individual tree distance independent growth models and size distribution models was used to represent alternatives in which the birch was removed at an early stage (Valkonen 1997). The data set had been put together from two different sources. First, a set of permanent sample plots in stands that were selected on systematic sampling grid of the 7th National Forest Inventory and measured three times at 5-year intervals was used. Secondly, a data set from temporary sample plots, that were subjectively selected with the help of forest extension organisations, was added. Stand age (T) ranged between 12-36 years, number of future crop trees (N) 930-3 560 ha^{-1}, dominant height (H_{dom}) from 1.5 to 10.8 m. The sample of 36 stands and 1900 growth sample trees covered all areas and most upland sites suitable for growing spruce in Finland.

3. The model sets 1 and 2 only covered the juvenile stages spruce up to H_{dom}<11 m. A stand level model set for pure middle-aged spruce stands was used for the rest of the rotation (Vuokila and Väliaho 1980).

An cross-testing procedure was performed in order to develop and validate the concerted and sequential usage of the models. Consequently, model 1 was found to perform best for the unreleased period and the next 5-year period thereafter. From then on, model set 2 was used, since the release effect was over and the spruces grew as fast as initially free grown trees of the same height or diameter. Additional models for generating the tree list at the simulation starting point were constructed.

Results

The starting point of simulations was a 15 years old spruce plantation of 1.5 m mean height and a density of 2 200 stems ha^{-1} , and a birch overstory of 500 stems ha^{-1} with a mean diameter of 10 cm and mean height of 10 m. Initial stand tree lists were generated with height or diameter distribution models and height-diameter relationship models. Three alternative treatments were simulated for both birch species *(B. pendula and B. pubescens)*:

1. Birch overstory completely removed
2. Birch overstory thinned (200 stems ha^{-1})
3. Birch overstory not thinned (500 stems ha^{-1})

Stand development was simulated with height and diameter growth models for 20 years, after which remaining birches were

harvested. From then on, development of the remaining spruce stand was estimated using the growth and yield model for spruce plantations (Vuokila and Väliaho 1980) until the end of the rotation (age 80-85 years). Sawlog and pulpwood volumes were calculated with taper curve models (Laasasenaho 1982) and translated into monetary values using average wood prices for Southern Finland.

The additional yield from growing the birch overstory and its monetary value were compared to slower spruce volume growth.

A typical management schedule from Vuokila and Väliaho (1980) was applied to the treatments. Thinnings (2) and harvest were applied at the same standing spruce volume level for all treatments. In the overstory variants they were delayed by a number of years depending on how much the birch overstory had reduced the growth rate of spruce (Table 1). The net present value of this delay was calculated using three interest rates, 1%, 3% and 5%.

The results indicated that growing a birch overstory was very profitable for all alternatives that were included in the exercise. The faster growing *Betula pendula* was a much better alternative than *B. pubescens.* A higher interest rate increased the profitability of birch overstory thanks to early returns from birch harvest.

Discussion

The purpose of the study was to calculate the profitability of growing a birch overstory up to sawlog dimensions in a spruce plantation. A few hypothetical management patterns were generated and simulated with three sets of models.

The preliminary results indicated that growing 200 to 500 birches per ha for 20 years caused a delay of 2 to 5 years in the development of the spruce plantation. This would mean a loss of 2-6 % sustainable yield on a forest property. However, the production of valuable birch veneer logs and pulpwood more than compensated the loss in economic returns. Furthermore, large returns from the birch on the first half of the spruce rotation were very valuable when interest was taken into account. With an interest rate of 5 %, the net returns more than doubled in the best birch alternative.

It is clear that the faster growing and better quality *B. pendula* is a much better alternative than *B pubescens.* However, *B. pubescens* also performed quite well. The management patterns were chosen subjectively to represent the range to be expected in practise. It seems that the optimal density would be between 200 and 500 ha-1 for *B. pubescens,* but could exceed 500 for *B. pendula.* Density and the length of the over-

Table 1. Volume production, sawlog percentage and delay in spruce volume development in treatments of birch overstory.

Treatment	Total yield m^3 ha^{-1}	Sawlog yield %	Delay in spruce development years
No birch	720	76	-
B. pendula 200 ha^{-1}	810	69	2
B. pubescens 200 ha^{-1}	800	55	2
B. pendula 500 ha^{-1}	930	67	5
B. pubescens 500 ha^{-1}	840	25	4

Table 2. Relative net present values for the treatments of birch overstory with 1 %, 3 % and 5 % interest rates. No birch = 100 % in each interest rate alternative.

Treatment	Interest rate		
	1%	3 %	5 %
No birch	100	100	100
B. pendula 200 ha^{-1}	117	131	155
B. pubescens 200 ha^{-1}	113	123	140
B. pendula 500 ha^{-1}	140	172	222
B. pubescens 500 ha^{-1}	113	121	136

story retention must be optimized in concert. The period used in this preliminary study might have been too short for some alternatives.

Wood quality remained outside the scope of the study. Probably the quality and sawlog percentage is a lot smaller than what the taper curve estimates would indicate, when birch is grown as a low density overstory. The sawlog percentage of *B. pubescens* is generally smaller than that of *B. pendula.* (Verkasalo 1997). Consequently, the calculations were also performed by reducing the birch sawlog volume by 50 % of the taper curve estimates. This reduced the relative net present values of the birch alternatives (Table 2) by 3-18 %, but they remained well ahead of pure spruce in all cases.

Obviously, the optimal birch management patterns are the next thing to produce. This work is on its way using the opimization tools of Valsta (1992).

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TREE GROWTH IN THE NEW STAND TYPES

Björn Elfving



Elfving, B. 1998. Tree growth in the new stand types. New stand types in boreal forestry. Metla, Research Papers 714: 133-140.

For general evaluation of tree growth and wood yield in the new stand types reliable growth simulators are needed. A complete simulator must include models for regeneration, tree growth and mortality. This paper only deals with tree growth.

General demands on tree growth models are discussed. Empirical/statistical distance-independent single-tree basal area growth models are proposed as the most realistic alternative for general evaluations. Such models are included in the MELA system in Finland and in the HUGIN system in Sweden. Possible and urgent improvements are outlined and exemplified. Knowledge must especially be improved on the following topics:

- Basal area as a measure of stand density. Tools are needed to distinguish sites with different carrying capacity. At a given basal area: have few large and old trees the same impact on tree growth as many small and young trees? Have spruce and pine the same impact on growth, despite higher biomass and more shade with spruce?
- Thinning response: time lag for response in relation to earlier suppression and site conditions, volume contra wood density in thinning response, selection effect and its decrease over time
- Alternatives to the age/dbh combination as expression for the growth capacity of the tree

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Introduction

With "new stand types" we mean uneven-aged and mixed-species stands, as opposed to manmade, even-aged monocultures. For a general evaluation of tree growth and wood yield in a diversified forestry we need reliable growth simulators. Direct empirical evaluation through field experiments can only cover some few examples. However, such examples are needed for calibration of the models.

There are numerous of ways to construct growth simulators. To evaluate the growth of uneven-aged and mixed-species stands it seems natural to use single tree models. There are baselines between distance dependent and distance independent models, and between mechanistic and empirical/statistical models. To my mind too little is still known about the complicated relations between site conditions and tree interactions to allow construction of reliable, general growth simulators based on the mechanis-

tic approach. On the other hand, empirical/statistical models should be constructed in such a way that basic relations can be properly expressed.

A complete growth simulator needs models for regeneration and ingrowth, tree growth and natural mortality. A proper functioning of all models is needed for evaluation of the long-term effects of different silvicultural operations. This paper will only deal with tree growth. Aspects on regeneration and mortality are given at other sessions of this meeting.

