Growth of Retained Scots Pines and Their Influence on the New Stand

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Abstract

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In the 1990s, management practice in forestry changed from a main focus on timber production into a deeper concern also for biological diversity and aesthetics. Two features of the changing priorities were retention of old trees on final harvest areas and increasing edge zones due to smaller-sized clear-cuts.

The overall purposes of this thesis were to establish the growth of retained Scots pines (*Pinus sylvestris* L.) and quantify the effect of their competition on the new stand, and to establish the effect of edge zones on the production in adjacent young and old stands.

Four separate studies were carried out to (i) establish the growth of Scots pines after liberation and their effect on the production in the new stand on a specific site, (ii) model the volume of the new stand as dependent on distance to a retained tree under different site conditions, (iii) model the thinning response of totally liberated Scots pines under different site conditions and establish the variation in basal area growth, (iv) establish the tree growth and composition of field vegetation in edge zones between adjacent old and young Scots pine stands.

Data on tree growth (six cores per tree) and volume of surrounding stand was gathered from 104 totally liberated retained Scots pines and from edges of four borders between young and old stands.

The effect on the production in the new stand was estimated as a reduction with 2-4 % per ha over one rotation with 10 evenly dispersed Scots pines per ha. During the same period the retained Scots pines had grown with more than that.

Retained trees increased their growth in basal area after liberation independently of age. The response in basal area growth culminated 5-7 years after initial growth increase on a level of 2.5 above that before liberation and lasted for more than 20 years. Growth was expressed as function of diameter, age and height level in the tree. The coefficient of variation in residuals in basal area growth was estimated as 41 % composed of random variation within trees, between trees and between stands to approximately equal shares. Age and diameter explained 34 % of the variation in basal area growth.

Retained trees increased their growth in the lower trunk the most after liberation resulting in deterioration in stem form, though less than expected. Over time, the stem form improved.

Of field vegetation lichens (*Cladonia* sp.) and heather (*Calluna vulgaris* L.) were more common close to the retained trees than further away.

The spatial extent of the effect of an edge on production in old and young Scots pine stands was 5 m. In the young stands the volume in the 5 m zone closest to the edge was 10 % of that beyond 5 m. The equivalent zone in the old stand had a 57 % higher basal area than further away. The vegetation cover in the edge zones differed from that in the stands with increased lichen and decreased blueberry (*Vaccinium myrtillus* L.), lingonberry (*V. vitis-idaea* L.) and bryophytes.

Keywords: *Pinus*, retention, remnant, growth variation, yield, competition, liberation, thinning response

Contents

Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Jakobsson, R. and Elfving, B. 2004. Development of an 80-year-old mixed stand with retained *Pinus sylvestris* in Northern Sweden. Forest Ecology and Management 194, 249-258.

II. Jakobsson, R. and Elfving, B. Effects of retained trees on the production of Scots pine stands in Sweden. Manuscript.

III. Jakobsson, R. and Elfving, B. Retained pines growth pattern and growth variation as measured on increment cores from standing trees. Manuscript.

IV. Jakobsson, R. and Nilsson, M. Effect of border zones on volume production in Scots pine stands. Manuscript.

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Introduction

Background

In the second half of the 20th century, plantations and clear-cuts were introduced on a broader scale in Sweden and forest management focused on even-aged monocultures (Enander 2003), with the aim of maximising volume production for mainly industrial purposes such as saw-timber and pulp-wood production. During the 1970s other priorities changed the attitude of society and increasing societal demands for aesthetics and conservation were expressed in the Swedish Forestry Act of 1979 (Enander 2003, Anon. 2001). In the following decade, the change in attitude of society eventually resulted in equal focus in legislation of both environmental and production goals (Enander 2003, Anon. 2001), a development supported by international treaties such as the Rio conference in 1992 (Anon. 1992) and the Helsinki congress in 1994 (Anon. 1994), where aspects of biodiversity were brought up on a global agenda. In the boreal landscape one important factor affecting the biological diversity is the natural occurrence of forest fires (Zackrisson 1977, Engelmark *et al*. 1994) in terms of frequency, intensity and extent. In Sweden the native Scots pine (*Pinus Sylvestris* L.) is adapted to these disturbances by its thick bark that enables an old tree to survive fires. This fire dynamic could eventually lead to a multi-storeyed forest merely constituting of pine, e.g. the virgin forest in the inland of Northern Sweden in some areas had a stand structure of grouped old pines with patches of regeneration between them (Axelsson, 2001). Imitating such natural disturbance regimes could lead to prolonged continuity and increased structural complexity, giving species adapted to such forests a better opportunity to survive (Franklin, 1997).

One silvicultural practice to maintain and promote biological diversity is retention of old trees on final harvest areas (green tree retention, GTR). The Swedish Forestry Act of 1993 (Anon. 1994), states that bushes and trees or groups of trees are to be left on final harvest areas. Apart from that, the two major forest certification schemes in Europe, FSC (Anon. 2000) and PEFC (Anon. 2002), both demand a certain number of trees to be retained per ha. They cover 45 % (Anon. 2004) and 17 % (Anon. 2004) of the forest in Sweden and some 20 % (Anon. 2004) and 40 % (Anon. 2004) of the European forests, respectively. Today the proportion of forest subject to GTR has become substantial. In this thesis, by retention was meant the active process of omitting trees from harvest, retained Scots pines (*Pinus sylvestris* L.) being a result of such a process.

Retained trees could also be dead trees, but they were not included in this thesis. A similar term is remnant trees, which hereby is referred to as trees older than the surrounding stand and being present in the forest due to other causes than human. The stand surrounding a retained tree is hereafter referred to as the new stand.

Another effect of the changing silvicultural practices was that the area of edge zones, where younger and older forests meet, increased, due to reduced size of the clear-cuts. In Sweden the average size of clear-cuts at forest companies has decreased from 17 ha in 1980 (Anon. 1983) to about 9 in 2002 (Anon. 2003). For private forest owners the clear-cuts are even smaller (Anon. 1983, 2003).

Knowledge about how retained trees grow, to what extent they affect the production in the new stand, and how bordering new and old stands influence each other is important for evaluating the long term production and also for understanding the competition process among trees and between trees and other vegetation.

Competition

The limiting factors for plant growth were studied especially in the agricultural field in the mid 1800s by for example Liebig in Germany (Liebig 1840), and later the law of diminishing return (Mitscherlich 1909) was a landmark. Studies of the effect of interaction between neighbouring plants and expressions for density-size relations, named after their main contributors, are for example Reineke's stand density index (Reineke 1933), the reciprocal density-yield relation (Shinozaki and Kira 1956) and Yoda's $-\frac{3}{2}$ power law of self thinning (Yoda *et al.* 1963). The self-thinning law was later combined with relative stand density indices, such as Reineke's, and forest production theories (Newton 1997).

Within the plant ecology field, competition is divided into one-sided and two-sided, the one-sided being competition above ground (for light) and two-sided being competition below ground (for nutrients) (Weiner and Thomas 1986). Often the terms symmetric and asymmetric competition are used. Symmetric competition can according to Weiner (1990) be divided into relative size symmetric and absolute symmetric. With the latter term is meant that all plants use the same amount of resources, irrespective of their size, whereas the former term is meant that plants use the resources in relation to their size. In contrast, asymmetric competition means that larger plants use a disproportionately big share of the resources or have a disproportionately big effect on neighbours. When modelling competition, the type of competition is of importance for choosing model. By using spatial information of neighbouring plants only, a model would be absolutely symmetric. If also information of size is included, the model would be relative size symmetric. Finally, if the growth of a plant is disproportionately affected by a neighbour, a model would be asymmetric.

This thesis mainly dealt with below-ground or relative size symmetric competition substantiated by totally liberated retained trees in relation to the new stand established beneath them. In this case the competition for light can be regarded as negligible. The area shaded per unit of time of the stem of a free-growing Scots pine is small in relation to the area not shaded. Additionally, one study addressed a case where also asymmetric competition is likely to occur, since the effect of shading from an older stand on a younger can be substantial.

Thinning response

After a tree has been liberated there is an increased growth in the lower parts of the stem as reported for Scots pines by Fahlcrantz (1901), Nyblom (1927), Hagberg (1942), Valinger (1992) and Nimistö *et al.* (1993) and for Norway spruce by

Table 1. *Examples of investigations of the effect of liberation on retained or remnant trees*

Author	Year	Years without response	Years to culmination in response	Duration of response	Magnitude of response, % of growth prior to liberation
Fahlcrantz	1901	-	-	15-20	-
Nyblom	1927	-	-	10-12	-
Baader	1939	-	10	60	160
Hagberg	1942	-	5-10	15-25	-
Näslund	1942	2-4	-	-	-
Youngblood	1991	2	8	>14	264
Valinger	1992	-	-	-	150
Niemistö *et al.*	1993	3	15-20	>25	200
Holgén *et al.*	2003	3	7	-	200
Varmola	2004	2-3	7-8	-	200-300

(Abetz 1977) and Holgén *et al.* (2003). Often there is a period of 2-4 years of no response in stem growth, as reported by Youngblood (1991), whereas the roots show an immediate response (Urban *et al.* 1993). The culmination in stem growth has been reported to occur between 7-20 years after liberation with magnitudes of response in relation to the growth before liberation between 150-300 % (Table 1). The duration of the response period can vary, from about a decade (Nyblom 1927) to more than 50 years (Baader 1939) (Table 1). The effect of age on thinning response was investigated by Jonsson (1995), who found no effect of age on thinning response up to tree ages of 165 years.

