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A Quarterly Journal of Forest Science

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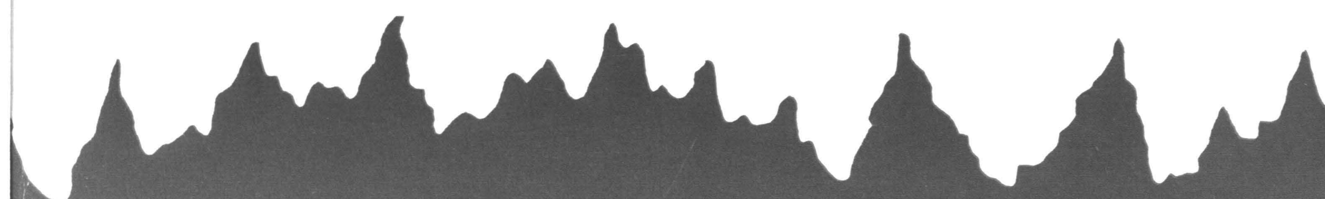

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SOCIETY OF FORESTRY IN FINLAND

SILVA FENNICA

A quarterly journal of forest science

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AIM AND SCOPE – TAVOITTEET JA TARKOITUS

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Models for height development of Norway spruce and Scots pine advance growth after release in southern Finland

Esa Koistinen & Sauli Valkonen

TIIVISTELMÄ: MALLIT KUUSEN JA MÄNNYN VAPAUTETTUJEN ALIKASVOSTAIMIEN PITUUSKEHITYKSELLE ETELÄ-SUOMESSA

Koistinen, E. & Valkonen, S. 1993. Models for height development of Norway spruce and Scots pine advance growth after release in southern Finland. Tiivistelmä: Mallit kuusen ja männyn vapautettujen alikasvostaimien pituuskehitykselle Etelä-Suomessa. Silva Fennica 27(3): 179–194.

Mixed linear models were constructed to describe the height development of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) advance growth after release. The models relate density of the overstory, time elapsed since release cutting and tree size with annual height increment. Parameters of preliminary models were estimated from a limited data set to judge the feasibility of the approach for further studies.

Tutkimuksessa laadittiin lineaariset sekamallit kuusen (*Picea abies* (L.) Karst.) ja männyn (*Pinus sylvestris* L.) alikasvostaimien pituuskehitykselle. Alikasvostaimien pituus, poistetun ylemmän puujakson tiheys ja vapauttamisesta kulunut aika selittivät malleissa alikasvostaimien vuotuista pituuskasvua. Mallien parametrit estimoitiin pienestä näyteaineistosta jatkotutkimuksen suunnittelua varten.

Keywords: advance growth, growth models, *Picea abies*, *Pinus sylvestris*, Finland.
FDC 56 + 243

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Symbols

Stand characteristics

G	Basal area at breast height, $m^2\ ha^{-1}$
G_s	Basal area at stump height, $m^2\ ha^{-1}$
H	Mean height, cm
H_{100}	Site index; dominant height at total age of 100 years, m
H_{dom}	Dominant height; mean height of 100 thickest trees per hectare
H_{gM}	Height of a tree of the median diameter class estimated with the height model of the stand
I_{Hdom}	Annual increment of dominant height
$I_{Hdom(5)}$	5-year increment of dominant height
N	Number of trees per hectare
$P_{main(N)}$	Proportion of the main tree species of the total number of stems, %
T	Time elapsed from the release cut, number of growing seasons
ETS	Effective temperature sum; sum of mean daily temperatures exceeding 5 °C of the growing season, average value for the period 1951–80 estimated by the model of Ojansuu and Henttonen (1983), degree days

Tree characteristics

h	Height, cm
i_h	Annual height increment, cm

1 Introduction

Advance growth established in mature forest stands plays an important role in the natural regeneration of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) in Finland (Mikola 1966, Rikala and Smolander 1984). The amount and quality of advance growth has been assessed in the national forest inventories, but the possibilities to utilise advance growth in southern Finland have not been studied in recent years (Ilvessalo 1956, Kuusela and Salminen 1991). New trends in forestry and the need to reduce the costs of regeneration call for more flexibility in the application of various silvicultural practices (Bradshaw and Gemmel 1992, Hagner 1992, Lähde 1992). Knowledge about the effects of various forest management activities is becoming increasingly important (Jeansson et al. 1989, Lund 1993, Pohtila 1993).

Norway spruce trees can survive in a suppressed position in a stand for decades in extreme cases. They may show little growth, but after a period of adaptation following a release cutting, they may recover and show a remarkable incremental acceleration (e.g. Schütz 1969, Indermühle 1978). Scots pine tolerates much less shading than Norway spruce and does not tolerate suppression as well as spruce (Vaartaja 1952, Mayer 1984).

In order to study the feasibility of utilising advance growth, it is essential to establish models that predict the development of advance growth trees under different management practices. Height growth has been commonly used to measure the recovery capacity of tree, and to compare the development of planted and natural seedlings (Cajander 1934, Vaartaja 1952, Fries 1990, Ferguson and Adams 1980).

According to Cajander (1934), size of the advance growth tree, its increment prior to release, density of the overstory and time elapsed since the release cut are the main factors affecting the height growth of Norway spruce advance growth after release in southern Finland. The results were presented graphically as curves of average height development. Vaartaja (1952) conducted similar studies with Scots pine, but did not present detailed results on height growth.

The purpose of this study is to construct preliminary models for the prediction of height increment of released advance growth trees, using a small data set to formulate a model and to estimate its parametres. It will be considered if the model could serve as a basis for further research in terms of model form, data requirements, and applications.