Many growth simulators of the advocated type have been constructed in the past decades. Viable pioneers in USA were Ek & Monserud (1974) and Stage (1973). The MELA system in Finland (Siitonen 1995) and the HUGIN system in Sweden (Lundström & Söderberg 1996) are also of this type.

Demands on tree growth models

Empirical/statistical models are strongly related to available data at parameter estimation and at application of the models. Logically, aboveground biomass would perhaps be the best expression for tree growth, but it is hard to measure and to break down to commercial components at valuation of the yield. The most used expression for tree growth is diameter or basal area growth at breast height. Volume growth can be estimated indirectly with help of static form height functions or through separate modelling of form height or height growth. In the latter case volume can be estimated with allometric volume functions. Also estimations of biomass components and assortment qualities can be derived by allometric functions.

Distance-dependent models are needed in evaluations of silvicultural methods that explicitly concerns the spatial distribution of trees. Advanced models of this type have been presented by Pukkala (1989) and Pretzsch (1995). However, in more general and long-term evaluations distance-independent models are probably sufficient to get a reasonable resolution. Tree interactions can still be accounted for if the area for stand description is of appropriate size.

The variation in tree growth, as reflected by the basal area growth at breast height, is very big. Even in pure and evenaged stands the variation coefficient for basal area growth between trees of the same size is of the magnitude 0.3 - 0.5, Fig 1. The growth is linearly related to tree size, but the correlation decrease with increasing age. If trees were growing independent of each other, we could expect that the growth variation between plots with 100 trees would be of the magnitude $0.4/\sqrt{100} = 0.04$. If fast-growers use resources given up by slow-growers, we could expect an even smaller variation. However, there is also a big, unexplained variation in time and space between plots. Several studies indicate that the variation coefficient for the unexplained variation in growth over longer periods is of the magnitude 0.1 (Eriksson 1976, Näslund & Stener 1984, Söderberg 1986, Kangas 1997). Despite the observed variation in tree growth it has seldom been taken into account in growth predictions. Stage & Wykoff (1993) demonstrated that this can give a too narrow diameter distribution and underestimate growth.

A key question is now to what extent existing growth simulators can forecast tree growth in the new stand types. The most general simulators available in the Nordic countries are the MELA system in Finland and the HUGIN system in Sweden. I have no experience of the MELA system, so my evaluation will be restricted to the HUGIN system. It was constructed 20 years ago and has not been much developed since that. I

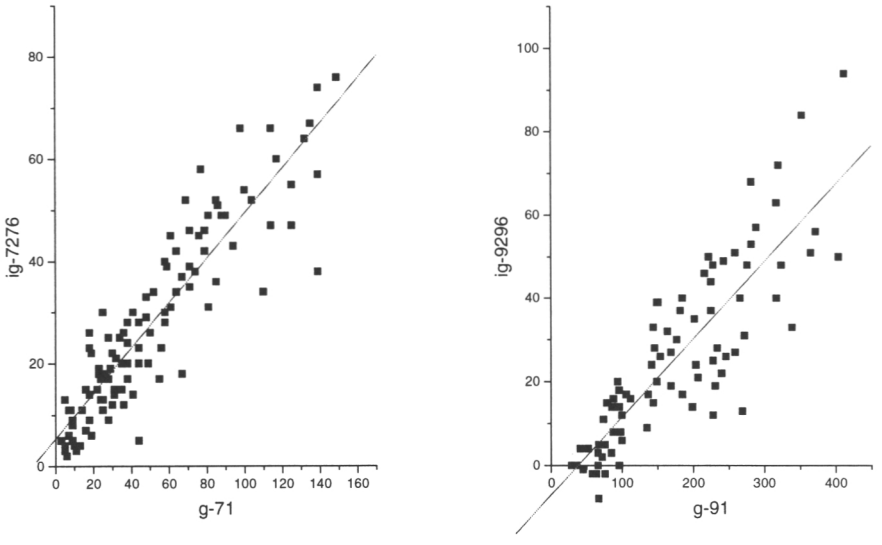

Figure 1. Relation between tree basal area before growth (g, cm²) and basal area growth in the following 5-year period (ig, cm²) for two periods in a young pine stand. Stand basal area was 14 $m^2 \cdot ha^{-1}$ in 1971 and 38 $m^2 \cdot ha^{-1}$ in 1991.

have especially scrutinised the distance-independent single-tree basal area growth functions used in this system. The functions were presented by Söderberg (1986).

Growth functions were constructed for 6 species, 2 age classes and up to 3 regions, so it is hard to get an overview of their general behaviour. Through simulation of data points with the various functions new data sets were generated and smoothed to one generalised function per species. For birch the function got the following form:

$$\ln(ig5) = -2.2350 + 1.0119*\ln(g) + 51.48/(t+10) - 0.006176*(t+10) - 0.3027*(G/(5+0.2*G)$$;

$ig5$ = 5 year basal area growth, cm² including bark

g = ree basal area before growth, cm² including bark

t = age at breast height, years

G = stand basal area before growth, $m^2 \cdot ha^{-1}$ including bark

This is a simple function with the basic relations included. The structure is essentially the same for all species. Tree growth increases almost linearly with increasing tree basal area and declines with increasing age and stand basal area. These functions concern pure unthinned stands on mesic sites of average fertility. There are general indications of higher growth on moist sites and lower on dry, and increasing significance of slope direction with increasing latitude: higher growth in south-slopes and lower in north-slopes. Pine and spruce also increase their growth level towards the south. Variables related to species mixture seems to be confounded with site variability. All species are predicted to grow best in spruce stands in the north and in pine stands in the south. The problem to separate site and species mixture effects can probably be overcome with use of the mixed linear model technique at smoothing, that is to separate the variances within and between plots (e.g., Hökkä et al. 1997).

To account for species differences in a proper way the following points should be considered:

- species differ in their development over age and time
- species differ in their interaction with the site properties
- species have different tolerance to shading
- species have different relations between basal area and tree biomass/ space occupancy

Let us now examine the given function in it's logical behaviour. The relation between tree basal area and basal area growth is not proportional, which can be seen in Fig 1. In open stands even trees with zero basal area will produce a substantial growth in a 5-year period. On the other hand, in dense stands there is a smallest tree size that can grow. By adjustment of the zero point, for the linear increase of tree growth with tree size, as a function of stand density, we can get a better description of the growth rate in different size classes in the stand.

A key question is if age should be included in the growth function. Its significance is related to the historical growth: age and tree size indicate past growth rate. After major disturbances and at higher ages this significance will decrease. Crown size and other measures of tree vitality are then better indicators of the trees capacity to grow. The problem is to find other measures that can be forecasted in a proper way to have significance in long-term projections. Much attention has been paid to crown size and crown expansion. Stage (1973) used crown ratio instead of age in his model. Cole & Lorimer (1994) found that a simple measure of exposed crown surface was an efficient variable together with dbh to predict growth in unevenaged hardwood stands. To be efficient in long-term projections, separate predictions must be done for these other measures. They may not be directly dependent on the tree diameter.

The stand density effect, as expressed by the stand basal area, has been modified in the generalised functions. In the original functions this effect was expressed by a second degree polynom, which resulted in increasing growth in denser stands after a minimum at 40-50 $m^2 \cdot ha^{-1}$. This is probably in accordance with the basic data but gives an erratic picture of the stand level growth. The maximum attainable basal area (the carrying capacity) varies between sites in an largely unpredictable way, and the tree growth at given G seems to be related to this maximum. The problems with this variability in carrying capacity have lately been discussed by Sterba & Monserud (1993) and Skovsgaard (1997). The modified expression for density effect locks the relation in a logical way but is not empirically confirmed.