Growth variation

For evaluation of growth models their accuracy and precision are important features to assess. Of these two, the precision is the most convenient to estimate since it concerns the random variation, while accuracy concerns both systematic and random errors and requires more data to assess. Matèrn (1961) measured radial increment on cores and estimated the within-tree coefficient of variation as 20 % and that between-tree as 25-38 %, in total 32-43 %. Fries (1966) estimated the within and between-tree coefficient of variation in diameter growth as 33 %. The growth varies both in nature and magnitude at different heights. Mäkinen (1997) reported increased variation at higher stem heights and lacking autocorrelation at those heights.

Growth of sheltered seedlings and trees

Effects of retained trees on the production of the new stand were observed in Sweden and Finland in the beginning of the 1900s on lichen (*Cladonia sp.*) type Scots pine heaths with zones of no or sparse regeneration within the vicinity of seed-trees (Hesselman 1909, 1917, Aaltonen 1919, 1923). For seedling height growth, Hagner (1962) estimated the reduction in seedling height growth as 40 % within 3

Table 2. *Examples of investigations on the effect of different degrees of density of retained or remnant trees on the production of the new stand. Species indicating Ps = Pinus sylvestris, Pa = Picea abies, Aa = Abies alba, Pm = Pseudotsuga menziesii, and Tp = Thuja plicata. Dev. stage indicates the development stage of the new stand, Early denotes stands up to ~4 m, Late denotes trees larger than that. Var is the measured variables, BA = basal area (*m^2*/ha), Ht = height, dens = number of stems per ha and V = volume. MAI is mean annual increment*

Author (year), country	Species	Dev. stage	Variable	Retention level, st/ha	Retention level, m^2/ha	Growth reduction, % (Var)	Spatial extent (m)
Mang (1956), Germany	Ps, Pa, Aa	Early	V			10 (V)	6
Hagner (1962), Sweden	Ps, Pa	Early	Ht	36-310		40 (Ht)	6-8
Ackzell&Lindgren (1992), Sweden	Ps	Early	Ht	60		22 (Ht)	
Niemistö *et al.* (1993), Finland	Ps	Early	Ht, dens	10-200		78-26 (Ht)	15
Skoklefald (1995), Norway	Ps	Early	Ht, dens	20-128		~25 (Ht)	>6
Valkonen *et al.* (2002), Finland	Ps	Early	Ht, dens	>20		6 (Ht)	6
Birch and Johnson (1992), USA	Pm, Tp	Late	V	0-49	16-38	6-25	
Long and Roberts (1992), USA	Pm	Late	BA	49 (0-86)	8.5 (0-14.5)	15-50 (V)	
Rose and Muir (1997), USA	Pm	Late	BA	0-45		0-72 (BA)	
Acker *et al.* (1998), USA	Pm	Late	BA	10 (3-57)	10 (5-48)	26 MAI (BA)	

m of a retained tree in seed-tree stands with 30-300 stems per ha. Ackzell and Lindgren (1992) reported a 22 % reduction in height growth in Scots pine seed tree stands with 60 stems per ha and Niemistö *et al.* (1993) a reduction of 28-76 % with 30-200 stems per ha. Skoklefald (1995) found reductions in height growth of 38 % comparing seedlings at distances of 3 m and more than 9 m from retained Scots pines. Valkonen *et al.* (2002) modelled the effect of retained trees on the seedling height growth, diameter growth and area of maximum branch diameter and total branching, with on average 15 % lower seedling height, 11-16 % lower diameter and 9-10% lower maximum branch diameter within a circle of 10 m radius.

The spatial extent of the competition effect of a retained tree on the new stand was in studies by Mang (1956), Hagner (1962) and Valkonen *et al.* (2002) estimated at 6 m whereas Niemistö *et al.* (1993) and Skoklefald (1995) noticed effects at distances further than 10 m (Table 2).

For estimating the effect over longer periods than prior to first commercial thinning, such as at least one rotation, retrospective studies can be used. In Germany, Mang (1956), reported reductions in volume production in Scots pine stands with 180-year old retained Scots pines with a 90-year old understory with Scots pine, Norway spruce (*Picea abies* L. Karst) and fir (*Abies alba* L.) as about 10 % within the crown radii of the retained Scots pines. In natural stands in the USA, with old remnant Douglas firs (*Pseudotsuga menziesii* (Mirb.) Franco) growing in younger stands, the remnants caused a significant reduction in the younger stand at remnant densities above 15 trees per ha (Rose and Muir 1997). In an 80-year old Douglas fir stand with remnants of western red cedar (*Thuja plicata* Donn ex D. Don) the mean annual increment was reduced with 20% due to the remnants (Long & Roberts 1992) and in a stand with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) as remnants the mean annual increment was reduced by 26% (Acker *et al.* 1998) (Table 2). Similar studies for Scots pine in Sweden have been lacking.

Edge zones

The edge effect can be defined as changes in biotic and abiotic factors that exist along the border of a habitat fragment relative to the interior environment (Gehlhausen *et al*. 2000). The edge zone is then the spatial extent of the changes (Cadenasso *et al*. 1997). The effect is influenced by the aspect, slope and physiognomy of the edge (Murcia 1995). Nordlander *et al*. (2003) showed greater effects on air and soil temperatures on sun-exposed than shaded edges of a clear-cut, the latter showing a distance-dependent effect too. Further, the edge effect can constitute abiotic and biotic effects (Murcia 1995) and the effects can be direct or indirect such as increased incoming radiation near the edge which changes the temperature and air humidity. Chen *et al*. (1995) reported changes in short-wave radiation at a distance of 30-60 m into the forest from the edge and as far as 240 m for air humidity and wind speed in the Pacific Northwest of USA. The changed abiotic conditions will in turn affect the flora and fauna communities. Light and nutrient demanding vascular plants like wavy hair-grass (*Deschampsia flexuosa* L. trin) and fire-weed (*Chamaenerion angustifolium* L. Scop), will be favoured as compared to more shade tolerant species such as several bryophytes (Hansson 1994).

Considering the effect on the production of the new stand, Chantal *et al*. (2003) reported an adverse effect on seedlings of Norway spruce (*Picea abies* (L.) Karst.) in an open clear-cut surrounded by dense forest depending on their position relative the sun. In British Columbia, lodgepole pine (*Pinus contorta* L.) seedlings were suppressed near the edge, especially on northerly exposed sites (Burton 2002). In north-western USA, Hansen *et al*. (1993), reported a negative effect on the production of the new stand for at least 20 m in Douglas fir stands. In studies of edge effects, it is important to clearly define the edge.

Model formulation

A model can generally be described as an abstraction of some aspect of reality. Models for describing tree growth can be divided into empirical and mechanistic or process-based models (Vanclay 1994). Empirical models are often used to describe or quantify the growth of forests. The purpose of mechanistic models is often to understand processes such as photosynthesis or soil-tree ion exchanges. However, such models, too, can have an empirical base. As proposed by Munro (1974) models can be further divided into stand and individual tree models, which in turn can be divided into distance-dependent and distance-independent models. Models for whole stands can use aggregated values only or size-class information (Burkart 2003) such as diameter distributions (Vanclay 1994). Commonly used functions to represent diameter distributions are the geometric, exponential, the Gaussian, Pearson, Beta, Weibull, and Johnson's S_B (Matérn 1991, Vanclay 1994). In general, for forest growth models, there exist many methods of estimation. For the diameter distributions for stand models, the parameter prediction or the parameter recovery approaches are used (Vanclay 1994). For other models, for example regression with linear or nonlinear ordinary least squares, maximum likelihood, Markov chains or neural networks can be used (Amaro *et al*. 2003).

The model choice depends on the purpose of the study, the stand conditions and the available data. For describing the effect of retained Scots pines on the production of the new stand there are clearly several options available. Since a major emphasis of this thesis was laid in quantifying rather than explaining processes, empirical modelling seemed appropriate.

Objectives

The overall purpose of this thesis was to predict the growth of retained Scots pines and quantify the effect of their competition on the new stand. The thesis was divided into four parts corresponding to the studies with the consequent objectives:

Study I. To test the hypotheses of reduced volume of the new stand as dependent on distance to a retained tree, of a stronger impact on the growth of the new stand by the growth than by the size of a retained tree, of deterioration of stem form after liberation and of a changed forest floor vegetation in the vicinity of a retained tree.

Study II. To model the volume of the new stand as dependent on distance to a retained tree under different site conditions.

Study III. To model the thinning response of totally liberated Scots pines under different site conditions and establish the variation in basal area growth.

Study IV. To establish the growth in adjacent old and young stands, and the difference in vegetation cover at different distances from the edge between the old and young stand.

Study I-III all dealt with single, totally liberated retained Scots pines and their effect on the production of the new stand. Study IV dealt with the production in border zones between young and old stands.

Material and Methods

Study I

The investigated stand was located in northern Sweden (64.2°N, 19.3°E) about 100 km from Umeå at an average altitude of 330 m a.s.l. The soil was a sandy moraine with an average depth of more than 0.5 m and the site was classified as a blueberry (*Vaccinium myrtillus* L.) type according to the field vegetation. Site index (SI_{100}), according to site factors (Hägglund and Lundmark 1981) expressing expected dominant height at an age of 100 years, was estimated to 20 m for Scots pine (*Pinus sylvestris* L.). The stand comprised an area of about 5 ha with 44 retained Scots pines in a naturally regenerated mixture of Scots pine, spruce (*Picea abies* L.) and birch (*Betula pubescens* Ehrh. and *Betula pendula* Roth.). The following variables were measured on the retained Scots pines: coordinates (m north and east), total tree height (with a Vertex hypsometer), height to green crown (defined as the height to the first living branch separated less than 4 whorles from the rest of the crown), crown radius (estimated with one person moving a stick to a vertical position below the crown limit as directed by an observer at the tree length distance), diameters at two perpendicular directions and bark thickness at 0.5 m, 1.3 m (breast height), 2 m, 4 m and 6 m height. At the same heights increment cores were taken, at breast height one from north and one from south and at the other heights from either north or south as allotted per tree. In a 9.5 m radius plot, centred on the retained Scots pine, all trees ≥5 cm diameter at breast height (DBH), were callipered, assigned coordinates and the species was recorded. On every fifth tree the height was measured and on the two by diameter largest trees, increment cores were taken at breast height.