2 Materials and methods

2.1 Study sites and stands

The sites for experiments were subjectively selected in three experimental forests of the Finnish Forest Research Institute among mature stands in which a dense advance growth was present in 1981. No attempt was made to select a sample of stands that would represent the whole population of silviculturally important advance growth in southern Finland. Therefore, the results of this study cannot be generalised to represent other locations, sites or stand structures than those included in the experiments.

The experimental stands grew on common forest sites on mineral soil in the Vilppula (62°01' N, 24°30' E, 150 m above sea level; stand 1), Vesijako (61°28' N, 25°02' E, 140 m; stands 2,3 and 4) and Lapinjärvi (60°38' N, 26°13'E, 50 m; stand 5) experimental areas in southern Finland (Table 1). The estimates of the mean temperature sum (ETS) were 1175 degree days for Vilppula, 1217 d.d. for Vesijako, and 1321 d.d. for Lapinjärvi.

Site indices (H_{100}) of the Norway spruce stands were determined according to Gustavsen (1980) before the release cut. Stands 2 and 4 were so old that the site index curves had to be extrapolated manually.

Thinnings or other treatments had not been carried out in the stands later than 15 years before the release cut. They were dominated by the same species as the advance growth, except for stand 3, where the dominating species was Scots pine. In addition to Norway spruce and Scots pine, the species composition of the stands included birches (*Betula pendula* Roth. and *Betula pubescens* Ehrh.). The release cut was carried out in spring 1982 in all stands except for stand 1, where it took place in spring 1980.

Three to seven square plots (20 m × 20 m) were systematically placed in each stand after release. The advance growth stands were thinned to different goal densities; trees that were less than 10 cm high were ignored (Tables 2 and 3). The treatments for each plot were chosen randomly. However, a few treatments had to be relocated because the initial density was considerably smaller than what was required for the treatment. Fertilisation with ash (5 t ha^{-1}) and some supplementary planting with deciduous species was carried out on 11 plots. The effect of the treatments on height growth of the advance growth trees was assumed negligible, because very few of the initially small number of planted seedlings had survived for more than a couple of years.

Table 1. Characteristics of the overstory stands before removal.

Stand no.	Site index (H_{100})	Site type	Age years	N no ha^{-1}	$P_{main(N)}$ %	G m^2/ha	H_{dom} m
1	-	VT	-	248	72	42 *	-
2	26	OMT (vs)	156	353	90	31	31
3	30	MT	100	262	72	25	29
4	30	MT	130	273	99	22	32
5	26	OMT (c)	94	405	80	23	25

* = G_s instead of G
Forest site types (Cajander 1909):
OMT = *Oxalis-Myrtillus*-type; (vs) = very stony, (c) = clayey soil
MT = *Myrtillus*-type
VT = *Vaccinium*-type

Table 2. Stand characteristics of the advance growth (h ≥ 10 cm) before the release cut.

Stand no.	N no./ha	SE	H cm	SE
1	7900	10600	53	39
2	6150	6810	136	103
3	16500	9510	370	192
4	8400	8230	160	133
5	3880	5400	90	80

SE = Standard error of mean

Table 3. Number of plots with different treatments.

Stand no.	Target density (no. of stems ha^{-1}) 1000	2000	4000	No treatment
1	3	2	1	1
2	2	4	1	1
3	1	1		1
4	3	2	1	1
5	2			5

2.2 Data collection

The advance growth was assessed for the first time in spring 1981. In stand 1, the overstory had already been removed, but in other stands it was still present. Basal area of the overstory was measured by a relascope count at the midpoint of each plot. In stand 1, stump diameter was used instead of breast-height in the relascope count, and the result was expressed as G_s (Table 1).

A systematic grid of 25 circular sample plots, 4 m^2 each, was placed on each treatment plot. The number of trees of each species was counted on each circular plot. Of the tree closest to its midpoint, height, height of the lowest living branch, stump diameter and height increments of the preceding five growing seasons were measured. The measurements were repeated after the release cut in 1982, after the treatments of the advance growth in 1983, and once again in August 1990 nine (Norway spruce) or eleven (Scots pine) growing seasons after release. Height increments in the ten previous growing seasons were also measured at the latest instance.

2.3 Data structure

The amount of advance growth and seedlings established after release of the main species were calculated in the data of 1990 and converted into average stand densities by treatments. The stands substantially overshot the target densities for each treatment, probably because a large number of advance growth lower than 10 cm had been ignored in the thinning (Table 4). Besides, a number of seedlingds were probably not yet present at the time of release.

The spatial distribution of trees in a stand was described by the Index of dispersion (I) (Fisher et al. 1922) based on the measurements of the numbers of trees on the circular plots (4 m^2) in 1990:

$$I = S_x^2/x \qquad (1)$$

where
S_x^2 = between-plot variance of the number of stems
x = average number of stems per plot.

If the trees of a stand are completely randomly distributed, I = 1, and the stand is called a "Poisson forest". If I > 1, the distribution is aggregated, and trees form groups more frequently than in a Poisson forest. If $0 < I < 1$, trees are more homogeneously distributed than in a Poisson forest. The observed I values indicated that the stands were aggregated (Table 4). This was also indicated by the large proportion of empty plots.

Table 4. Density of the advance growth stands at the end of the study period.

Target density no./ha	N	Actual density no./ha	SD	I	Empty plots %	SD
Scots pine						
1000	3	5100	2270	2.44	28	8
2000	2	4400	2840	2.89	55	28
4000	1	5900	-	1.30	20	-
No treatment	1	11300	-	5.81	16	-
Norway spruce						
1000	8	2125	890	1.52	46	14
2000	7	2360	740	1.36	38	8
4000	2	3050	50	1.35	36	4
No treatment	8	3730	3250	3.88	49	28

Target density = Number of advance growth trees taller than 10 cm after release
N = Number of plots within treatment
SD = Standard deviation of plot mean
I = Index of dispersion (Fisher et al. 1922), see text (mean value of plots)

Table 5. Mean age and age range of approximately 1 m high advance growth at release.

