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Helsinki 2003

ISSN 0039-5471
Suo 54(3): 93–104

Development of planted black spruce and Scots pine on an oligotrophic drained peatland

Mustakuusen ja männyn istutustaimikon kehitys karulla ojitetulla suolla

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The development, structure, production and fertilisation of planted black spruce (*Picea mariana* (Mill.) B.S.P) and Scots pine (*Pinus sylvestris* L.) stands growing on a drained, originally treeless *Sphagnum papillosum* fen (LkKaN) in Central Finland up to the age of 30 years were studied. For black spruce the stem number was 2250 stems ha^{-1}, dominant height was ca 7.1 m, the mean stand volume 26 m^3 ha^{-1}, the annual mean volume increment 1.5 m^3 ha^{-1} and the total mortality based on stem number was 21%. For Scots pine the comparable characteristics were 1015 stems ha^{-1}, 10.4 m, 45 m^3 ha^{-1}, 3.3 m^3 ha^{-1} and 59% respectively. Fertilisation had no apparent impact on the stand characteristics. About 63% of the planted black spruce individuals had at least one vegetatively generated layer. High number of layers seemed to have a negative effect on dominant parent tree growth. It is concluded that growth and yield of black spruce are generally not competitive in operational forestry in Finland. However, black spruce could be used as an alternative tree species in treeless areas that resist afforestation, and it might also be cultivated for decorative purposes.

Keywords: Afforestation, treeless peatlands, young stand development, *Picea mariana*, *Pinus sylvestris*

Introduction

Peatland drainage and afforestation

In Finland, most of the drainage, totalling 5.4 million hectares, has been carried out on naturally forested mires in order to obtain better growing conditions for trees (Tomppo 1999, Hökkä et al. 2002). Only a small percentage of this has involved drainage and afforestation of treeless mires, estimated to have been about 220 000 hectares (Kaunisto and Tukeva 1984, Keltikangas et al. 1986). As late as in the beginning of 1970's minerotrophic treeless mires were considered suitable for forestry in southern Finland (Heikurainen 1973). Nowadays, however, pristine mires (total area over 4 million hectares) are no longer reclaimed for forestry.

In Finland only two coniferous (Scots pine, *Pinus sylvestris* L. and Norway spruce, *Picea abies* (L.) Karst.) and one deciduous (pubescent birch, *Betula pubescens* Ehrh.) tree species grow on naturally forested peatlands. Most of the drainage and afforestation of treeless mires took place in the 1960s and 1970s and was mainly carried out by planting Scots pine (Kaunisto and Päivänen 1985). On nutrient-poor sites Scots pine was also seeded. On drained peatlands, afforestation with

Norway spruce was strongly restricted, because of its sensitivity to spring frost and its need of at least mesotrophic site conditions. Pubescent birch was hardly used at all for active afforestation on an operational scale.

Black spruce — an alternative tree species?

Black spruce (*Picea mariana* (Mill.) B.S.P) has wide, natural site amplitude in North America. It occurs from the northern United States up to the climatic tree line in northern Canada and from Newfoundland to Alaska (Sarvas 1964). It grows on a wide variety of sites; both on dry upland sites and on wet nutrient rich minerotrophic and poor ombrotrophic mires (Haavisto et al. 1988). Regeneration from seeds takes place quite easily, especially following fire, leading to more or less even-aged stands (Lieffers 1986, Groot and Horton 1994). Uneven-aged stands develop in the absence of fire, especially on poor, wet sites, where reproduction by layering is common (Stanek 1968, 1975, Groot 1984, Groot and Horton 1994). The term "layering" refers to the process by which an embedded branch takes root and is evidently capable of independent growth forming "a layer".

In Canada, black spruce is one of the most important tree species on peatland sites, especially in the region of Ontario (Haavisto and Jeglum 1995, Hökkä and Groot 1999). On its natural range, the growth of black spruce has proved to be rather low, generally as a result of the poor growth conditions of the sites (Payandeh 1973). Most of the total cut of black spruce in Canada is harvested from pristine peatland sites. On these sites there is often advance growth, which has been defined as natural regeneration that exists in a stand prior to harvesting (Sims and Walsh 1995). After careful logging, where the advance growth is protected during harvest, the remaining tree stand may reach merchantable size more quickly than planted or naturally regenerated, even-aged stands (Hökkä and Groot 1999).