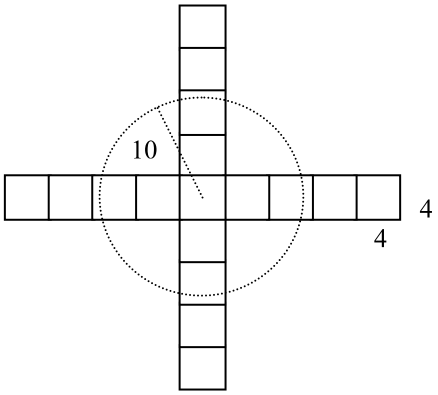

Figure 2. Principal arrangement of the sample plots. In Study I the radius of the circular plot was 9.5 m.

From the centre of each retained tree, 18×4 m corridors were laid out in the directions north, east, south, and west, wherein all trees ≥5 cm DBH were assigned coordinates and species, callipered at breast height and height measured. Trees with DBH less than 5 cm were counted. Occurrence (values 0 or 1) of indicator species in the forest floor vegetation according to Hägglund and Lundmark (1981) was noted for each square meter in 4×4 m subplots of the corridors with the centre 4×4 m plot counted as common for all corridors (Figure 1). The occurrence for each 4×4 m plot was expressed as a proportion of 16.

Before measurement the cores were soaked in water for at least one hour and then planed. They were measured using a modified version of the Langlet-Lindblad year-ring measurement machine (Eklund, 1949) (magnification 1×100). For increased contrast, zinc-paste was put upon the cores.

For the circular plots, the trees were assigned a height from the height curve of Näslund (1936), estimated by non-linear regression, using data from the 18 m corridors. Thereafter the volume, basal area, and number of stems per ha in the new stand were calculated at different distance classes from the retained Scots pines. The data from the circular plots and the corridors was treated separately.
From the increment cores, the growth 1903-2000 of the individual retained trees was measured and the last 50 years basal area growth was calculated. The ratios of basal area increment for the decade before liberation (1903-12) and the following decades were calculated. The ratios of the diameters at 0.5 m, 1.3 m, 2 m and 4 m, to the diameter at 6 m were calculated for different years. The retained trees were split into two groups, one with heights taller than the average height of the retained trees and one with heights shorter than the average.

For the retained trees, diameter under bark, annual radial and basal area increment at the different heights of the stem, mean crown width and sapwood proportion were calculated.

The circular plot was divided into three zones of equal area and differences in the mean volume per ha between the zones was tested for using ANOVA and Tukey's studentized range test.

Correlation between occurrence of each indicator species in the forest floor and combinations of distance, basal area and basal area growth of the retained tress, volume of the new stand was estimated by logistic regression analyses.

Multiple regression analyses were performed with the volume of the new stand in each zone of the of the 9.5 m plot as the dependent variable and of zone and basal area and basal area growth of the retained tree as independent variables.

Study II

Data was collected from stands in Sweden ranging from 55°N to 68 °N (Figure 2, Table 3). Each stand contained between 1 and 6 retained Scots pines (*Pinus sylvestris* L.). The prerequisite for a tree being selected were that there was more than 50 % basal area (m^2) of Scots pine and no other retained tree within 20 m. Furthermore, the retained Scots pine had to be totally liberated at least 20 years ago and the site conditions had to be homogeneous. In total 64 Scots pines were investigated. The same sampling procedure as in Study 1 was practiced. Additionally, standing at the southern side of the tree, at a distance of the tree height, the number of detectable not unripe (not opened) cones was counted.

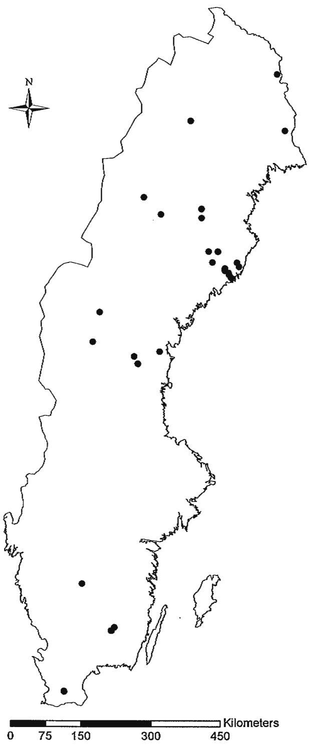

Figure 2. Map of Sweden showing the locations of the investigated stands, dots indicate stands.

Every tree in the new stand was assigned a distance class. For the 10 m plot the classes were set from 1 to 10, where class 1 represented the distance from the pith of the retained tree up to 1 m. For the 18 m corridor the classes were set from 1 to 18 in the same manner. The area for each section was calculated. The basal area at stump height of the retained tree was subtracted from the area of the innermost section.

In total 203 stumps were recorded at 21 plots. To estimate the DBH of all cut trees a form quotient of 0.65 over bark was assumed. With the use of taper tables (Edgren and Nylinder 1949), given

Table 3. *Tree and associated stand characteristics for the examined retained Scots pines. Site is the site, Lat is latitude °N, Alt is the altitude, SIS is site index according site factors, Agebhret is age of the retained tree at breast height (1.3 m), Libyear is the year of liberation, Htret is the height of the retained tree, DBH is the diameter at breast height of the retained tree, DBHlib is the diameter at breast height of the retained tree at liberation, Htnew is the basal area weighted height of the new stand and Regmeth is method of regeneration. Sites indexed "2" were omitted from the analysis of Study III due to uncertainties in determining the year of liberation or due to too a small diameter at the time of liberation which distorted the early ring width development. Data on the stand in Hällnäs (8) included for comparison*

	Site	n	Lat, °N	Alt, m.a.s.l	SIS, m	$\text{Agebh}_{\text{ret}}$, years	Libyear, year	Ht_{ret}, m	DBH, cm	DBH_{lib}, cm	Ht_{new}, m	Regmeth
1	Ahmakero	5	67.6	270	19	221	1951	14.8	33.2	21.6	8.7	Sowing
2	Tjåmotis	1	66.7	306	18	83	1958	13.0	22.3	12.6	9.1	Natural
3	Tjåmotis 2	1	66.7	316	14	133	1910	13.0	30.2	14.4	11.2	Natural
4	Vittakero	1	66.5	220	18	263	1963	16.5	54.1	45.5	8.7	Natural
5	Gardsjöb.	1	65.2	448	18	204	1956	18.2	39.8	29.3	10.5	Natural
6	Näsbergsbrännan	5	64.9	321	21	246	1927	17.7	34.0	23.3	14.6	Natural
7	Stensele	1	64.8	325	20	197	1961	18.5	37.0	26.3	7.4	Natural
8	Hällnäs	44	64.2	330	20	256	1913	16.4	42.4	21.1	17.9	Natural
9	Kussjö	1	64.1	238	18	166	1978	24.6	41.4	34.5	6.0	Natural
10	Småtjärnm.	1	63.9	89	22	229	1932	18.8	32.1	20.1	18.5	Natural
11	Tväråलund	1	63.9	175	22	129	1964	21.3	41.8	27.2	8.6	Natural
12	Galgbacken	1	63.8	64	22	204	1952	21.8	49.4	37.2	16.0	Natural
13	Kassjö	1	63.8	180	22	156	1972	21.5	39.8	33.7	7.4	Natural
14	Klockarb.	1	63.7	41	23	140	1971	20.8	44.3	32.7	8.4	Natural
15	Normanstorp	3	63.7	114	22	140	1970	20.6	34.4	23.8	9.4	Natural
16	Röbäck	1	63.7	66	22	109	1971	20.1	39.9	27.4	7.3	Natural
17	Degernäs	4	63.6	56	23	108	1969	20.2	40.4	26.3	9.6	Planted
18	Fillsta	1	62.9	368	23	289	1957	18.5	32.1	19.8	13.0	Planted
19	Fillsta 2	2	62.9	386	23	99	1957	15.9	25.9	63.0	13.3	Planted
20	Klövsjö	1	62.3	622	19	154	1955	17.8	47.4	35.4	11.3	Natural
21	Klövsjö 2	1	62.3	622	19	63	1956	13.8	31.7	6.4	11.2	Natural
22	Matfors	1	62.1	105	24	100	1968	22.9	40.8	25.2	12.9	Natural
23	Naggen	2	62	424	23	126	1959	21.3	46.1	28.5	9.8	Natural
24	Digerön	3	61.9	293	20	135	1967	21.3	41.2	28.8	9.8	Natural
25	Axamo	2	57.6	242	26	128	1979	25.0	41.6	35.7	9.8	Natural
26	Storasjöområdet	6	56.7	257	22	167	1975	18.2	31.3	25.9	8.7	Natural
27	Attsjö	5	56.6	200	25	114	1970	21.7	36.6	28.7	10.2	Natural
28	Vombsjön	3	55.4	40	27	118	1969	21.7	42.4	31.5	10.9	Natural
29	Vombsjön 2	4	55.4	30	23	122	1957	22.5	44.7	29.7	23.7	Natural

the relative height of each tree (1.3 divided by tree height), the diameter at the base was estimated as a percentage of the diameter at breast height. A linear relation between the two diameters was then regressed for. Using the linear relation the diameter at breast height of the stumps was estimated. In case no bark existed on the investigated stumps, the diameter over bark was estimated as the diameter under bark×1.15. Height curves for all species were calculated using Näslund's height curve (1936). In order to detect differences in stem form at different distances to the retained tree, height curves were constructed for all distance zones. Volumes of all trees were then calculated with the volume functions presented by Brandel (1990). The volume per ha per distance class was calculated for the 10 m radius plot and the 18 m corridors. An anamorphous growth curve was fitted to the data by non-linear regression. The model formulation included independent variables expressing the successional stage of the new stand (basal area weighted mean height), the site fertility (site index) and distance to the retained Scots pine. The volume of the new stand was used as dependent variable. Combinations with basal area and basal area increment of the retained tree were tested.