Age years	Stand, species 1 Spruce	2 Spruce	3 Spruce	4 Spruce	5 Pine
Mean	16	37	34	40	35
Range	13–19	30–41	26–40	35–52	30–43

To get a general idea of the age of the advance growth, five trees belonging to the height class 90–109 cm were cut in autumn 1981 in each stand (Table 5). They were chosen randomly just outside the plots, and their age was counted from annual rings at stump. A few taller trees in broader height classes were chosen and treated in the same manner in the Norway spruce stands. Their mean ages were:

Stand	n	Height class m	Mean age years
2	2	3.5–4.4	48
2	1	4.5–6.4	62
3	1	5.5–6.4	44
3	1	9.5–10.4	58
4	2	3.5–4.4	57
4	1	4.5–6.4	63
5	1	2.5–3.4	52
5	2	3.5–5.4	60

The height distributions of advance growth that was present on the circular plots both at the beginning (spring 1981) and at the end (spring 1990) of the study period are shown in Figs. 1 and 2. All Scots pine sample trees were shorter than 250 cm at release, and the great majority was less than 50 cm high. The height range was very much broader for the Norway spruce (up to 16.5 m). Height distributions became broader towards the end of the study period.

In all analyses, only trees that were alive at the beginning of the study period in spring 1981 were used. The Scots pine data covered a period from the second through to the eleventh growing season, and the Norway spruce study from the first through to the ninth growing season after release. The Scots pine height growth data set included 613 observations from 64 trees and the Norway spruce data set 2646 observations from 294 trees. Seven Scots pine observations were removed because of measurement errors.

2.4 Climatic variation and height increment

Variation in annual height increment due to climatic factors could have had a large effect on the results of the study, because the release cut took place in the same year (except for the Scots pine stand no. 1).

Growth index for each year was calculated as the size corrected mean height increment in that year of all trees divided by the size corrected mean height increment of the whole period of the same trees. Growth trend due to increasing

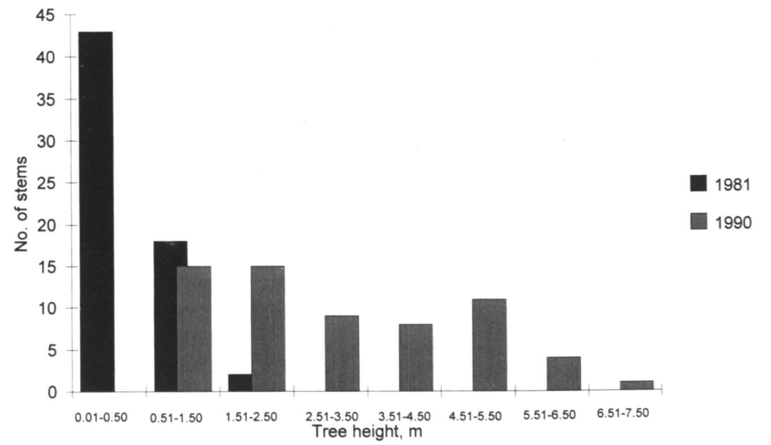

Fig. 1. Height distribution of Scots pine advance growth. Nearest tree to the plot midpoint on each circular plot in stand no. 1 in spring 1981 and in spring 1990.

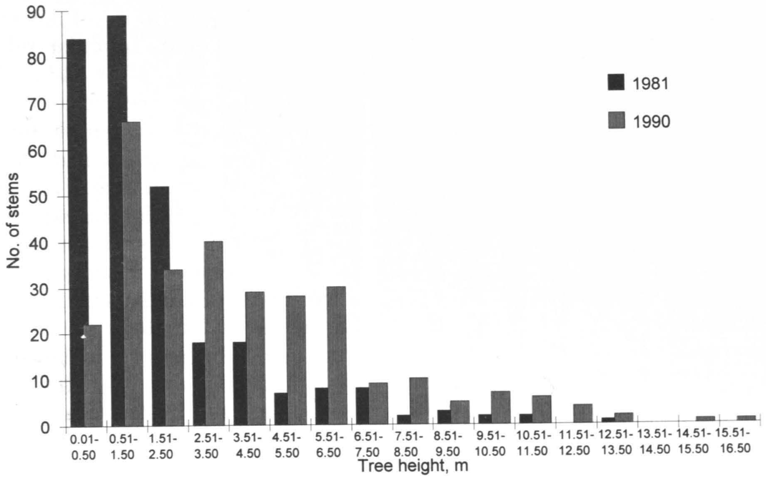

Fig. 2. Height distribution of Norway spruce advance growth. Nearest tree to the plot midpoint on each circular plot in stands 2, 3, 4 and 5 in spring 1981 and in spring 1990.

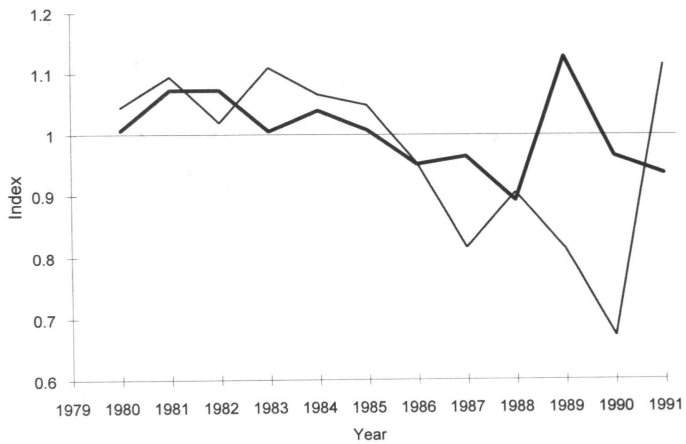

Fig. 3. Variation in height increment in 1980–91 in the data of the National Tree Research Project. See text for details on the index variable.

size of trees towards the end of the period was eliminated by applying a correction model. The calculated indices were compared with growth trends of Scots pine and Norway spruce in southern Finland in 1980–91 with an independent data set by Korhonen and Maltamo (1990), and Mäkelä and Korhonen (1992).