Due to its ecological adaptation, black spruce might be one of the most suitable exotic tree species for afforestation on drained peatlands in Finland. It seems not to be sensitive to spring frost, and it might be suited to mire sites on which the only domestic alternative is Scots pine. In Norway (Braekke 1990) and in southern Sweden (Ståhl and Persson 1992) black spruce has been included in planting and fertilisation experiments on drained treeless mires. Reports on the early performance of planted black spruce on drained peatlands are available for southern (Päivänen 1983) and northern Finland (Numminen 1983). However, published reports on the young stand development prior to the first commercial thinning are still scanty.

The aim of the study

This study investigates the development of black spruce in a deep peat site drained for forestry. We aimed to compare the development, structure and productivity of planted black spruce and Scots pine stands in Finnish conditions up to the age of about 30 years, and to study the effects of fertilisation on stand development.

We postulate that black spruce can be grown on nutrient poor peatland sites where the only native alternative is Scots pine. Because the study material is based on an experiment in which the growing conditions e.g. site properties and climate, were homogenous for both of the tree species, we assume that differences between the tree species are mainly due to their ecological characteristics. We assumed their response to fertilisation to be alike.

Material and methods

Experimental design

The experimental field is situated in Central Finland (61°52' N; 24° 22' E), 154 m above sea level (Fig. 1). The annual precipitation is about 600 mm, of which about 320 mm falls during the summer months (June–September). The temperature sum of the growing season is 1150 degree days (threshold value +5 °C) for this area.

The experimental field was established in 1969 (see, Päivänen 1983, Sarkkola and Päivänen 2001, p. 80–83) on a drained treeless *Sphagnum papillosum* fen (LkKaN). The site is oligotrophic and represents the lowest level of minerotrophy in the Finnish peatland site type classification

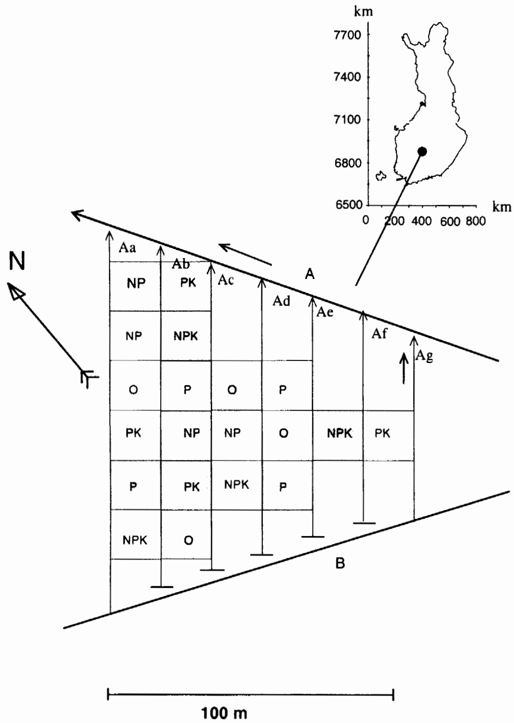

Fig. 1. The design of the Scots pine and black spruce plots in the experimental field in Nuijaneva mire, Orivesi, Finland. Grey boxes indicate black spruce plots and white ones indicate Scots pine plots; fertilisers: N = nitrogen, P = phosphorus, K = potassium. Aa – Ag are contour ditches, A is a collecting ditch and B is a cut-off ditch.

Kuva 1. Männyn ja mustakuusen istutuskokeen koejärjestely Oriveden Nuijanevalla. Harmaat laatikot ovat mustakuusi- ja valkoiset mäntykoealoja; lannoitteet: N = typpi, P = fosfori, K = kalium. Aa– Ag ovat sarkaojia, A on kokoojaoja ja B on niskaoja.

(Laine 1989). The field layer is characterised by *Trichophorum cespitosum* (L.) Hartm., *Eriophorum vaginatum* L. and *Carex pauciflora* Lightf. and the bottom layer by *Sphagnum papillosum* Lindb.

Peat thickness at the study site is 3 m. A main ditch on the eastern side of the field was dug already in the 1930's. However, a proper drainage network, consisting of plastic pipes placed 35 m apart, was not installed until 1965. Because of insufficient drainage, the drains were opened in 1976 with a tractor digger and each strip was split with an additional open ditch to form a network of ditches with a spacing of 17.5 m. Thereafter the condition and the drainage effect of the ditches have been adequate.