The thinning response has generally been calculated with special thinning response functions in the HUGIN system (Jonsson 1974, 1995). These functions express tree growth in thinned stand in relation to the growth in unthinned stand as a function of time since thinning and strength and form of the thinning. An alternative way to account for the thinning response is to use the thinning coefficients in the original functions. Trees in thinned stands were found to grow about 10 % better than expected at given density. Also the modified density in itself increases the calculated growth after thinning. Hynynen (1995) compared this density regulation method to account for thinning response with explicit modelling of the response. He found a difference in temporal distribution of the growth between the systems but no difference in the growth over a longer period.

Observed and predicted growth in new stand types: some examples

Green-tree retention, partial cutting and multistoried stands are some features of the new stand types which we can fear that existing growth models are less suited to handle. I will end up with some examples of this.

For preservation of biological diversity in the forest it is recommended to leave some old trees at the final harvest. To what extent will those trees compete with the new stand? In an unpublished study some old single-growing pine standards with 20-year old pine saplings below were examined. Based on the pattern of sapling diameter decrease in vicinity of the standards future growth was predicted. For plots with 10 m radius, with and without a standard, the same volume growth was predicted in the first 30-year period after clear-cut. However, in the following 60 years the plot with a standard was predicted to grow about 20 % less than the plot without a standard. Can we trust in this result? I have some doubt. A key question is if the basal area of old trees and young trees express the same competitive effect. On the other hand a quite different study by Rose & Muir (1997) indicates the same magnitude for the green-tree retention effect.

An example of tree response to heavy release cutting was given by Eklund (1952). A repressed spruce stand in northern Sweden, naturally regenerated after wild-fire around 1795, contained 30 000 st·ha^{-1} and 28 m^2·ha^{-1} before thinning to 1500 st·ha^{-1} in 1923. Ring width at breast height started to increase in the fourth year after release and culminated in year seven with an about four times wider ring, Fig 2. The generalised growth function predicts ring width in unthinned stand to 0.28 mm and in thinned stand to 0.62 mm. The former value is accurate but the latter is by far too low. Ac-

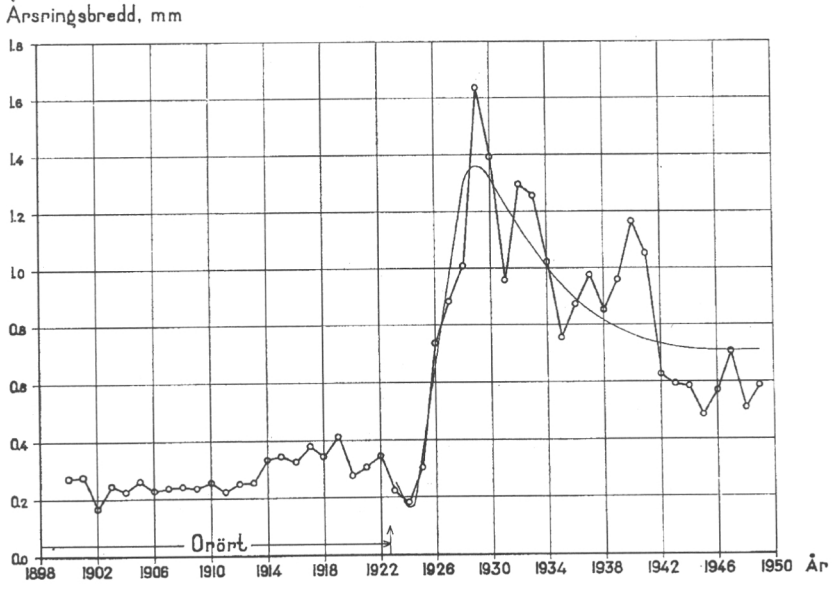

Figure 2. Annual ring development during the period 1900-1949 for spruce (34 trees) in a very dense stand that was heavily thinned in 1923. From Eklund (1952).

cording to Jonsson (1995) ring width 6-10 years after release should be 0.49 mm. No selection effect has been included in this calculation since growth before and after release have been measured on the same trees. It is obvious that thinning response needs further investigations.

Conclusions

In future work with growth models for evaluation of growth and yield in the new stand types I will stress the following points:

1. It is important to develop **general** tools for evaluation of alternative silvicultural treatments.
2. Existing functions for tree growth have obvious shortcomings and must be improved.
3. Knowledge must especially be improved on the following topics:

- Basal area as a measure of stand density. Tools are needed to distinguish sites with different carrying capacity. At a given basal area: have few large and old trees the same impact on tree growth as many small and young trees? Have spruce and pine the same impact on growth, despite higher biomass and more shade with spruce?
- Thinning response: time lag for response in relation to earlier suppression and site conditions, volume contra wood density in thinning response, selection effect and its decrease over time.
- Alternatives to the age/dbh combination as expression for the growth capacity of the tree.

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DEVELOPMENT OF TREE STAND DURING A PROTRACTED NATURAL REGENERATION PERIOD OF SCOTS PINE

Pentti Niemistö



Niemistö, P. 1998. Development of tree stand during a protracted natural regeneration period of Scots pine. New stand types in boreal forestry. Metla, Research Papers 714: 141-146.

The effect of pine trees left as hold-overs on the structure and development of young stands was examined on 69 regeneration sites in southern and northern Finland. Also the increment of Scots pine seed trees was measured. On average, the seedlings were measured and seed trees bored 17 years since regeneration felling (range 8-35 years).

Due to competition at the root system level, the young growth around seed trees left to grow for lengthy periods of time had become sparse with openings here and there. The height increment of young trees was so much the slower the closer such a seedling was to a seed tree.

Increment of seed trees began to increase approx. three years from the time of regeneration felling and in 15 years their volume increment per year almost doubled. Due to the drastic reduction in number of trees per hectare, radial increment was most pronounced at the base of the trees. The volume increment, with a mean of 1 m^3/ha/yr, consisted almost entirely of high-quality saw timber. Due to poor stem form, however, about half of the volume increment will be unsuitable for the production of sawn goods.

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Introduction

Increment data for forest growth models is needed on the new stand types including hold-over trees. One source of material in this sense is provided by stands of seed trees where the widely spaced trees were standing over the normal regeneration period.

The purpose of this paper is to report on the impacts that the hold-overs left standing have on the structure and development of new growth. The initial results were publiched earlier in Finnish (Niemistö et al. 1993). Also the increment and stem form development of the remaining pine trees was examined after a drastic change in the growth conditions in connection of seed-tree felling for natural regeneration.

Material

A total of 69 regeneration sites relying on seed trees were measured throughout Finland (Fig. 1) with the emphasis on northern Finland. The basic criteria was at least 8 years having passed since the regeneration felling. Two to three circular sample plots of the kind described in Fig. 2 were established in each stand. Increment measurements of seed trees were based on increment boring made of a total of 1576 trees.

The average spacing of the seed trees was 75 per hectare for the material as a whole and the average age of the growing stock at the time of regeneration felling was 115 years (Fig. 3). The time passed since regeneration cutting varied within the range of 8-35 years and the temperature sum variation was within the range 750-1350 dd.



Figure 1. Location of the material.