A diminutive trend in the height increment of Norway spruce was found (Fig. 3). However, it was not certain how well the growth trend curves represented those of advance growth trees, because they were derived from a data set consisting mainly of dominant trees. Consequently, it was decided not to use the indices to adjust the advance growth height increment data.

2.5 Calculations

Because the consecutive height increment observations for each tree were mutually dependent and the effect of increasing height and the re-

Table 6. Description of the data used in estimating parameters for models 3 and 4.

Variable	Mean	Standard deviation	Minimum	Maximum
Scots pine (n = 64)				
i_h (cm)	25	18	2	62
h (cm)	150	130	4	525
G_s (m^2 ha^{-1})	41	3	37	47
T (no.)	6.5	2.9	2	11
Norway spruce (n = 294)				
i_h (cm)	20	18	1	90
h (cm)	268	277	5	1515
G (m^2 ha^{-1})	26	7	15	43
T (no.)	5.2	2.6	1	9

lease effect could not be separated from each other, only one increment observation per tree was randomly selected for use in modelling (Table 6).

Observations on a plot and in a stand were mutually dependent. The effect of this interdependence was eliminated in the models by the application of a mixed linear model in the manner of Henttonen (1990). For a presentation of mixed linear models and their application see Searle (1971), and Lappi (1986).

The values of the increment observations were assumed to deviate from the expectation value of the model according to the following pattern:

$$id_{kjt} - E(id_{kjt}) = u_{1k} + u_{2kj} + e_{kjt} \qquad (2)$$

where

id_{kjt} = natural logarithm of the annual height increment of tree t on plot j in stand k

u_{1k} = random stand effect (assumed to be sampled from a normal distribution with mean zero and variance σ_1^2)

u_{2kj} = random plot effect in stand k (assumed to be sampled from a normal distribution with mean zero and variance σ_2^2)

e_{kjt} = random effect corresponding to error (assumed to be sampled from a normal distribution with mean zero and variance σ_e^2)

Each random parameter vector u_i is thus connected with a parameter σ_i^2. The parameters σ_i^2, i = 1,r, are called variance components. The deviation of a single random parameter (u) from the general level defined by the fixed part of the model was uninteresting. The estimates of the variance components (σ_i^2) were used to examine the amount of total variance and its origin from different sources. The choice of the variables in the fixed part of the model was based on the results of an ordinary least squares regression analysis performed prior to the application of each mixed model design.

3 Results

3.1 Height growth trends

Figs. 4 and 5 show an example of the height development of advance growth after release. In Figs. 6 and 7, average height increment is shown by height classes defined by initial height in spring 1981. Norway spruce advance growth that had been growing well before release, continued to grow relatively well after a few years of equal or reduced growth (Fig. 8). The greatest increase in height increment was shown by trees that had grown 8 to 22 cm per year before release. Trees that had grown very slowly ($i_h < 8$ cm) increased their growth only slightly. The growth decrease in the ninth growing season in 1990 was probably related to an overall poor growing season for spruce (Fig. 3).

The growth of Scots pine reacted similarly to that of Norway spruce. However, the lag between release and the acceleration of height increment seemed to be shorter in Scots pine. Furthermore, differences in increment seemed to persist to a greater extent (Fig. 9).

3.2 Height growth models

Parameters of the height increment model (2) were estimated separately for both species. Tree height and a variable describing the effect of the removed overstory were used to predict the height increment in the models 3 and 4 (Table 7). The Norway spruce model (4) contained both ln(h) and h as independent variables. The coefficient

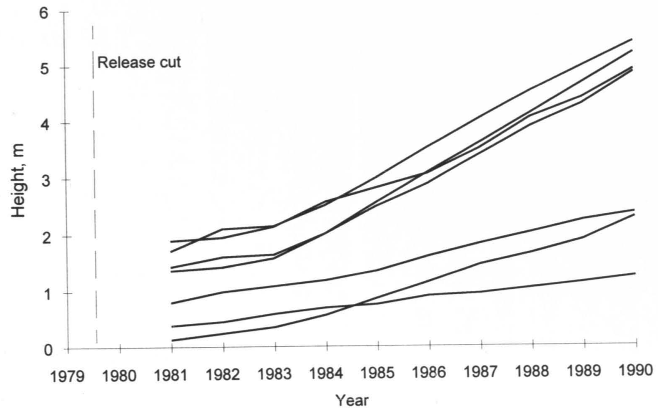

Fig. 4. Example of typical height development of Scots pine advance growth trees. Height of each tree at the end of each growing season in stand 1, plot 1.

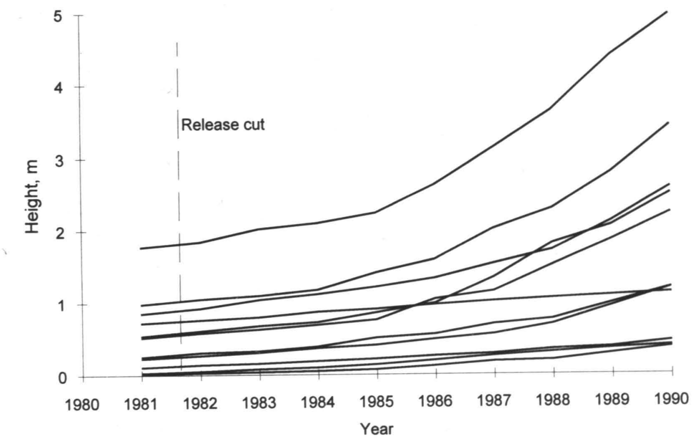

Fig. 5. Example of typical height development of Norway spruce advance growth trees. Height of each tree at the end of each growing season in stand 2, plot 1.