The crown radii were divided into classes of crown size. Differences of the residuals of the volume of the new stand between the classes of crown size were tested for different distances.

Using analysis of variance and Tukey's post hoc test for differences of means, with the ratio of occurrence of vegetation by species as dependent variable and distance as independent variable, the influence of retained trees on vegetation was tested.

From the diameter under bark of the retained trees the annual diameter increment was calculated as well as the annual basal area increment. The basal area increment was also calculated for the last 5, 10 and 25 years.

Study III

The collected data consisted to the major part of the same as that in Study II, but some trees (one tree at Tjåmotis and one at Klövsjö, two at Fillsta and four at Vombsjön, Table 3) were omitted from this analysis, due to uncertainties in determining the year of liberation or too small diameters at the time of liberation which distorted the early year ring development.

For 52 retained Scots pines the annual radial increment was adjusted with regional year ring indices (Eklund 1954, Jonsson 1972, Jonsson and Stener 1987, Westerlund 2004) and the age at breast height of the retained trees determined from the cores. The year of liberation was defined as the first year in a period of at least 4 years with an ascending trend above the 10-year average before that period. From that, the age of liberation was calculated and the corresponding diameter at breast height and at 0.5, 2, 4 and 6 m, was calculated. The trees had been liberated at different times.

The annual basal area increments under bark 10 years before and 20 years after liberation were calculated for the different heights from the radial increments of the cores of each tree. For modelling the basal area growth after liberation the log value of the log ratio of annual basal area increment to the basal area growth at the year of liberation was used as dependent variable. As independent variables we used site index, years after liberation and years to culmination in basal area growth. The data was pooled in two site index classes and the model was based on the pooled data. The pooled data sets are referred to as sites with high site index (32 trees, mean SIS=23.6) and sites with low site index (20 trees, mean SIS=19.4), the grand mean being 22.2.

For estimation of the within- and between-tree variation, a mixed model was used where the dependent variable was the log of basal area growth. Independent variables were, as continuous variables, age and diameter, and as class variables tree, site and bore height of which tree and site were random. Trees were nested within site.

The dependent variable was the basal area growth, which was either annual values from 10 years before to 20 years after liberation or 5 year basal area growth from year 11 to 15 after liberation. The basal area growth from year 11 to 15 was used since the variation in basal area increment was the least in the approximate interval from 10 to 20 years after release. The material was divided into two classes of age, below and above the median age, representing the older half and the younger half of the trees.

The Proc Mixed of the SAS system (Littell *et al.* 1996) and Proc Reg (Anon. 1990) were used for computations.

Study IV

Data was collected in northern Sweden (Latitude 64 ºN) close to Vindeln and Umeå, in four young stands (15-30 years old) bordering old stands (more than 80 years old). There had to be more than 50% of basal area Scots pine. Corridors were laid out perpendicular to the stand edge in the younger and older stands, where diameter, height and distance to the edge were measured and increment cores from the trees in the old stands were taken. The radial increment since the estimated time of release was measured in the field as well as the 10-year radial increment before release. The corridors were 2×20 m in the young stands and 4×20 m in the old stands (Figure 3). Vegetation coverage was also noted. In the extension of each corridor, in both the old and young stands, at a distance of 35 m from the edge, a 5.64 m radius plot was laid out, where the diameter of all trees was measured. The distance from the edge was divided into classes of 5 m and each tree was assigned a distance class. The volume and basal area per ha in the 5 m distance classes were calculated for corridors and in the circular plot. In the old stands the basal area and basal area growth of the old trees since the time of establishment of the young stands was calculated. Differences in means was tested on the log values of the dependent variables (volume, basal area and stem number per ha).

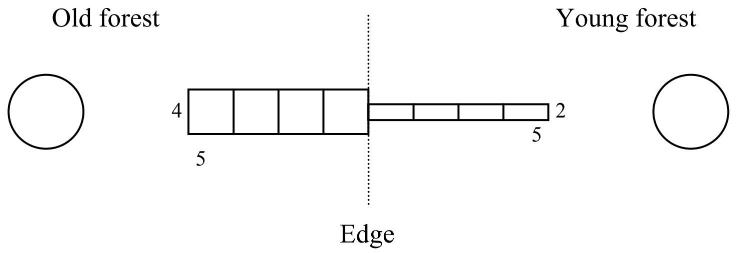

Figure 3. Principal drawing of the sample design. The dotted line denotes the edge. The circular plots are located with the centre at 35 m from the edge, the radius being 5.64 m. Figures denote the side of the sub sample plots in the transects.

Results

Study I

A significant correlation of volume of the new stand and the distance to a retained Scots pine was established. In a 5.48 m zone closet to the retained Scots pine, the volume was on average 23 % lower than at distances further out. The number of small trees per ha showed no significant deviations at different distances to the retained Scots pines, neither did the stem form of the large trees of the new stand.

Both the size and the growth of the retained trees affected the volume of the new stand but in opposite directions. The volume of the new stand was negatively correlated with the basal area growth of the retained Scots pine, whereas it was positively correlated with the basal area of the retained Scots pine. A fast-growing small retained Scots pine was seen to affect the growth of the new stand as much as or more than a big slow-growing tree.

The stem form gradually improved, especially for the shorter trees. However, in the first two decades after liberation the stem form deteriorated. Though the retained Scots pine trees were old, about 180 years at the time of liberation, they responded well to the release. The radial increment showed a more than double growth in 30 years after liberation, where after it grew for another 40 years above the level before liberation.

Lichen (*Cladonia sp.*) occurrence was positively correlated with the basal area growth of the retained Scots pines and negatively correlated with the distance to retained Scots pines, the basal area of the retained Scots pines and the volume of the new stand.

Study II

The model was efficiently adapted to the data (Figure 4) and predicted a 24 % reduction in volume of the new stand within 5 m from a retained Scots pine as compared to the volume at distance outside 5 m. Applied on the data from Study I, the model fitted well, but showed some overestimation of the adverse effect of the retained Scots pines. According to the function, for a site index of 16 m, the volume relative the asymptote would at distances from the retained tree of 1, 2, 3, 4, 5, 6 and 7 m account 8, 28, 53, 74, 88, 95 and 98 %, respectively, resulting in area weighted reduction within 7 m of 25.5 %. For a site index of 26 m the volume relative the asymptote would at distances 1, 2, 3, 4, 5, 6 and 7 m account 13, 42, 70, 89, 97 and ~100 %, respectively, with a reduction within 7 m of 14.8 %.

The number of cones had a stronger positive correlation with last 5-year basal area growth of the retained Scots pines ($p=0.0271$), than with basal area of the retained Scots pines ($p=0.065$). No effect of age, height and crown ratio of the retained Scots pines was found.

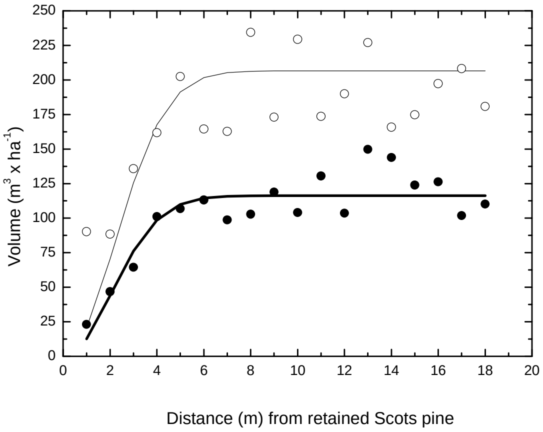

Figure 4. Observed (open and filled dots) and predicted (lines) values for the investigated stands in Study I (○) and study II (●). The model was $V = 2.947\times H^{1.5}\times(1-e^{(-0.00521\times SIS\times Dist^{2})})$ with volume (V, m3) in the new stand as a function of basal area weighted mean height (H, m), site index (SIS, m) and distance to the retained Scots pine (Dist, m). Dependent mean is 104.0, r-square 0.296, and n 1080.

Study III

The basal area growth after liberation culminated 5 years after liberation at sites with high site index (SIS >22) and after 7 years at sites with low site index (Figure 5). The peak occurred at all heights at the same time apart from that at 6 m where

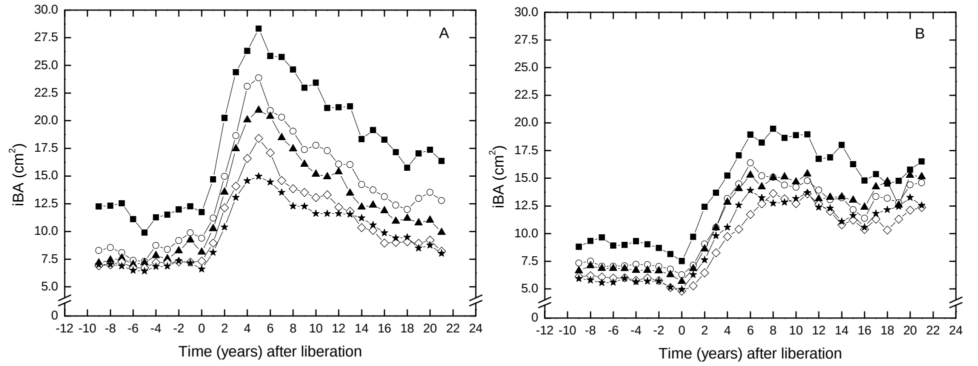

Figure 5. Average annual basal area growth for trees larger than 10 cm at breast height at the time of liberation during 10 years before and 20 years after liberation. A and B denote sites with high site index (SIS>22.2) and low site index (SIS ≤ 22.2) respectively. (■) 0.5 m height, (○) breast height, (▲), 2 m height, (◊) 4 m height, (★) 6 m height.