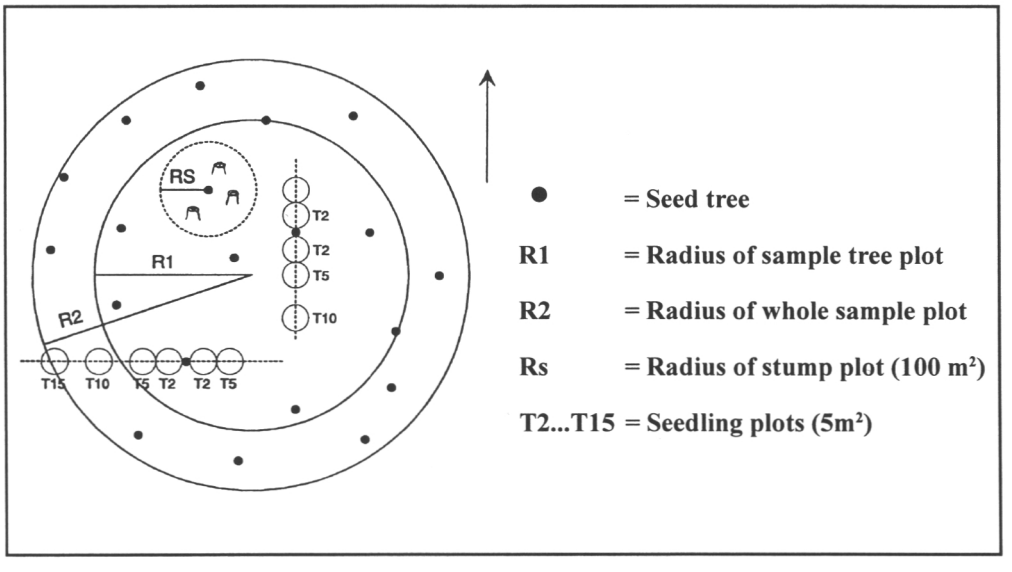

Figure 2. Structure of a study sample plot. Two to three such plots were measured in each stand.

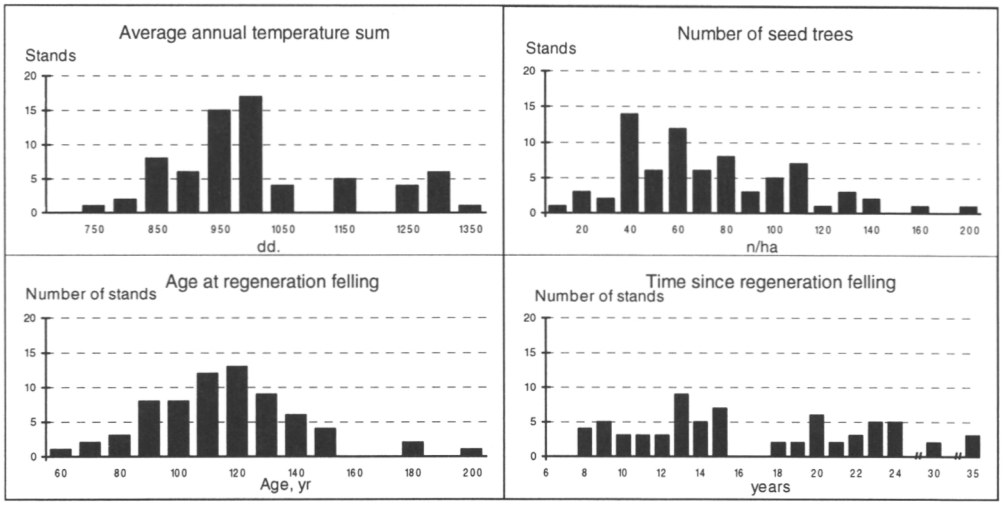

Figure 3. Distribution of the number of stands included in the study terms of temperature sum, number of seed trees per hectare, their age, and the time passed since the regeneration felling.

Influence of hold-overs on structure of young stand

There were 30-40 % less seedlings next to seed trees than at a distance of 10 m (Fig. 4a). The height of seedlings increased up to a distance of 15 m from seed trees (Fig. 4b). Another significant factor restricting restocking was the presence of a thick humus layer. Site preparation increased the number of seedlings on sites where the thickness of the humus was 3 cm or more. Average seedling age increased slower than the number of years passed since the regeneration felling. This is explained by the mergence of new seedlings and the death of older ones.

Volume growth and stem form of seed trees

The increment of the seed trees did not increase during the first 3-year period since the regeneration felling (Fig. 5). Thereafter, increment increased for over ten years and then remained at a level averaging almost double (= 1 m^3/ha/yr) that recorded for the same trees prior to regeneration felling. The number and volume of seed trees per hectare, temperature sum and time passed (in years) since the regeneration felling were selected as the independent variables included in the stand level volume growth model (Fig. 6).

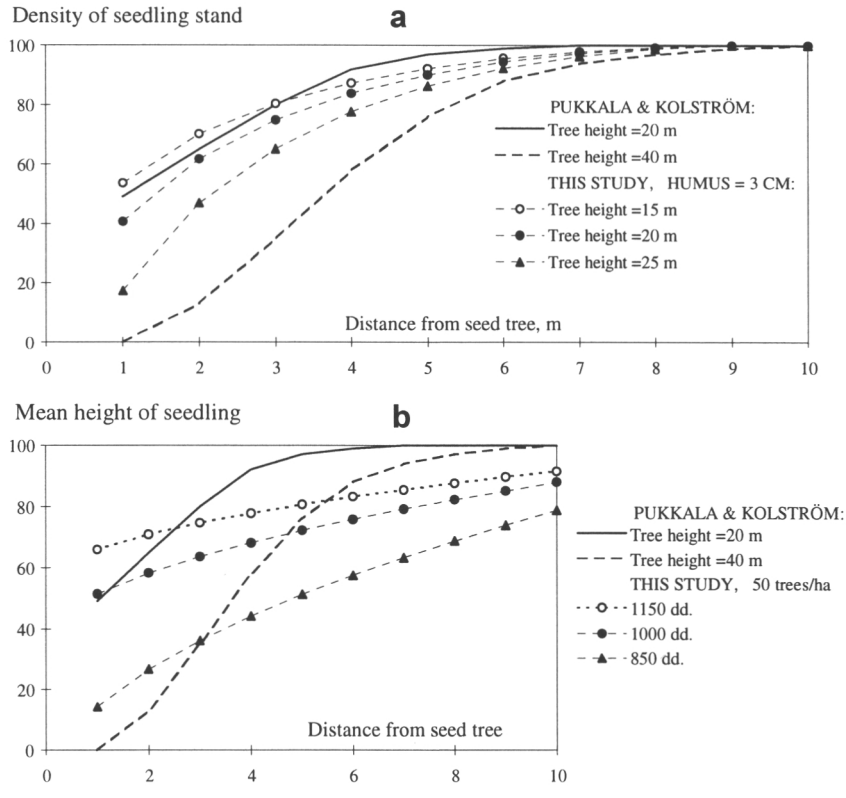

Figure 4. The relative density (a) and relative mean height (b) of young stand at various distances away from seed tree estimated using the models based on the study material and compared to the proportion of available growth resources as predicted by Pukkala & Kolström (1992).

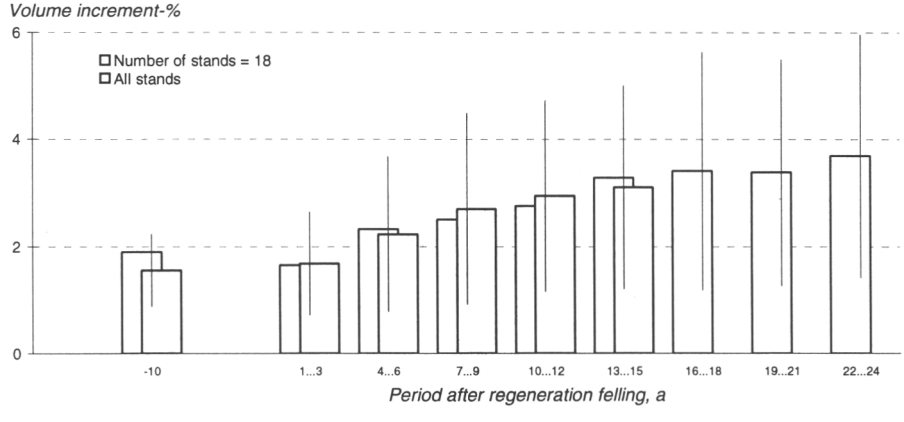

Figure 5. Mean volume increment-% of seed trees following regeneration felling as compared to the volume increment-% of the same trees during the precending 10-years period.