Table 7. Fixed part of the height increment models.

Dependent variable: $\ln(i_h + 0.01)$

Constant or independent variable	Model 3 Coefficient	Model 3 p-value	Model 4 Coefficient	Model 4 p-value
Constant	1.00646	0.153	–0.83183	< 0.001
ln(h + 0.01)	0.49527	< 0.001	0.76707	< 0.001
h			–0.00046	0.125
G_s/T	–0.01332	0.504		
G/T			–0.01917	0.002

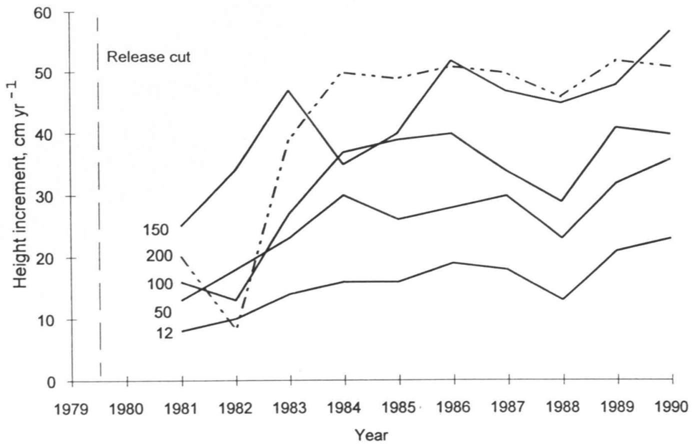

Fig. 6. Mean height increment of Scots pine advance growth in each growing season by initial height classes. Class indicated by class midpoint (cm), class interval 50 cm (first class 1–25 cm).

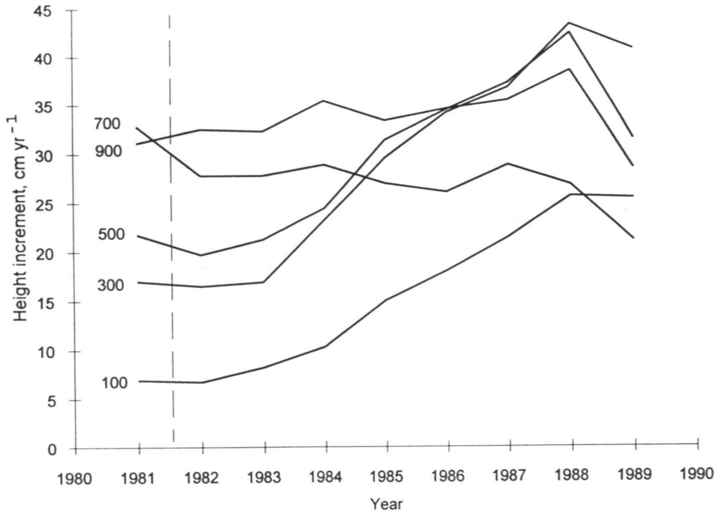

Fig. 7. Mean height increment of Norway spruce advance growth in each growing season by initial height classes (cm). Class indicated by class midpoint (cm), class interval 200 cm.

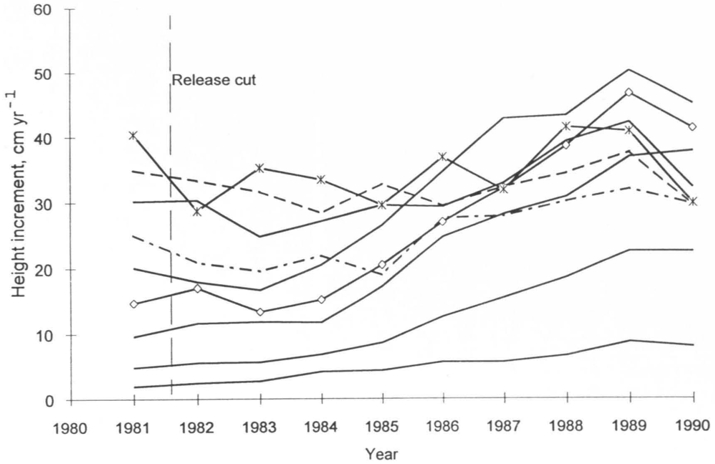

Fig. 8. Mean height increment of Norway spruce advance growth each growing season in classes of initial height increment in 1981. Class interval 5 cm (first class 0.1–2.5 cm yr^{-1}).