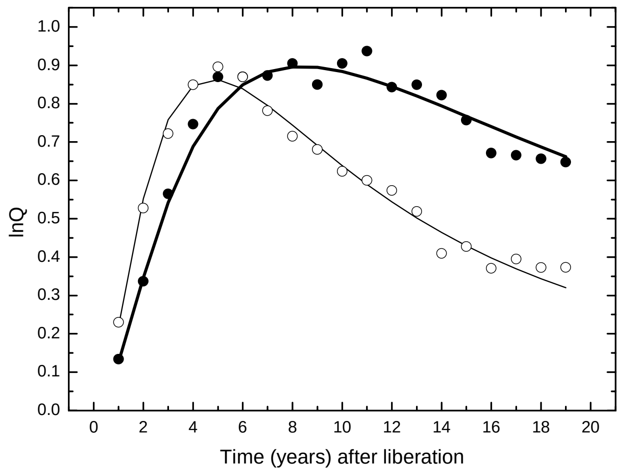

Figure 6. Observed and predicted values of the dependent variable lnQ. (○) observed mean values for all heights at sites with high site index, (●) observed mean values for all heights at sites with low site index, thin line denotes the predicted values (F1, Table 3) of the sites with high site index and the thick line denotes the predicted values of the sites with low site index. The model was
$\ln(\ln Q) = -6.54583 + 0.25797 \times SIS + 0.10915 \times \ln(T) \times SIS - 0.20007 \times f(T_{max}) \times SIS$
where the log value of the log ratio of annual basal area growth to the growth at the year of liberation is the dependent variable (ln(lnQ)), SIS is the site index according to site factors, T is the number of years after liberation, T_{max} the number of years to culmination and $f(tT_{max})=\ln(T+T_{max})-\ln(T_{max})$. Adjusted R-square is 0.907, n is 190.

it was two years delayed. The magnitude of the growth response was about 2.5 times the growth before liberation. The growth never declined to the level before liberation during the period studied (20 years after liberation). On the sites with low site index the persistent growth was especially pronounced. The basal area growth response after liberation was efficiently described as a function of time and site index (Figure 6).

Concerning the variation in basal area growth, the variance components determined were between-site, between-tree and within-tree variation of the retained Scots pines. With height level in the tree as the only covariate the total variance was 0.294, distributed on 0.123 between-site, 0.109 between-tree and 0.062 within-tree (Table 4) and an R-square of 0.09.

Table 4. *Variance components of basal area growth of the retained trees*

Component	With diameter and age			Without diameter and age
	All	Young	Old	All
Between-site	0.05681	0.11130	0.03639	0.1233
Between-tree	0.06440	0.02894	0.07517	0.1085
Within-tree	0.06211	0.04501	0.77440	0.0621

If age and diameter were added as explaining variables, the total residual variance decreased to 0.188, that is 10 percentages, and the degree of explanation increased to 43 %. The between-stand and between-tree variance was about halved as compared to the model without diameter and age. The variation increased with the age of the tree. The trees were measured 20-80 years after liberation and the development of the new stand at the time of measurement varied substantially. Despite this, there was no effect of the volume of the new stand on the growth of retained trees during the last 5-year period before measurement.

Study IV

In the young stands, the volume in the 5 m zone closest to the edge was on average 10 % of that at a distance of 35 m. The basal area showed the same pattern. In the old stands the basal area and basal area growth were at the highest in the 5 m zone closest to the edge. The testing of differences between means in volume in the 5 m zones was not significant for a pooled data set. However, when comparing the 5 m zone closest to the edge with the mean for the distance 5-20 m, there was a difference, in both the new and old stands. Also, for the old forest, basal area growths before and after liberation in the 5 m zone closest to the edge were significantly different from the corresponding mean of the zones further away. The basal area growth in the zone closest to the edge was after liberation 37 % higher than that before liberation.

The volume in the young stand was negatively correlated with the basal area growth of the old stand.

In the field vegetation, lichens peaked in occurrence in the 5 m zone closest to the edge in the young stand, while other vegetation components decreased in occurrence in that zone (Figure 7). Heather (*Calluna vulgaris* L.) and blueberry also

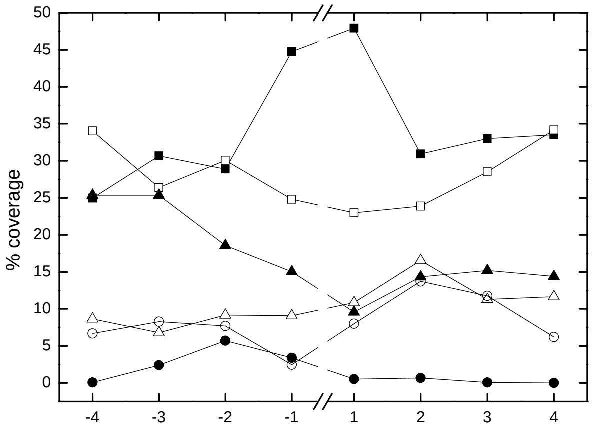

Figure 7. Mean vegetation coverage (%) per species group in the distance zones. The left half of the figure (minus scale) represents old forest, the right half (positive scale) represents young forest. (■) denotes lichen, (Δ) heather, (□) mosses, (▲) lingonberry, (○) blueberry and (●) crowberry.

peaked in occurrence in the young stand but in the 5-10 m zone. Lingonberry (*Vaccinium vitis-idaea* L.) and mosses dipped in occurrence in the 5 m zone in the young stand and increased with distance to the edge. Crowberry (*Empetrum nigrum* L./*E. hermaphroditum* Hagerup) showed no significant trend.

Discussion

Growth of the new stand

The retained Scots pines affected the growth of the new stand within their vicinity negatively. This could be established for a Scots pine forest in northern Sweden in Study I and was verified for other site types and modelled in Study II. The effect on production in the new stand with 10 evenly dispersed Scots pines per ha was estimated as 2-4 %. Within a zone of 5 m from the retained Scots pine the reduction was 23-26 % as compared to the volume outside 5 m and within 3 m the corresponding figure was 46 %. Comparing the effect according to the model on site indices of 16 and 26, the basal area weighted volume relative the asymptote was reduced by 25.5 % within 7 m on the lower site index and by 14.8 % on the higher site index. With 10 retained trees per ha (representing an area of 1540 m^2) the reduction would amount 3.9 % for the lower site index and 2.3 % for the higher site index. For the stand in Hällnäs (Study I) the site index was 20 m and the production loss estimated as 2.5 %. Corresponding model predicted value would be 2.9 %.

The negative effect of retained trees on the growth of seedlings and saplings has been reported earlier. Hagner (1962) reported a 40 % reduction in height close to retained trees and Ackzell and Lindgren (1992) a 22 % reduction on stand level. Hagner's study concerns the distance within 8 m from retained trees with the severest reduction in the innermost 3 m zone and on a 10 m radius plot the effect in his study would be diluted. Both studies were performed in seed tree stands with a retention level of 60 stems per ha in the latter study (Ackzell and Lindgren 1992) and at least 30 and with many observations of 100 to 300 stems per ha in the former study (Hagner 1962). With that number of stems per ha, apart from root competition with the retained trees, the seedlings are also affected by competition for light, induced by the shadowing of the retained trees. In this thesis the retained Scots pines were well separated, at least 20 m, and therefore the competitive effects should be due to the pure effect of single trees and without substantial light competition. Apart from the higher levels of retention, those studies concerned younger stands, whereas this thesis dealt with larger trees. In the study by Valkonen *et al.* (2002), the levels of retention were about 30 stems per ha and the estimated reduction in potential production in height and diameter growth within 10 m from a retained Scots pine from 9 to 17 %. That retention level was 3 times the assumed level in this thesis and the production loss more than estimated in this study, but clearly less than the 22 % reported by Ackzell and Lindgren (1992). Simulating 10 retained Scots pines per ha Valkonen *et al.* (2002) estimated the loss in production potential as 2.7-5.3 %, which is close to the 2.5 % in Study I and 2-4 % in Study II. Niemistö *et al.* (1993) estimated a loss in height growth of

26-76 % within 10 m from a single Scots pine. The difference as compared to Valkonen *et al.* (2002) could be due to that the latter study was undertaken in southern Finland while the former was undertaken in northern Finland on drier and less fertile soils. Study I of this thesis was conducted in a bilberry type forest on a moraine, which is less dry than pine heaths on sandy soils.

Lindén (2003) investigated a 25-year old Norway spruce plantation with retained broad-leaves spruce stand with retained broadleaves based on a grid of 10 m radius plots. The mean annual increments were 0.7, 1.2 and 1.2 m^2 per ha and year for three retention levels (82, 41 and 0 stems per ha) corresponding to a basal area of 17.0, 26.4 and 28.3 m^2 per ha, respectively. With 41 retained broad-leaved trees per ha, as compared to zero retained broadleaves, the basal area was thus reduced by 7 % (from 28.3 to 26.4 m^2 per ha). In this thesis a 25 % reduction was found in the innermost 5 m zone from a retained Scots pine. One retained Scots pine on a 10 m circular plot corresponds to 32 stems per ha, and with a 25 % reduction in volume in the innermost 5 m, the total reduction in the 10 m plot would amount 6.2 %, somewhat lower than the 7 % of Lindén (2003).