Figure 6. Predicted stand volume increment following regeneration felling for certain temperature sums (TempS), stem numbers per hectare (StemN) and initial growing stock (V) values.

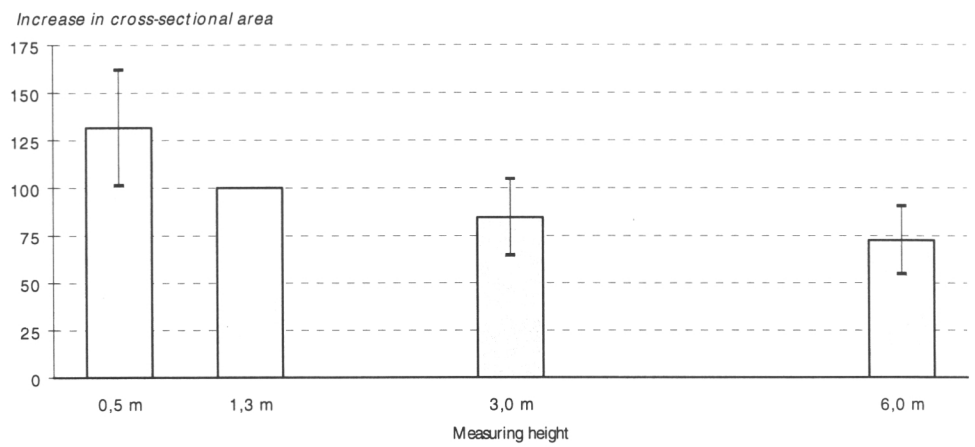

Figure 7. Mean cross-sectional increment of the stem at various heights over the 10-year period following regeneration felling in relation to tree's own increment at breast height (=100).

The cross sectional increment of the seed trees was reduced by nearly a third when comparing measurements made at 0,5 m above ground level and at breast height (1.3 m) and by another third when comparing measurements made at breast height to those made at 6.0 m (Fig. 7). Cross-sectional growth models were formulated for four heights (0.5, 1.3, 3.0 and 6.0 m) using mixed linear model technique for the purpose of predicting individual tree growth. Worsening of stem form reduces economic returns because only half of the seed trees' volume increment can be exploited by the sawmilling industry (Fig. 8). The other half ends up as pulpwood.

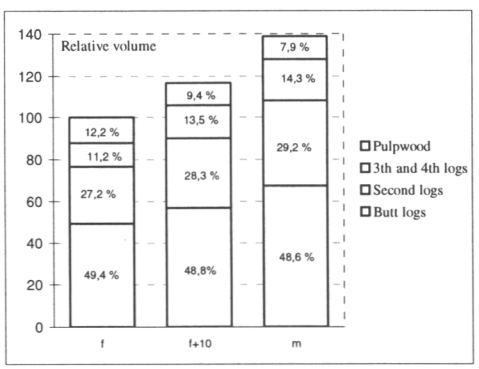

Figure 8. The amounts of saw timber and pulpwood in the seed tree material immediately following regeneration felling (f, total = 100), 10 years later (f + 10) and at the time of measurement (m, on average 17 years since felling).

Discussion

Leaving seed trees to grow for prolonged periods in excess of the time required for regeneration is not economically feasible in pine stands, because competition at the root system level causes undue restriction to the development of new growth. The timber produced consists mostly of knot-free saw timber, but poorer stem form means that half of the increment ends up as chips for the pulp and paper industry. Reasons such as forest certification and landscaping may favour two-storeyed stands as tending goals. On nutrient-poor sites this goal is difficult to attain without the application of intensive measures such as site preparation and fertilisation.

Scots pine is able to exploit improved growing conditions and the more abundant availability even at an old age. Growth increases for about 15 years following regeneration felling and then levels out. On regeneration sites with seed trees this characteristic needs to be taken into account when comparing the economics of different regeneration methods. The increase in growth does not, however, provide adequate grounds for leaving seed trees standing longer than is required for the establishment of new growth. At the same time, one should take into consideration logging costs, the capital tied up in the growing stock and the risk of wind damage.

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NEW STAND TYPES IN THE COASTAL AREAS OF THE GULF OF BOTHNIA

Kristian Karlsson



Karlsson, K. 1998. New stand types in the coastal areas of the Gulf of Bothnia. New stand types in boreal forestry. Metla, Research Papers 714: 147-152.

Rapid land uplift, soil quality and climatic conditions, and the historical use of forests make the coastal area forests around the Gulf of Bothnia very much different than for example forests in the inner parts of Finland. In the coastal region much of the general interests in forests is focused on the seashore forests. The usual regeneration strategies applied are presented here together with a description of other acts taken to preserve nature.

The possibilities to increase the number of stems left at final harvest is discussed critically. Other solutions to maintain biodiversity as well as economical and social sustainability will be sought for. A research project has started in the Finnish Forest Research Institute where the special ecological and management aspects of the coastal area will be examined. This research will provide some information for managing 'new stand types' as defined in the presentation. Still, a more direct approach is needed in order to provide several different management alternatives for the seashore forests that the public is expecting.

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Regional zonation

Coastal zones have not earlier been separated in soil, climate and vegetation classifications used in forestry in Finland. Still, it has been commonly recognized that coastal area and archipelago forests are different from the ones in the inner parts of Finland. Some differences between stand characteristics of forests along the Gulf of Bothnia compared to the forests in the middle and eastern parts of southern Finland were described by Karlsson (1996). Based on these differences the area below 80–100 m above sea level was referred to as a coastal area. This area has been covered by the Lithorina sea and has gradually risen above sea level as a result of isostatic rebound (Atlas of Finland 1990). The reason for the differences in forest characteristics between regions are, thus, mainly the structure of the soils close to the coast, to a lesser extent climatic conditions and historical use of forests.

As such the coastal area stretches some 20–50 km away from the shorelines and one of the administrative forestry organizations, the forestry board district of Ostrobothnia,

is entirely located within that area. This administrative region covers 476 000 ha of forest land (Aarne 1993), which generally is less productive than forest land in the middle and eastern parts of southern Finland (Karlsson 1996).

When extending the view to other coastal areas of Finland one should notice that there are some significant changes in the growing conditions, not only the climate but also soil and topography (Atlas of Finland 1986). Going further up north the portion of sedimentary soil gets larger and the moraine soils less common. And on the south and south-west coast of Finland exposed bedrock and shallow soils on the bedrock result in a large portion of relatively dry sites with pine as the main, naturally occurring tree species. The differences in growing conditions between the south-west coast and the coast of the Gulf of Bothnia are clear and they have also affected the silvicultural practices used in these areas.