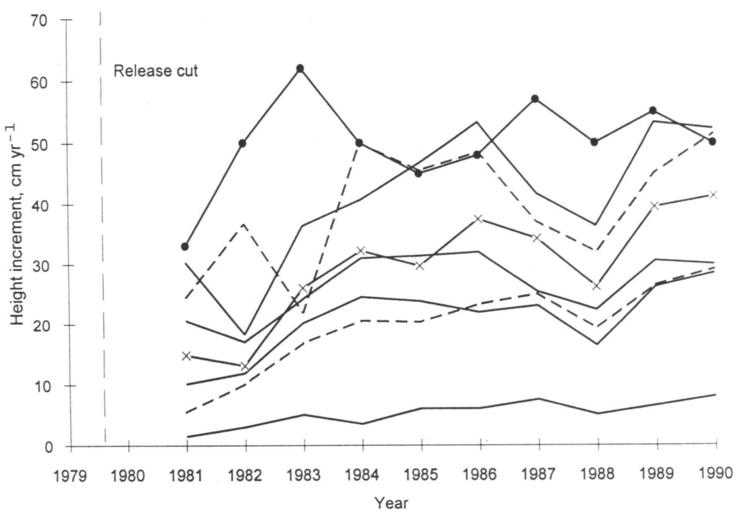

Fig. 9. Mean height increment of Scots pine advance growth each growing season in classes of height increment in 1981. Class interval 5 cm (first class 0.1–2.5 cm yr^{-1}).

of h was negative, because it represented the effect of diminishing increment after culmination. Since the Scots pine trees were considerably smaller and younger, there were very few height increment observations from the period after culmination. Consequently, the model did not include h but only ln(h). Therefore, the Scots pine model (3) should not be applied on trees that are taller than 7 m, where there were no observations. A model that could predict the growth of taller trees more reliably could be constructed only after the height increment has levelled out and begun to decrease for the majority of the trees.

The effect of the overstory density (expressed as basal area) on height increment was assumed to be negative and its absolute value to be diminishing during the whole study period. The overstory effect diminished in proportion to the time elapsed from release. Coefficients of the variables representing different treatments, such as density of the advance growth stand, and dummy variables for fertilisation and supplementary planting did not deviate significantly from zero, and they were omitted from the models.

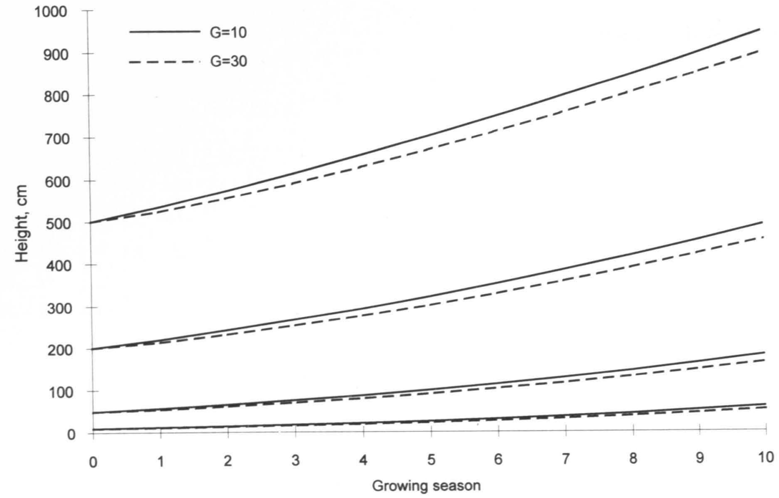

Fig. 10. Height development of Norway spruce advance growth model trees (model 4). Height at the end of each growing season. Basal area of removed overstory 10 and 30 m^2 ha^{-1}.

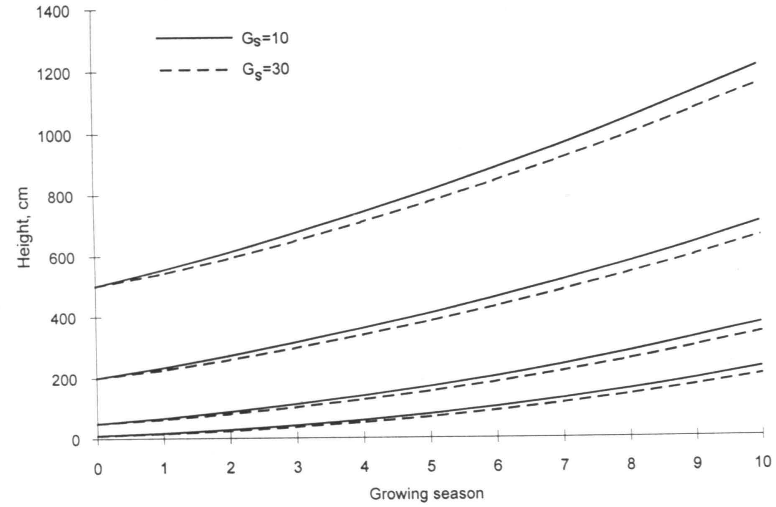

Fig. 11. Height development of Scots pine advance growth model trees (model 3). Height at the end of each growing season. Basal area of removed overstory 10 and 30 m^2 ha^{-1}.

The residual variation that was not explained by the fixed part of the models 3 and 4 was divided into the variation between plots (0.5 %) and error (99.5 %) in the Scots pine data (Table 8). In the Norway spruce data, a between-stands component was also present, and it accounted for 2.5 % of the residual variation. The between-plot variation was 4.4 %, and error 93.1 % of the total variation.

Figs. 10 and 11 illustrate the height development of advance growth after release calculated with the models. The initial height (h) was varied between 10 and 500 cm, and the basal area (G, Gs) was 10 or 30 m^2 ha^{-1}. The increment increased consistently throughout the simulation

Table 8. Estimates of the parameters of the random part of the height growth models.

Dependent variable: $\ln(i_h + 0.01)$

Variance component	Model 3	Model 4
σ_1^2	-	0.01306
σ_2^2	0.00253	0.02365
σ_e^2	0.48665	0.49672

σ_1^2 = Variance component connected with the random stand effect
σ_2^2 = Variance component connected with the random plot effect
σ_e^2 = Variance component connected with random error

period (first through tenth growing season after release), along with increasing height and decreasing effect of removed overstory.