While the volume of the new stand in Study I was negatively correlated with basal area growth of the retained Scots pines, it was positively correlated with basal area of the retained Scots pines. The positive correlation can be interpreted as an effect of site. On sites of high fertility trees grow better. If the retained tree was growing on a site of high fertility it was likely to grow fast, and so was the new stand. The negative correlation with basal area growth of the retained Scots pine can be interpreted as an effect of competition. Thus, the volume of the new stand was especially low around well-growing Scots pines.

In study I, during the period investigated, the retained Scots pines had grown with more than the estimated loss. The retained Scots pines could use available production resources before the new stand was fully established.

On average for forest land in Sweden the level of retention accounts about 5 m^3 per ha. For example, with a diameter of 42 cm and a height of 19.4 m, the volume for a retained Scots pine is 1.2 m^3 over bark (using the volume functions of Brandel, 1990), equivalent to 4.1 stems per ha. For a 30 cm diameter tree of 18 m height, the corresponding volume would be 0.62 m^3, equivalent to 8.1 stems per ha. Thus, the effect per ha is in practice likely to be less than reported in this thesis, though on particular areas the level of retention may well exceed 10 stems per ha. Also, since Scots pine dominated forest land accounts to some 12 million ha (Anon 2003), out of total 22 million ha (Anon 2003), results from this thesis should preferably be applied to that forest type.

Observations of a negative effect of large Scots pine on seedling growth and occurrence was reported in forest literature in the beginning of the 20th century by Hesselman (1917) in Sweden and Aaltonen (1919, 1923) in Finland, where old trees on pine heaths seemed to suppress seedlings surrounding them. However, both authors noted a high irregularity in spatial distribution of seedlings and thus volume. Also in material collected later by Valkonen *et al.* (2002) there were retained trees with high abundance and volume in the new stand in their vicinity. This is in contrast with Niemistö *et al.* (1993), who concluded that surrounding retained Scots pines, there is often an area with low density. This thesis found no distance-dependent effect on density in the new stand, no matter the size class of plants larger than 1.3 m in height.

Occurrence of field vegetation

In Study I, for lichens there was a distance-dependent effect in occurrence and it was also negatively related to the growth of the retained Scots pines and positively to their size and the volume of the new stand. Thus, the competitive effect of the retained Scots pines decreased the volume of the new stand and increased lichen occurrence, but the causal relationships are still unknown. For other vegetation components the occurrence was not significantly affected by the presence of the retained Scots pines.

In Study II, apart from lichens, also crowberry-heather (*Empetrum nigrum* L./*E. hermaphroditum* Hagerup and *Calluna vulgaris* (L.) Hull) showed a higher occurrence close to retained Scots pines. For crowberry-heather the effect was only visible on the 16 m^2 plot centred on the retained Scots pine, that is, up to 2 m from the retained tree. For lichen the effect on occurrence extended to 10 m. Skoklefald (1995) reported similar effects for wavy hair-grass (*Deschampsia flexuosa* (L.) Trin) and Kuuluvainen and Pukkala (1989) found effects on the amount of grasses, herbs and mosses around seed trees up to a distance of about 10 m from the seed-trees. Though we could see the same trends for those species, apart from mosses, where there was no trend, they rendered no significant differences at different distances from the retained Scots pines.

Growth of the retained trees

In the studies compiling this thesis, there were stands represented which had reached such development stage that they could be assumed to exert a negative effect on the growth of the retained Scots pines, some stands were of the same height as or even taller than the retained trees. However, in Study III there was no effect of the volume of the new stand on the growth of the retained trees. For seedlings and saplings the competitive effect on the retained trees could be assumed to be small which makes comparisons with most other European studies (e.g. Kuuluvainen and Pukkala 1989, Niemistö 1993, Skoklefald 1995, Valkonen 2002 and Chantal 2003) difficult, since those studies focused on the advancement in younger stands, the effect over one rotation or more was less addressed. Possibly, since the major part of the stands investigated in this thesis was shorter than the retained Scots pines, about half the height, it was too early to detect any influence of the new stand on the retained trees.

At some sites the new stand had surpassed the retained Scots pines in height. It could be due to increased atmospheric deposition of nitrogen to which the old forest could be less able to respond than the younger. Elfving e*t al*. (1996), Elfving and Nyström (1996), Eriksson and Karlsson (1996) report increased growth where atmospheric deposition of nitrogen is high. Also Skovsgaard and Henrikssen

(1996), Wenk and Vogel (1996), Pretzsch (1996), and Schadauer (1996) report increasing growth in younger forests as compared to older. The causes could apart from increased deposition of nitrogen, be due to changed atmospheric composition with increased level of carbon dioxide and changed management practices.

Changes in stem form were early reported in Sweden by Fahlcrantz (1901), Nyblom (1927) and later Hagberg (1942) and Holgén et al (2002) as well as in other countries such as Niemistö *et al.* in Finland (1993). As indicated in Study I by the decreasing ratios of the diameter of the lower trunk to that at 6 m, the stem form improved over time. In the first two decades after release, however, the ratio of ten-year basal area increment to that before release showed an increased growth in the lowest stem part as compared to 6 m. Shorter trees responded more than taller trees which can be due to the relatively higher degree of change after liberation.

The basal area growth of the retained Scots pines after liberation, increased by a factor of 2.5, in relation to the growth before liberation. This can be compared with thinning experiments reported by Jonsson (1995) where the maximum value of the thinning response was 2.7 for Scots pine. Since that material covered thinning intensities up to 69 %, it must be emphasized that this is a hypothetical value. As compared to studies by Youngblood (1991), Valinger (1992), Niemistö *et al.* (1993), Holgén *et al.* (2003) and Varmola (2004), 2.5 is a higher value, but that could also be expected for free-growing trees. In this thesis the culmination occurred after 5 to 7 years, with an unknown number of years without response. With a period of 2-4 years without response as reported by Näslund (1942), Youngblood (1991), Niemistö *et al.* (1993), Holgén *et al.* (2003) and Varmola (2004), the number of years to culmination in response would be 7-11 years. This is comparable with the 10 years to culmination reported by Baader (1939), the 5-10 years by Hagberg (1942), the 8 years by Youngblood (1991), the 7 years by Holgén *et al.* (2003), and the 7-8 years by Varmola (2004). It is less than Niemistö *et al.* (1993), but their study concerned volume growth.

The retained Scots pines in this thesis were probably dominant trees at the time of liberation and for trees of smaller size-classes the relative response can be bigger than for trees of larger size-classes (Bucht and Elfving 1977). The extended growth reaction in radial growth in Study I was clearly longer than Niemistö *et al.* (1993) and Latham and Tappeiner (2002) reported for thinned stands, but the effect could be expected to be endured for totally liberated trees. When comparing with old Scots pines being released in Germany, the period of response was comparable, about 60 years (Baader 1939), as compared with 70 years for the trees in this study.

For the retained Scots pines there was no effect of age on the response in basal area growth after liberation. Even though some trees were almost 200 years old at the time of liberation, they responded well, which has earlier been indicated by Jonsson (1995). Neither was there, in relative terms, any difference in magnitude in growth response between more or less fertile sites. In fact, the basal area growth response at sites with lower site indices was sustained for a longer period than at sites with higher site indices, and the response continued beyond the period of study.

The sustained growth could first be due to an altered stem form after liberation, and later that the demand for extra stem growth decreased but that the tree built up a larger needle mass with which it could sustain growth. Around totally liberated trees there is more incoming radiation reaching the ground, thus increasing temperature and turnover of the soil microbes and withering processes, contributing to the growth. That could also result in more favourable conditions for ground vegetation which can compete for resources such as tree-*Ericaceae* interactions reported by Jäderlund *et al*. (1997) an eventually cause a decline in growth.

Variation in basal area growth

Tree age and breast height diameter explained 25 % of the growth variation in basal area growth. The residual variation coefficient was 43 % and was composed by between-site, between-tree and within-tree variation to approximately the same proportions. Compared with Matérn's (1961) variation coefficients concerning diameter growth of 20 % for within-tree variation the residual variation coefficient between cores within trees in our study was larger (25 %). The between-tree variation Matérn estimated at 25-38 %, for the retained trees it was 35 %. Including age and diameter as explanatory variables reduced the variance, which meant a reduction in the coefficient of variation by 11 percentages.

The total variation coefficient in basal area growth of 42 % reported by Fries (1966) concern both the between-tree and within-tree variation, which is to compare with 41 % in our study. The between-site and between-tree variation in our study was reduced by almost half when including the age and diameter at the time of liberation, whereas the residual part remained almost intact. Thus, for single-tree growth models, we could expect the coefficient of variation of residuals to be about 40 %. Probably the variation within the tree increases with tree age. Dividing the material into two classes, above and below the median age, showed a higher residual variation among the older trees.

Edge effects

The effect of an edge on production in two adjacent Scots pine stands can be substantial. In Study IV, a 90 % reduction in volume of the young stand could be established, but this effect did not spatially extend more than into the first 5 m zone of the young stand from the edge. In the old forest on the other hand, in the equivalent zone the basal area was higher (57 %). What was lost in the young stand seemed to be at least partly compensated for in the old stand, though the magnitude of compensation over time remains to estimate. For other species and site types the effect is likely to differ. In experiments in Finland, Isomäki and Niemistö (1990) measured effects up to 3 m and in Sweden Bucht and Elfving (1977), Bucht (1981), Elfving (1985) and Eriksson (1987) reported effects up to between 3 to 6 m.

For the young stand, the effect on volume was negative. In comparison with studies on Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), where Hanson *et* *al*. (1993) found effects up to 20 m from the edge, the spatial effect on production was less. The Douglas fir stands were about 45 m tall which could partly explain the difference. Also for lodgepole pine (*Pinus contorta* L.) the distance-dependent effect was far-stretched, it reached >50 m for the current leader (Burton 2002).