It is much more difficult to define seashore forests according to growing conditions. Conditions change slowly as one goes from the inland down to the shore, generally with an increasing soil fertility but also increasing exposure to the maritime climate. Seashore forests have recently been defined as forest management units within management plans reaching the shore line or as close to this as 50 m or less (Karlsson 1997). This definition is based on actual forestry practices, since a forest manager would have to take the seashore into consideration when applying silvicultural treatment to such forest stands. The following figures are for the forestry board district of Ostrobothnia, where the area of seashore forests is relatively small (< 12 % of the region), but the length of the shoreline (6900 km) and the number of islands (11 000) very large (Atlas of Finland 1986). The rapid land uplift can result in an increase in land area of as much as 750 ha or 0.2 % annually

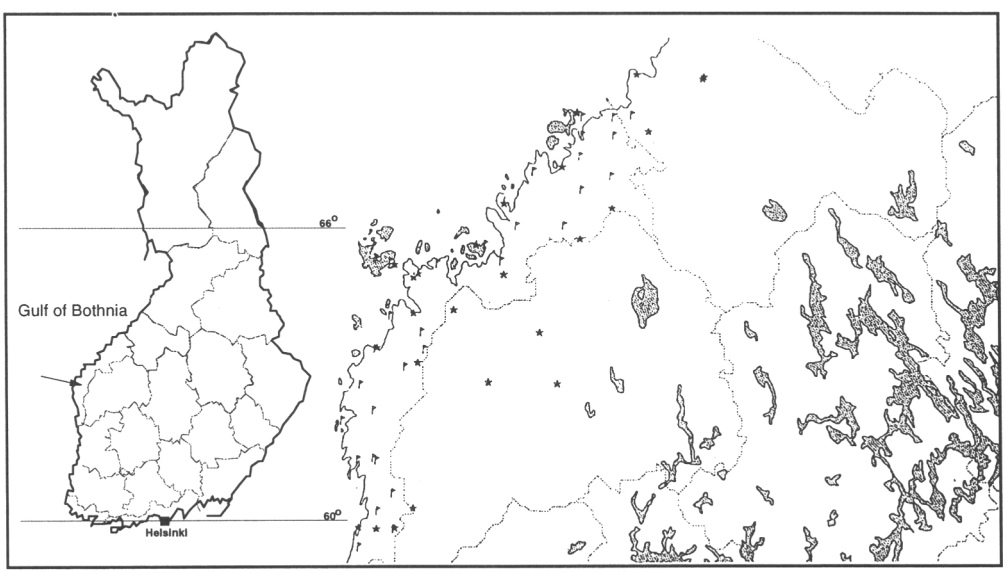

Figure 1. Arrow showing the forestry board district of Ostrobothnia (left), which is located within the coastal area. Same area enlarged (right), symbols showing some survey plots used in the project 'Sustainable forest management in the coastal areas of Ostrobothnia.

(Suomen pinta-ala kunnittain 1982). The seashore forests, especially pure spruce or spruce dominated stands on very fertile soils, are the most productive forests within the coastal area (Karlsson 1996). Much of the human activities are also concentrated to an area close to the sea.

Regeneration in seashore forests

An inventory of regeneration areas located in seashore forests within the forestry board district of Ostrobothnia was carried out in 1995–96. The goal of this inventory was on the one hand to evaluate the regeneration result from a traditional forestry point of view and on the other hand to describe specific acts taken to preserve nature during the regeneration (Karlsson 1997).

The seashore forests had generally been regenerated by planting new trees after a final harvest, where old-growth spruce had been clear-cut. This was the case on 96 % of the regeneration areas. Some trees had been left standing on 38 % of the clear-cut areas, but not to a larger extent in the seashore forests than in other parts of Finland. The average volume of those trees left were 19 m^3 ha^{-1}. The investigation also included observations of how well key biota's had been preserved during logging and regeneration. The result was that the regeneration areas in the seashore forests were very much like any clear-cut areas in Finland, except for an additional riparian zone or a corridor, which in most cases had been left between the logged area and the shore. 97 % of the regeneration areas had a riparian zone wider than 5 m, the average being about 40 m. The area left out from the main logging practices was, thus, 22 % of the total area included in the investigation. The forests in the riparian zone consisted of several tree species and the standing volume was 140-150 m^3 ha^{-1} in pine or spruce dominated areas and 106 m^3 ha^{-1} in alder or birch dominated stands as an average. Light thinnings for domestic fuel wood had been done in some riparian zones, but over 50 % were untouched. The riparian zone had a large variation in tree species composition, but there is also in many cases a large variation in size and age distribution, since the stand development close to the sea is part of the primary succession on land exposed after land uplift (Svensson, this publication).

Increasing diversity

No other coastal areas of Finland were included in that inventory. We know, however, that the regeneration strategy is quite different in the south and south-west archipelago of Finland compared to the coast along the Gulf of Bothnia (Köhler 1996). The conditions there are very favorable for natural regeneration, since the sites are dry and pine dominated. During recent years small patches within large logging areas have been clear-cut, still leaving large areas in between completely unlogged. Many single trees and groups of trees have also been left on the logged areas to ensure natural regeneration. Even if no investigations have been done, one can conclude that this results in a larger biodiversity and landscape diversity than the regeneration regime registered in our inventory along the Gulf of Bothnia.

Still, the possibilities to increase diversity by logging small patches and using natural regeneration are restricted along the Gulf of Bothnia, because of the growing conditions. The spruce forests along the Gulf of Bothnia are very sensitive to exposure in late stages. Both the degree of exposure to climate and the sensitivity of the spruce trees are larger on the Finnish side than on the Swedish side of the Gulf of

Bothnia (Raitio 1996). The larger sensitivity would mainly be a result of the specific soil conditions on the Finnish side. Late thinnings or cuttings for shelterwood stands will result in trees drying out as exposure increases, it will also increase the risk of wind-induced damage and spruce decay will advance. Leaving more spruce on the regeneration areas would then have small benefits on the regeneration result and the landscape, but it can be done as a way of increasing dying and decaying wood (biodiversity) on the regeneration area.

New stand types and research topics

In the coastal region along the Gulf of Bothnia the public demands for new forestry will focus largely on the seashore forests. The riparian zone is the essential element making the seashore forests 'new stand types' after the common regeneration regime used. In this specific environment there is a lack of information about the relationship between the riparian zone and the regeneration area. Ecological and economical criteria for determining the minimum size and the shape of the riparian zone are needed as well as knowledge of alternatives such as gradual transition zones between riparian zone and regeneration area.

In some cases the riparian zones will be left completely untouched as nature reserves, but in most cases some kind of treatment is needed in order to achieve ecologically, economically and socially sustainable forest management (Baeredygtigt skovbruk i Norden). It is possible to apply general silvicultural treatments in this zone as if it was a separate stand, but this would not always meet the public demands. Taking into account the uneven stand structure, selective cuttings can be one alternative for management on some sites. Some moist seashore forests seem to have a sufficient production of seedling and saplings to make a continuos silvicultural system possible. The practical arrangements are, however, difficult and the economical benefits unclear. The most economically attractive alternative to traditional stand treatment would be regeneration through clear-cut and planting after a prolonged rotation with selective thinnings preserving the uneven-aged structure of the stand. The effects of the alternative treatments on biodiversity, landscape and recreational values must also be evaluated.

These research topics will partially be addressed in the project 'Sustainable forest management in the coastal areas of Ostrobothnia', a research project launched by the Finnish Forest Research Institute last year. One main goal is to adapt general growth models for the specific environment along the coast of the Gulf of Bothnia. Simulations can then provide some solutions to the problems and uncertainties described. Clearly, some additional field experiments including alternative stand treatments are needed in order to draw new guidelines for practical forest management.

Conclusions

Forest researchers interested in the ecological, economical and social consequences of 'new forestry' practices should consider to examine the south-west archipelago of Finland. This area has been the subject of less intensive forestry than the mainland of Finland for a period of at least ten years. In other areas diversity aspects have been introduced into forestry practices only recently.

The possibilities to intensify acts taken to preserve nature are more restricted in the fertile, spruce dominated seashore forests along the Gulf of Bothnia. The main regen-

eration scheme with planting after a final clear-cut will remain. The general interest will focus on the riparian zone left along the shore after clear-cut. Forest researchers should produce different alternatives to manage forests within these zones, evaluating the ecological advantages and disadvantages and economical benefits and costs of these alternatives as well.

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PREDICTING TREE GROWTH IN IRREGULAR STANDS

Jari Hynynen



Hynynen, J. 1998. Predicting tree growth in irregular stands. New stand types in boreal forestry. Metla, Research Papers 714: 153-158.

The consequences of the new silviculture on the development of growth models applied in forest management planning are discussed. From the growth modelling point of view, the most important result of new silvicultural methods is increased within-stand irregularity.