3.3 Evaluation of the models and comparison with other studies

Cajander (1934) studied the height growth of released Norway spruce advance growth on grass-herb forest sites (*Oxalis-Myrtillus* type) in southern Finland. A comparison with his results was carried out by simulating a height development curve with similar initial values for overstory stand and advance growth tree variables with model 4 for the first through to the tenth growing season after release. A curve that represented a density of 300–400 overstory trees per hectare was selected from the height development curve family of Cajander, because the average N was 319 stems ha^{-1} in this data, which represented about 30 m^2 ha^{-1}. Height development curves according to Cajander (1934) and this study were fairly similar in form (Fig. 12). In this study however, height increment was influenced by height to a greater extent.

The simulated height development of advance growth was also compared with the mean height of planted and sown seedlings growing on a similar site types (Scots pine: *Vaccinium type*, VT; Norway spruce: *Oxalis-Myrtillus type*, OMT (Cajander 1909)) in southern Finland (Räsänen et al. 1985), and the height development of planted Scots pine seedlings according to a model by Varmola (1987).

Height development of Scots pine advance growth model trees that were 5, 20 and 50 cm high at release was simulated by model 3 (Fig. 13). Height development of planted seedlings was simulated using Varmola's (1987) model 431.1. The dominant height of seedlings were calculated at 0, 5, 10 and 15 years of age, adding five-year increment estimates to the seedling height. Values for each age between 0 to 15 years were interpolated using cubic spline functions. Since the dependent variable of the model

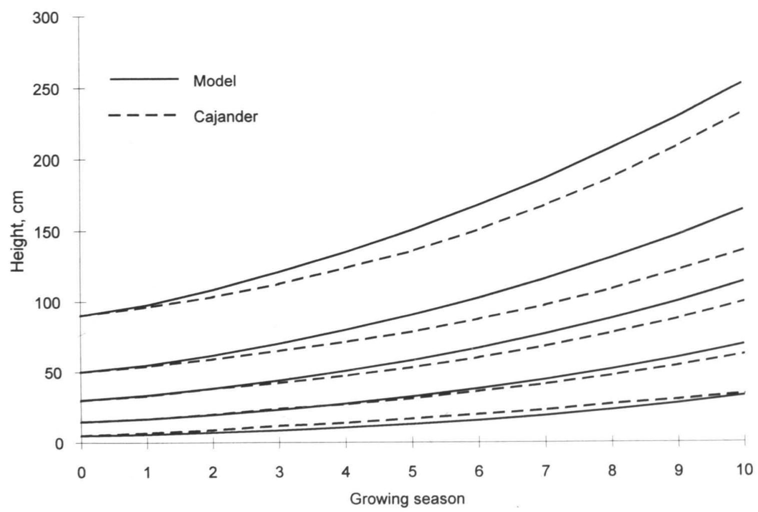

Fig. 12. Height development of released Norway spruce advance growth according to a curve by Cajander (1934) and simulated with model 4 with comparable tree and stand parameters. See text for details.

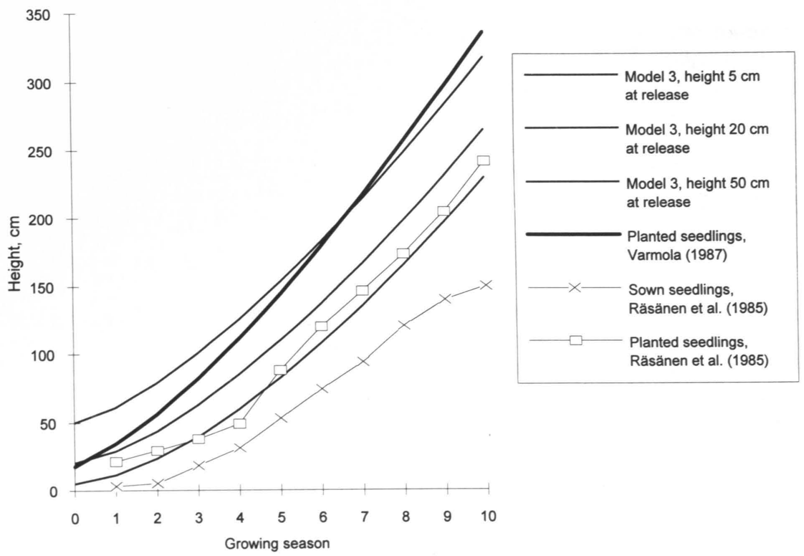

Fig. 13. Simulated height development of Scots pine advance growth (model 3), simulated height development of planted seedlings by Varmola (1987), and average height of planted and sown seedlings in the survey by Räsänen et al. (1985). See text for details.

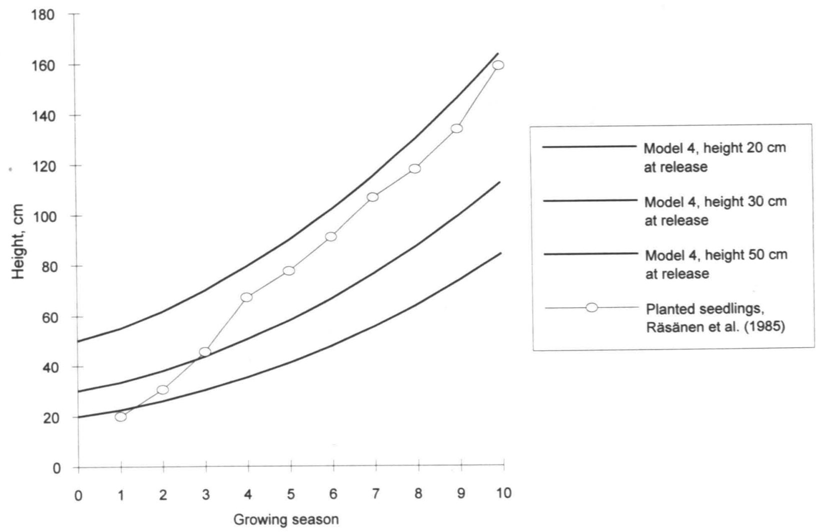

Fig. 14. Simulated height development of Norway spruce advance growth (model 4) and average height of planted seedlings in the survey by Räsänen et al. (1985).

was five-year increment of the dominant height ($I_{Hdom(5)}$), the height was converted into mean height (H_{gM}) with model 83.1 by Varmola (1987). The model 83.1 could not be used when the dominant height was less than 1.4 m. Beneath that height, the relationship between mean and dominant height was assumed to be constant and the same as at 1,4 m dominant height (0.93). The seedlings were supposed to be three years old at planting, which represented a mean height of 17.5 cm.