In our study the growth increase was 30 % in basal area growth for the trees in the 5 m zone closest to the edge as compared to the zone 5-20 m. Isomäki and Niemistö (1990) estimated the growth increase as 25 % more for the edge trees conducted in Norway spruce (*Picea abies* (L. Karst.)) stands, a species reported to respond well to thinnings (Eriksson 1976). Considering the extreme situation of a clear-cut with adjacent old forest, as compared to a strip road, the results could be corresponding but further analyses are required, especially for Norway spruce stands. The decrease in volume of the young stand was also correlated with an increase in basal area growth of the old stand.

In Study I, lichen occurrence was more common close to well- growing retained trees and less common the higher the volume in the surrounding stand. Also in Study IV lichen occurrence increased in the edge zone, that is, with decreasing volume. Other vegetation changed too. The changes in vegetation coverage of different species can partly be compared with Hansson (1994), who described blueberry and mosses as decreasing when going from the old forest interior to the edge eight years after a clear-cut.

Since there are effects in both the young and old stand which occur at different points in time and can be assumed to have relatively different impacts dependent on the stand development stage, evaluation of the long-term effects are difficult to assess. Also the alignment of the edge line must be considered. If the 5 m zone closest to the edge in the old forest is shifted in direction to the young forest, the volume per ha will be lower. It would be reasonable to do so since the area occupied by the older trees probably is greater than implied by a line along the stem base of the edge trees.

In a young (~20 years) forest surrounded by an old (~100 years), with a 90 % reduction in volume production in the 5 m zone closest to the edge and with the side 100×100 m, the loss in production per ha could be estimated as 17 %. With the side 1000×1000 m, the effect would constitute 1.8 %. If an 100×100 m old forest is surrounded by a young forest the gain in basal area in the old forest would be 21 % and 2.2 % in a 1000×1000 m old forest. These figures are hypothetical and limited to Scots pine stands on sandy soils in northern Sweden. For determining the effect on production representative of the forests in Sweden, combinations of ages of young and old stands on different site types and with different admixtures are needed.

Concluding remarks

This thesis addressed the effect of competition in two simplified cases. One case dealt with competition between large, old trees and younger, smaller trees and one case dealt with competition between young and old stands. The results concerning the negative effect of retained Scots pines on the production in the new stand were somewhat lower, but still comparable, with other studies. Differences were probably enhanced due to levels of retention, species composition and stage of stand development.

In practice trees are often retained in groups, partly for enhancing and preserving biodiversity, partly for reducing the effect of the retained trees on the production of the new stand. In this thesis the effects of single trees was quantified and the results implied that, from a production point of view, the demand for groups was less than previously thought. The effect was however different on different sites with more severe reduction on sites with lower site index.

For other species with different growth strategies, the effects are still not well known and in more complicated cases with mixtures even less so. This is also of interest for practical implications. For example, another tree species often retained, is aspen (*Populus tremula* L.). It generates root sprouts which can be assumed to compete both internally, with other vegetation and with the parent tree.

Concerning the effect of liberation on trees, this thesis only dealt with a shorter period in detail, the first twenty years after liberation. How the growth is affected beyond 20 years after liberation still remains unclear and for establishing that, studies directed on even longer periods are needed.

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References

Aaltonen, V.T. 1919. Über die natürliche Verjüngung der Heidewälder im finnischen Lappland. Communicationes ex Instituto Questionum Forestalium Finlandiae 1. In Finnish with German summary.

Aaltonen, V.T. 1923. Über die räumliche Ordnung der Pflanzen auf dem Felde und im Walde. Acta Forestalis Fennica 25. In German.

Abetz, P. 1977. Zuwachsveränderungen in verschiedenen Schafthöhen. In: Mitteilungen der forstlichen Bundes-Versuchsanstalt Wien, 120. Heft. Beiträge zur Zuwachforschung (3) /Contributions to increment research (3)/. Presented at the XVI Congress of IUFRO, Oslo, 1976. In German with English summary.

Acker, S.A., Zenner, E.K., Emmingham, W.H., 1998. Structure and yield of two-aged stands on the Willamette National Forest, Oregon: implications for green - tree retention. Canadian Journal of Forest Research 28, 749-758.

Ackzell, L. Lindgren, D. 1992. Seed-tree stand: Threat or protection for artificial regeneration. In: Hagner, M. (Ed.), Silvicultural alternatives: Proceedings from an internordic workshop. Swedish University of Agricultural Sciences, Department of Silviculture, Reports 35. Umeå, June 22-25, pp. 86-95.

Anon. 2005. Annual review. In: News + notes 3(1), FSC International Center Bonn.

Anon. 2005. Statistic figures on PEFC certification. PEFC Council Information Register. PEFC™ . URL http://www.pefc.cz/register/statistics.asp (accessed 21st of January 2005).

Anon. 2003. Statistical yearbook of forestry 2003. National Board of Forestry, Jönköping. In Swedish with English summary.

Anon. 2002a. System för certifiering av skogsbruk och virkesflöde. Tekniskt dokument. Pan European Forest Certification 05-1-1. In Swedish.

Anon. 2001. Skogsvårdsorganisationens utvärdering av skogspolitikens effekter - SUS 2001. Skogsstyrelsen. Jönköping.

Anon. 2000. Svensk FSC-standard för certifiering av skogsbruk. FSC Trademark® Forest Stewardship Council A.C. In Swedish.

Anon. 1994. Helsinki conference. European criteria and most suitable quantitative indicators for sustainable forest management. Ministerial conference on the protection of forests in Europe. European liaison unit in Helsinki, Helsinki and Geneva, June.

Anon. 1994. The Swedish Forestry Act. National Board of Forestry, Jönköping.

Anon 1992. Report on the United Nations Conference on Environment and Development. Annex III (A/CONF. 156/21 (Vol III)). Rio de Janeiro, June.

Anon. 1990. SAS/STAT User's guide. Version 6 Fourth Edition, Volume 2 793 pp. SAS Institute inc., Cary, North Carolina. ISBN 1-55544-376-1.

Anon. 1983. Statistical yearbook of forestry 1981-1983. National Board of Forestry, Jönköping. In Swedish with English summary.

Assman, 1970. The principles of forest yield study. First English edition. Oxford.

Axelsson, A.-L. 2001. Forest landscape change in boreal Sweden 1850-2000: a multi-scale approach. Acta Universitatis Agriculturae Sueciae. Silvestria 183, 44 pp. + 4 appendix papers.

Baader, G. 1939. Der Kiefernüberhaltbetrieb im Hessischen Forstamt Eberstatdt. II Teil. Das Verhalten der Überhälter. Allgemeine Forst-und Jagdzeitung 115, 141-148. In German.

Brandel, G. 1990. Volume functions for individual trees. Scots pine (*Pinus sylvestris*), Norway Spruce (*Picea abies*), Birch (*Betula pendula & Betula pubescens*). Report No 26, Department of Forest Yield Research, Swedish University of Agricultural Sciences, Garpenberg. In Swedish with English summary.

Bucht, S. 1981. The influence of some different thinning patterns on the development of Scots pine stands. Swedish University of Agricultural Sciences, Department of Silviculture, Reports No 4. In Swedish with English summary.

Bucht, S. & Elfving, B. 1977. Thinning Response and Increment in a Strip-Thinned Stand. Sveriges skogsvårdsförbunds tidskrift, 4. In Swedish with English summary.

Burton, P.J., 2002. Effect of Clearcut Edges on Trees in the Sub-Boreal Spruce Zone of Northwest-Central British Columbia. Silva Fennica 36 (1), 329-352.

Cadenasso, M.L., Traynor, M.M., and Picket, S.T.A. 1997. Functional location of forest edges: gradients of multiple physical factors. Canadian Journal of Forest Research 27, 774-782.

Chantal, M. d., Leinonen, K., Kuuluvainen, T., and Cescatti, A. 2003. Early response of *Pinus sylvestris* and *Picea abies* seedlings on an experimental canopy gap in a boreal spruce forest. Forest Ecology and management 176 (1-3), 1-16.

Chen, J., Franklin, J.F., and Spies, T.A. 1995. Growing Season Microclimatic Gradients from Clearcut Edges into Old-Growth Douglas-Fir Forests. Ecological Applications 5 (1), 74-86.

Elfving, B., and Nyström K. 1996. Stability of site index in Scots pine (*Pinus sylvestris* L.) plantations over year of planting in the period 1900-1977 in Sweden. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Elfving, B., Tegnhammar, L., and Tveite, B. 1996. Studies of growth trends of forests in Sweden and Norway. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Elfving, B. 1985. Five year growth in a line-thinning experiment with pine and spruce. In: Gallagher, G (ed.): The influence of spacing and selectivity in thinning on stand development, operations and economy. Proceedings, IUFRO P4.02.02, Dublin sept.-84. Forest and Wildlife Service, Dublin. P. 114-121.

Enander K. G. 2003. Skogsbrukssätt och skogspolitik 1950-2000. Swedish University of Agricultural Sciences, Department of Silviculture, Reports No 54. With English summary.

Engelmark, O., Kullman, L., and Bergeron, Y., 1994. Fire and age structure of Scots pine and Norway spruce in northern Sweden during the past 700 years. New Phytologist 126, 63-168.

Eriksson, H., and Karlsson, K. 1996. Long-term changes in site index in growth and yield experiments with Norway spruce (*Picea abies* (L.) Karst) and Scots pine (*Pinus sylvestris* L.) in Sweden. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Eriksson, H. 1987. New results from plot no. 5 at Sperlingsholm estate in southwestern Sweden in the European Stem Number Experiments in Picea abies. Scandinavian Journal of Forest Research 2, 85-98.

Eriksson, H. 1976. Yield of Norway spruce in Sweden. Royal Collage of Forestry, Department of Forest Yield Research, Research notes 41. In Swedish with English summary.