The performance of growth models applied to stands treated according to new silvicultural methods is largely dependent on how well we are able to describe the effects of within-stand irregularity on tree growth. Three types of irregularity brought up in the presentation are species mixture, variation in tree size, and spatial irregularity. Some alternatives in describing the effects of different types of irregularity on tree growth in individual-tree growth models are discussed.

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Introduction

The new silvicultural methods emphasizing the nature preservation and environmental objectives have a strong impact on the environment in which trees are growing. For forest policy and forest management planning, reliable information is needed about the consequences of this new silviculture to the future development of our forest resources. So far, reliable predictions are not available. The models of the growth simulation systems applied in practical forest management planning are based on information collected from commercial forests in which more or less "traditional" silviculture has been applied. These simulators can hardly provide reliable predictions for forests in which new silvicultural methods are applied.

Today, we do not yet have comprehensive empirical research results about tree growth in new stand types. However, we have much information about the growth responses of trees to various changes in the growth factors, although the information is mainly obtained from stands with relatively regular stand structure. Further, we can judge, how the new silvicultural practices affect the growth factors. We can apply this information assuming that our empirical knowledge about the responses in tree growth to growth factors is valid also in the new stand types. Nevertheless, we have to be aware of the uncertainty included in this assumption.

Growth and yield models applied in forest management planning and inventory updating have to be compatible with forest inventory data. Input variables of the models need to be restricted to a limited number of measured stand and tree characteristics available in forest inventory data. Thus, the inventory data should include the most important measures of stand structure, which are relevant for tree growth. When the structure of forest stands changes, we at least have to check that the information we collect from the stands is still up-to-date.

In this presentation it is discussed, how the structure of new stand types can be described in growth models using the variables available in forest inventory data, and how the growth models applied in forest management planning could be improved.

Description of within-stand irregularity

From the growth modelling point of view, the most important result from applying new silvicultural methods is increased within-stand irregularity. The irregularity in stand structure can be grouped into the three categories; species mixture, variation in tree size, and spatial irregularity (Figure 1).

Species mixture

As the result of the silviculture applied today, the proportion of mixed stands is increasing. In mixed stand, different tree species have different competition effects on a growth of a given tree. In Scandinavia, growth modellers have shown an interest in these effects since 1980's. Growth models for mixed stands have been developed both on stand-level as well as on individual-tree level (e.g., Mielikäinen 1980 & 1985, Agestam 1985, Thamm 1988). The effects of species mixture on the growth of a given tree can be taken into account by including the effect in the variable describing the stand density. This can be done, for example, with a variable expressing the proportion of tree species of total basal area, as in HUGIN-models (Söderberg 1986), or by expressing stand density variables separately by tree species, as in MELA System (Hynynen and Ojansuu 1996).

Experiences in validation of models suggest that the effects of species mixture can be predicted without a significant bias by applying the above mentioned techniques in model development.

Variation in tree size

In pure, even-aged stands, the within-stand size variation is mainly a result of competition. In growth models, size variation has been described with absolute and relative tree size. Tree diameter, tree basal area and tree height are the most common variables for the absolute tree size. The competitive status of a tree has been expressed using size ratios, such as ratio of tree diameter to diameter of largest tree in a stand (Söderberg 1986), or ratio of tree basal area to basal area of largest tree in a stand (Ojansuu et al. 1991). Cumulative basal area of trees larger than the subject tree (BAL) has also been applied in some models (e.g., Wykoff et al. 1982, Hynynen 1995). Tree crown ratio that is widely applied as a major driving variable in growth models (e.g., Wykoff et al. 1982, Burkhart et al. 1987) is also regarded to serve as a sensitive indicator of tree's competitive status.

In real forest stands, however, size variation among trees is often connected with age variation. Retained stems after final felling of stands, as well as utilizing advance growth in establishing stands are practical

examples of stand treatments producing size and age variation within stand. In these cases, many of the competition variables mentioned above cannot describe the competitive status of a tree detailed enough without additional information. For example, the growth response of understory trees to competition from overstory trees (high shade) may be quite different compared with the response to competition from trees of same height (low shade) (Oliver and Larson 1990).

Spatial irregularity

Empirical based knowledge about tree growth in spatially irregular, clustered stands is rather limited. Most of the results concerning the effect of spatial pattern of trees on tree growth have been obtained from simulation studies that are based on the relatively narrow empirical data (e.g., Pukkala 1988, Pukkala and Kolström 1991).

To explicitly include the effect of spatial irregularity in growth models, distance-

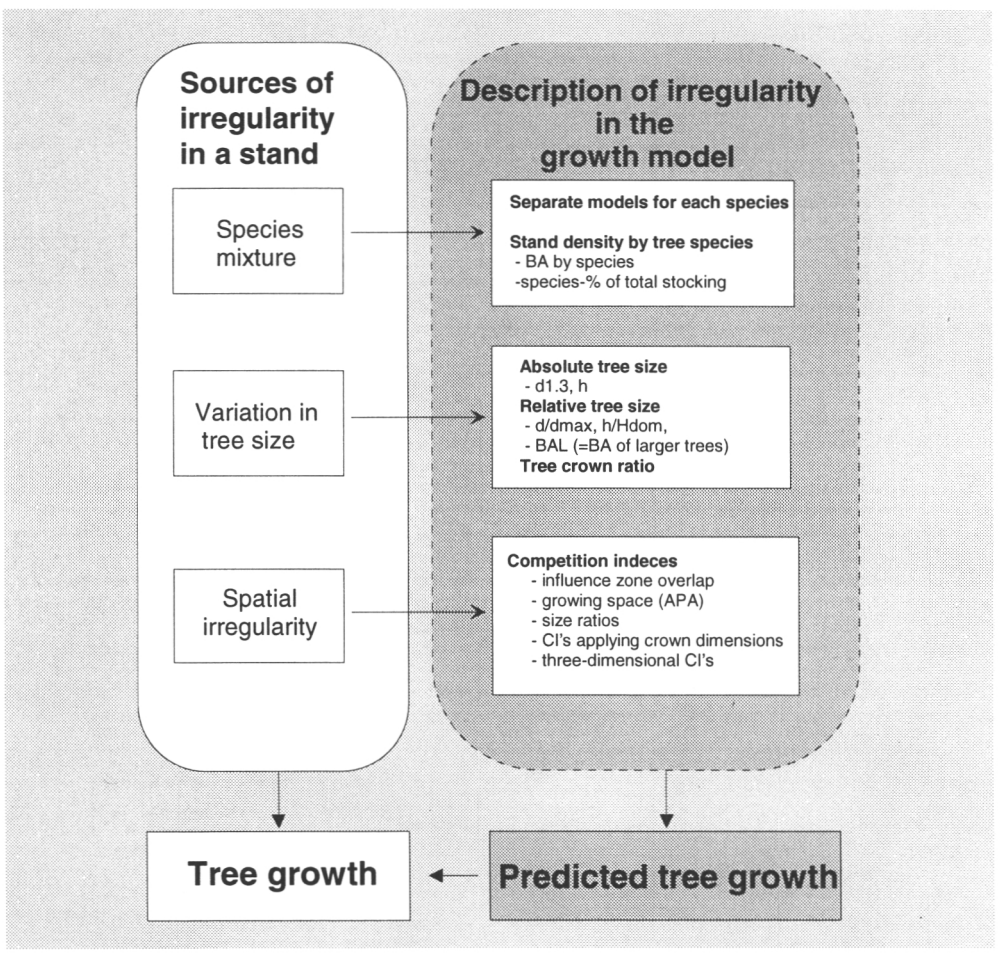

Figure 1. Description of within-stand irregularity in individual-tree growth models.

dependent models are needed. There has been developed a large number of distance dependent competition indices to quantify the competitive interactions from neighboring trees (e.g., Opie 1968, Bella 1971, Hegyi 1974, Biging and Dobbertin 1992). So far, introducing distance dependent competition indices into the models has not resulted in a significant improvement in growth prediction. One of the major reasons for this is, that a majority of the competition indices are strongly correlated to distance-independent tree characteristics, such as tree size.