The mean height of planted and sown seedlings on *Vaccinium* site types in southern Finland (Räsänen et al. 1985) from one to ten growing seasons after planting are also shown in Fig. 13.

A similar comparison with Norway spruce (model 4) is shown in Fig. 14, with the exception that a widely applicable model for the development of the seedlings did not exist. The initial heights of advance growth trees were 20, 30 and 50 cm.

Scots pine advance growth model trees grew more slowly than planted seedlings according to models by Varmola (1987) during the whole 10-year period. The model by Varmola (1987), however, represented height development of seedlings under very favourable growing conditions as stated by the author. In practice, seedling growth tends to be slower, as the mean heights in the survey (Räsänen et al. 1985) indicate.

Norway spruce advance growth model trees grew much slower than the average heights of planted seedlings would suggest. An advance growth tree had to be at least 50 cm high at release to attain the mean height of planted seedlings in 10 years.

4 Discussion

The results of this study were based on one Scots pine and four Norway spruce experiments that were observed for nine to eleven growing seasons after release. They were not likely to represent the entire spectrum of stands with advance growth in southern Finland, because the experimental sites were selected subjectively from a limited population of stands with fairly old overstories. Consequently, the presented models and other results are only preliminary and need to be derived from a large, representative data set.

Fertilisation, thinning and supplementary planting had been applied on some of the plots, but variables representing the treatments were not found to have had a significant effect on height growth.

The growth of Norway spruce generally began to show a substantial increase on the fourth or fifth growing seasons after release. Cajander (1934), Skoklefald (1967) and Bergan (1971) observed a similar acceleration that began three to four growing seasons after release. A slight reduction in height increment of the tallest trees (h > 2 m) that lasted a couple of years after release that was observed on some of the experimental plots by Skoklefald (1967), was also observed.

There were large differences between individuals in height growth and its acceleration due to size and previous growth. During the last inventory, it seemed as if the position of a tree in a stand also caused such differences. Height differences that existed at release were constantly increased during the study period as in Skoklefald's (1967) study. The height and spatial distribution of the advance growth varied widely. It might be beneficial to include competition and distribution variables in models in further studies in order to describe the stand dynamics in more detail.

The effect of the removed overstory on growth seemed not to have expired at the end of the study period. A longer observation period is necessary in further studies. The decreasing growth trend of Norway spruce during the last years (1987–90) of the study period could have lead to an underestimation of the release effect in the later half of the study period, or an overestimation of it in the first half. More data of climatic growth variations of small trees should be acquired and used to adjust the observations in further modelling work.

Site index did not correlate with the increment of released Norway spruce advance growth. The site index range in the data was very narrow. It would be difficult to combine the models as such with most tree growth models, where site index is usually a very important coefficient.

Comparison of the simulated growth curves with those presented by Cajander (1934) did not reveal major differences in the results of the studies. However, Cajander did not publish detailed stand descriptions of the data. Consequently, it can not be appraised as to what extent the data sets in the two studies were similar in relation to growth factors. The comparison of results contributed little in terms of validation of the results. The possibility to use the data of Cajander as an independent data set in further studies should be examined.

A direct comparison of the results with a Norwegian study by Skoklefald (1967) was not possible. The stands in that study had been established with the shelterwood method and had enjoyed a period of reduced competition before the release cut. The same applies to the study of Bergan (1971), according to which the tall trees (h > 1 m) increased their height growth much more than in this study.

Released Scots pine advance growth trees had a slower height increment than planted seedlings according to Varmola's (1987) model, but kept better in pace with the mean height of planted seedlings surveyed by Räsänen et al.(1985) in southern Finland. Norway spruce advance growth trees grew substantially slower than the mean height development of planted seedlings of the survey would suggest.

Bergan (1971) found that planted Norway spruce seedlings grew slower than released natural seedlings in a shelterwood stand during their first 15 years in northern Norway. The results were thus somewhat contadictory to those obtained in this study. Fries (1990) also found that 17 years after planting, height increment was significantly greater for planted than for naturally regenerated spruce advance growth seedlings in two of three treatments in northern Sweden.

The applied model form is suitable for incorporation in a long-term planning system which is used to simulate the development of forests assessed in the Finnish National Forest Inventory (Siitonen 1983, Ojansuu et al. 1992). Obviously, the height growth model must include variables describing the density of removed and residual overstory, time elapsed from the release cut, and probably site index in addition to tree variables. In a study with Grand fir (*Abies grandis* [Dougl.] Lindl.), Ferguson and Adams (1980) found that young advance growth trees were able to adjust quicker to overstory removal than older trees. Tree vigour was also an important variable in their growth model, represented by the 5-year height increment before release. The uneven spatial and size distribution of advance growth should be taken into account in further studies. Models for the prediction of diameter increment and mortality of advance growth must be developed for the planning system.

A large data set should be acquired through the measurement of a representative sample of temporary plots in released advance growth stands. However, it is not certain that such a sample is yet to be acquired in Finland, since it is only for some years that the utilisation of advance growth has been gaining in popularity.

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