Fahlcrantz, E.G., 1901. Undersökning af ljusningstillväxten (Lichtungszuwachs) hos tallen vid fullständig friställning. Tidskrift för skogshushållning (3). In Swedish.

Franklin, J., 1997. Creating a Forestry for the 21st Century - The Science of Ecosystem Management. Section II: Silvicultural Systems and Management Concerns, Island Press. USA.

Fries, J. 1966. On the accuracy of estimates of diameter growth and basal area growth from repeated caliperings and from increment borings. In: Mitteilungen, Schweizerischer Anstalt für das forstliche Versuchswesen. Band/Volume 42, Heft/Fasc 4. Ed. A. Kurth.

Gehlhausen, S.M., Schwartz M.W., and Augspurger, C.K. 2000. Vegetation and microclimatic edge effects in two mixed-mesophytic forest fragments. Plant Ecology 147, 21-35.

Hagberg, N. 1942. Stamformens förändringar hos tall och gran under beståndsutvecklingen och efter friställning. Svenska skogsvårdsföreningens tidskrift (1), 44. In Swedish with German summary.

Hägglund, B., and Lundmark, J.E. 1981. Handledning i bonitering med Skogshögskolans boniteringssystem. Jönköping. Skogsstyrelsen. In Swedish.

Hagner, S., 1962. Natural regeneration under shelterwood stands. Meddelanden från statens skogsforskningsinstitut 52 (4), 263. In Swedish with English summary.

Hansson, L. 1994. Vertebrate distributions relative to clear-cut edges in a boreal forest landscape. Landscape Ecology 9 (2), 105-115.

Hesselman, H. 1909. Redogörelse öfver Skogsförsöksanstaltens verksamhet. III. Berättelse öfver den botaniska avdelningens verksamhet åren 1906-1908 jämte förslag till program. Meddelanden Statens skogförsöksanstalt 6, 27-52. Stockholm. In Swedish with English summary.

Hesselman, H. 1917. Studier öfver de norrländska tallhedarnas föryngringsvillkor. II. Meddelanden Statens skogförsöksanstalt 13-14, 1221-1286. Stockholm. In Swedish with English summary.

Holgén, P., Söderberg, U., Hånell, B. 2003. Diameter Increment in *Picea abies* Shelterwood Stands in Northern Sweden. Scandinavian Journal of Forest Research 18, 163-167.

Isomäki, A. and Niemistö, P. 1990. Ajourien vaikutus puuston kasvuun etela-suomen nuorissa kuusikoissa. Effect of strip roads on the growth and yield of young spruce stands in southern Finland. Folia Forestalia 756.

Jäderlund, A., Zackrisson, O,, Dahlberg A., and Nilsson M-C. 1997. Interference of *Vaccinium myrtillus* on establishment, growth and nutrition of *Picea abies* seedlings in a Northern boreal site. Canadian Journal of Forest Research (1997) 27, 2017-2025.

Jonsson, B. 1969. Studies of variations in the widths of annual rings in Scots pine and Norway spruce due to weather conditions in Sweden. Thesis. Royal College of Forestry, Department of Forest Yield Research, Stockholm. In Swedish with English summary.

Jonsson, B. 1972. Total annual ring indices for Scots pine and Norway spruce in different regions of Sweden during the period 1911-1968. Royal College of Forestry, Department of Forest Yield Research, Research notes 22. In Swedish with English summary.

Jonsson, B. 1995. Thinning Response Functions For Single Trees of *Pinus sylvestris* (L.) and *Picea abies* (L.) Karst. Scandinavian Journal Forest Research 10, 353-369.

Jonsson, B., and Stener, L.-G. 1986. Total annual ring indices for Scots pine and Norway spruce in different regions of Sweden between 1950 and 1983. Swedish University of Agricultural Sciences, Section of Forest Mensuration and Management, Report no 15. Umeå. In Swedish with English summary.

Kuuluvainen, T., and Pukkala, T. 1989. Effect of Scots pine seed trees on the density of ground vegetation and tree seedlings. Silva Fennica 23 (2), 159-167.

Latham, P., Tappeiner, J., 2002. Response of old-growth conifers to reduction in stand density in western Oregon forests. Tree Physiology 22, 137-46.

Liebig, v.J. 1840. Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie. Braunschweig: Vieweg.

Lindén, M. 2003. Increment and yield in mixed stands with Norway spruce in southern Sweden. Acta Universitatis agriculturae Sueciae. Silvestria, 260. 42 pp + 5 appendix papers.

Littel, R.C., Milliken G.A., Stroup, W.W., Wolfinger, R.D. 1996. SAS$^{®}$ System for mixed models, Cary, NC: SAS Institute Inc.

Long, J.N., Roberts, S.D., 1992. Growth and Yield Implications of a "New Forestry" Silvicultural System. Western Journal of Applied Forestry 7, 6-9.

Mäkinen, H. 1997. Reducing the effects of disturbance in tree-ring datra using intervention detection. Scandinavian Journal of Forest Research 12, 351-355.

Mang, K., 1956. Der Fohren-Überhaltbetrieb im FA Lindau. Allgemeine Forstzeitschrift (37-38), 473-475. In German.

Matérn, B. 1961. On the precision of estimates of diameter growth from increment borings. IUFRO 13. Congress Wien September 1961, Vienna. 25/8-S/2.

Mitscherlich, E.A. 1909. Das Gesetz des Minimums und das Gesetz des abnehmenden Bodenertrages. Landw. Jahrb., vol. 38 (1909), pp. 537-52.

Munro, D.D. 1974. Forest growth models – a prognosis. In: Fries, J. (ed).Growth models for tree and stand simulation. Royal College of Forestry, Department of forest yield research, Research notes 30, Stockholm p 7-22.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10 (2), 58-62.

Näslund, M. 1936. Die Durchforstungsversuche der Forstlichen Versuchsanstalt Schwedens in Kiefernwald : Primärbearbeitung. Meddelanden från statens skogsförsöksanstalt 29 (1). In Swedish with German summary.

Näslund, M. 1942. Die Reaktionsfähigkeit des alten norrländischen Fichtenwaldes nach durchhauung. Meddelanden från Staten Skogsförsöksanstalt, 33(1). In Swedish with German summary.

Newton, P.F. 1997. Stand density management diagrams: Review of their development and utility in stand-level management planning. Forest Ecology and Management 98, 251-265.

Niemistö, P., Lappalainen, E., Isomäki, A. 1993. Mäntysiemenpuuston kasvu ja taimikon kehitys pitkitetyn lountaisen uudistamisen aikana. Summary: Growth of Scots pine seed bearers and the development of seedlings during a protracted regeneration period. Folia Forestalia 826 (26).

Nordlander, G., Örlander, G. and Langvall O. 2003 Feeding by the pine weevil *Hylobius abietis* in relation to sun exposure and distance to forest edges. Agricultural and Forest Entomology (5).

Nyblom, E., 1927. Alteration of the form of wholly liberated trees. Svenska skogsvårdsföreningens tidskrift (25). In Swedish with English summary.

Pretsch, H. 1996. Growth trends of forests in southern Germany. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agriculture Research 46, 627-638.

Rose, C.R., Muir, P. S., 1997. Green -tree retention: Consequences for timber production in forests of the Western Cascades, Oregon. Ecological Applications (7), 209-217.

Schadauer, K. 1996. Growth trends in Austria. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Shinozaki, K., and Kira, T. 1956. Intraspecific competition among higher plants. VII. Logistic Theory of the C-D Effect. Journal of the Institute of Polytechnics, Osaka City University D 7, 35-72.

Skoklefald, S. 1995. Natural regeneration in seed-tree stands of Scots pine. Naturlig gjenvekst i frötrestillinger av furu. Rapport fra Skogforsk 3 (95). In Norwegian with English summary.

Skovsgaard, J., and Henrikssen, H.A. 1996. Increasing site productivity during consecutive generations of naturally regenerated and planted beech. (*Fagus sylvatica* L.) in Denmark. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Urban, S.T., Lieffers, V.J., Macdanold, S.E. 1994. Release in radial growth in the trunk and structural roots of white spruce as measured by dendrochronology. Canadian Journal of Forest research 24 (8), 1550-1556.

Valinger, E., 1992. Effects of wind sway on stem form and crown development of Scots pine (*Pinus sylvestris* L.). Australian Forestry 55, 15-21.

Valkonen, S., Ruuska, J., Siipilehto, J. 2002. Effect of retained trees on the development of young Scots pine stands in Southern Finland. Forest Ecology and Management 166, 227-243.

Vanclay, J.D. 1990. Modelling forest growth and yield : applications to mixed tropical forests. CAB international. Copenhagen 1994.

Weiner, J. 1990. Asymmetric competition in plant populations. Trends in Ecology and Evolution 5, 360-364.

Westerlund, B. 2004. Swedish University of Agricultural Sciences, Department of Resource Management and Geomatics, Umeå, Sweden. Personal communication.

Weiner, J., and Thomas, S.C. 1986. Size variability in plant monocultures. Oikos 47, 211-222.

Wenk, G., and Vogel, M. Height growth investigations of Norway spruce (*Picea abies* (L.) Karst) in the eastern part of Germany during the last century. In: Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J. (Eds). Growth trends in European forests. Springer. Berlin-Heidelberg.

Zackrisson, O., 1977. Influence of forest fires on the north Swedish boral forest. Oikos 29, (1), 22-32.

Yoda, K., Kira, T., Ogawa, H., and Hozumi, K. 1963. Self-thinning in overcrowded pure stands under cultivated and natural conditions. Journal of Biology, Osaka City University, 14,107-129.

Youngblood, A.P. 1991. Radial growth after a shelterwood seed cut in a mature stand of white spruce in interior Alaska. Canadian Journal of Forest Research 21(3), 410-413.