Conclusions

Empirical growth models applied in forest management planning purposes cannot include highly detailed tree and stand description. Many variables that are used to describe competition in a stand and the competitive status of a subject tree can be derived from a small number of measured stand and tree characteristics. Therefore, many of tree and stand variables applied in growth models are strongly correlated. Applying complex model structure and adding too many variables into the model may easily result in overparametrisized models, that are highly data specific, difficult to interpret, and therefore difficult to apply as forest management planning tools. In developing models for irregular stands, special attention must be paid to the selection of variables into the model. The relationship between independent variable and tree growth should not only have a statistical correlation, but also a sound biological interpretation.

In new stand types, there are many factors affecting tree growth that cannot be described using variables measured in inventory data. Nevertheless, there are many other sources of empirical based knowledge that could be used also in model development. For example, results from physiological studies, as well as data from intensively measured arranged growth and yield experiments certainly provide valuable sources of detailed information. It is a challenging task for growth modellers to incorporate this detailed, but statistically not representative information into growth models.

Collection of data for growth models from new stand types requires further research, as well. The more irregular stand is the more attention we must pay to the methods applied in collecting representative data. For example, further research is needed to study the effect of sample plot size on stand density measures in irregular stands.

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LANDSCAPE ECOLOGICAL PLANNING IN METSÄHALLITUS – THE FOREST AND PARK SERVICE

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Karjalainen, J. 1998. Landscape ecological planning in Metsähallitus – The Forest and Park Service. New stand types in boreal forestry. Metla, Research Papers 714: 159-160.

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Metsähallitus - the Forest and Park Service (FPS) is a state enterprise that rules a good quarter of Finland's land area, i.e. 8.7 million hectares. One third of our land area is used for commercial forestry and two thirds of the lands are protected or recreational areas. Every year we sell over four million cubic meters of timber to our customers and that is the main source of income.

The tasks of the FPS are to manage, utilise and protect government-owned land, forest and waters. The FPS's lands serve many purposes. We produce timber, give work and income, promote nature protection and give recreation and pleasant experiences to people. The management of commercial forest is based on the sustainable use of natural resources.

One basic goal in the management of the commercial forest of the FPS is the maintaining and raising of the biological diversity. The Forest and Park Service and the Finnish Environment Institute have together developed landscape ecological planning in Finland. The landscape ecological planning is an ecological study of a large forest area of 10,000 to 80,000 hectares. This plan guides forestry operations and the utilisation of forest resources in such a way that the natural species of the forest area are maintained and the chances of the species to disperse are safeguarded in the long run.

The landscape ecological planning guarantees the biodiversity of large forestry areas in the future. We study and protect the occurrences of endangered and threatened species. Special attention is paid to saving important habitats. Valuable natural sites, such as herb-rich forests, lush mires, primeval forests, cliff tops, foots of steep cliffs, brook banks and other key biotopes are left uncut or will be treated imitating Nature's own ways of regeneration. Some ecological corridors and stepping stones are left. Clumps of living trees, dead standing trees and some decaying trees are left on the cut areas. Thus we ensure habitats for many endangered species. Buffer zones will be left along waterways in order to prevent the

leaching of nutrients and solid particles into waters, and to improve the scenery.

A participatory approach has been implemented in the process of landscape ecological planning, too. We have organised more than one hundred public meetings and established working groups with a wide range of interest parties. The participatory planning procedure we have executed has been welcomed with great appreciation.

The extent of the landscape ecological planning has grown significantly during the last year. Plans under preparation are in the finishing stage on a total of over 30 areas, or on nearly one million hectares. The target for 1998 is to make plans on the total area of 1.2 million hectares. It is our goal to cover all uniform state-owned land areas with landscape ecological plans by the end of 2000.

A guiding group of researchers, specialists and members of important interest parties has been established to develop and guide the landscape ecological planning within the FPS. We are looking for more detailed research data of how to amalgamate the demands of safeguarding the natural diversity and other special values of forests with forestry activities in the best possible and most widely acceptable way.

Minutes of concluding discussion

The objective of the concluding discussion was to define a common platform for continued Nordic co-operation within the fields of practical forest ecology and applied silviculture. Preparatory group discussions were held in four working groups led by Jörgen Bille-Hanssen, Mats Hagner, Jari Hynynen and Sauli Valkonen.

The groups were instructed to address three different aspects of future Nordic research co-operation. The first was Forest research and development of scientifically based silvicultural knowledge (I), the second: Economic and structural preconditions for research within the fields of practical forest ecology and silvicultural applications (II), and the third: Motives for Nordic co-operation and how efficient forest research networking among the Nordic countries should be organised (III).

Urgent research needs relating to new stand types were listed by all groups and general topics that were supported by the symposium participants are presented below (I, a-d). It was emphasised that projects including a wide variety of stand structures are needed and that our aim should be to reach beyond current and conventional methods. Some specific research efforts were recommended within each topic.

I Forest research and development of scientifically based silvicultural knowledge

a) Forest yield and biodiversity development prognoses following different forms of logging

- Monitoring of abiotic factors in uneven stand types
- Description of within stand competition
- Development of quantitative competition measures
- Ingrowth, regeneration and mortality models
- Estimation of risks for calamities
- Interaction between tree and site properties

b) Management plans to maintain or increase biodiversity values in current stand types

- Evaluation of efforts to enhance biodiversity values
- Value of buffer zones, corridors, eternal trees etc. for biodiversity and wood production
- Description, mapping, and nomenclature for uneven forest structure

c) Technology and wood quality

- Develop harvesting technique for selective cutting
- Stand structure effects on wood quality
- Develop technique for supplementary planting in uneven stands

d) Compilation of national data from long term monitoring of forest development

II Economic and structural preconditions for research within the fields of practical forest ecology and silvicultural applications

A majority of the participants seemed to agree that these questions have a greater importance from the national perspective of the Nordic countries than from the European (EU) perspective. Consequently several speakers proposed that research primarily needs national funding and that no major contributions could be expected from EU. Research projects focusing on boreal tree species common outside the Nordic countries and/or high altitude areas in central Europe might however improve the chances for EU-funding.

It was also suggested that we should try to obtain economic contributions and moral support for joint Nordic projects from SNS since that kind of back-up could be useful when applying for national and EU-funding. SNS also provides opportunities for co-operation with Russian and Baltic scientists which could be useful considering site condition and forest type similarities in our countries. Another possibility worth looking further into is to propose that Nordic forest companies together should set aside money for high quality applied silvicultural research. This would improve the chances for company-relevant projects to reach the advantages of critical mass and complimentary skills that only could be attained through Nordic research co-operation.

III Motives for Nordic co-operation and how efficient forest research networking among the Nordic countries should be organised

The formal organisation of Nordic research co-operation within the fields of practical forest ecology and silvicultural applications was discussed. The participants found meetings of the current type very valuable for the exchange of research ideas concerning forest management and silviculture. But no immediate need to establish a permanent research network was recognised. Progress in practical forest ecology and applied silviculture also depends on input from more specialised disciplines and a too tight organisation might be counter-productive. Some spontaneous working groups were however expected to form and a time interval of 2-3 years was suggested for meetings of the current type.

Final statement

During recent years, forest managers have altered the logging operations creating stands that are more uneven horizontally, vertically, and age-wise. Empirical data from uneven stand types is scarce and simulation models available today can not account for the variation found in these stands.

The need for new scientifically based knowledge is evident. A major challenge for the years to come will be to perform integrated research on forest yield, regeneration, wood quality and biodiversity. Without such an approach we will not be able to answer the current and future questions of forestry in the Nordic countries.

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