In the spring 1969 ten randomised 16.25 × 16.25 m sample plots were planted with 2 + 2 year old black spruce and 10 sample plots with 2 + 1 year old Scots pine (Fig. 1). Each sample plot had 81 transplants, i.e. about 3070 transplants per hectare. The black spruce material belongs to the second generation growing in Finland. The seeds were from a tree stand established in 1932 in the Punkaharju experimental forest by the Finnish Forest Research Institute. Although the original seed source was the St. John River Valley, New Brunswick, Canada, the more detailed information concerning the origin of this black spruce material is unfortunately lacking (Päivänen 1983). The Scots pine seedlings were obtained from the local nursery of the Finnish Forest and Park Service.

In connection with planting, the transplants were fertilised with phosphorus rich compound fertiliser (15% N; 11% P; 8% K) applied around each transplant 30 g or 60 g at a radius of 15 cm and 30 cm, respectively. However, the different amounts did not show any impact on early height development (Päivänen 1983).

Refertilisation was carried out in spring 1976 by hand-applied broadcast applications of 0, P, PK, NP, NPK combinations with two replicates for both of the tree species. The fertilisers and amounts used were as follows:

– ammonium-nitrate limestone 385 kg ha^{-1} (N 26%)

– granulated super phosphate 575 kg ha^{-1} (P 9%)

– muriate of potash 150 kg ha^{-1} (K 50%)

After establishment, the plantations have developed without any silvicultural treatments.

Inventories

The sample plots have been inventoried repeatedly in years 1969, 1970, 1971, 1978, 1982, 1991 and 1998. In the first five inventories, the survival, condition and height growth of the transplants were recorded (Päivänen 1983). In the latest two, done for this study, the tree height and the diameter at the breast height (DBH) of each tree were also measured. The vegetatively generated layers of each black spruce were also inventoried and their heights were measured. In the latest inventory, the 5-year height increment above 2.5 metres was measured on three dominant Scots pine trees per sample plot in order to estimate the site index according to Hägglund´s (1976) intercept method.

Calculations

Stand characteristics

For the two latest inventories stem number (number ha^{-1}), stand basal area (m^2 ha^{-1}), stand mean diameter (cm), dominant height of the stand (m) and total stand volume (m^3 ha^{-1}) were calculated for each sample plot using the KPL software (Heinonen 1994). Due to the lack of convenient tree volume models for black spruce, the models for Norway spruce (*Picea abies* (L.) Karst) were applied. The dominant height was determined as the mean height of the 100 thickest trees per hectare. All of the stand characteristics are based on trees that were living trees at the time of each survey. Tree mortality was determined on the basis of the difference of the stand stem numbers between successive measurements.

Stand structure

DBH distribution was used to describe the structural characteristics of the stands and to assess the differences between the species. The DBH distributions per hectare with 1-cm classes were calculated for the two latest measurements on each sample plot (1991 and 1998). In order to analyse the DBH distributions statistically, they were smoothed and parameterized with the two-parameter Weibull-function (e.g. Bailey and Dell 1973, Kilkki and Päivinen 1986). The probability density function has the form:

$$f(x) = \frac{c}{b}\left(\frac{x}{b}\right)^{c-1} \exp\left[-\left(\frac{x}{b}\right)^{c}\right], \text{ when } x >= 0 \quad (1)$$

$f(x) = 0$, when $x < 0$,

where $f(x)$ is the number of trees in DBH class x, the scale parameter b describes the location of peak of the DBH distribution, and shape parameter c describes the shape of the DBH distribution as follows:

$c \leq 1$, the distribution pattern is a reversed J,

$1 < c < 3.6$, the distribution is dome-shaped and positively skewed,

$c = 3.6$, the distribution is approximately normal,

$c > 3.6$, the distribution is negatively skewed.

The Weibull-function was fitted to the DBH distributions using the MODEL procedure included in SAS statistical software, which applies the maximum likelihood (ML) method (SAS 1996).

Site index

The site index was estimated for the unrefertilised control plots in order to assess and describe the sites potential for wood production. Although Hägglund's (1976) method was originally developed for Swedish Scots pine plantations growing on upland sites, it has been proved to be valid also for Finnish conditions (Salminen and Varmola 1990, Varmola 1993). However, this is the first application of Hägglund´s site index method in a study of pine plantations growing on drained peatland.

Assessment of the stand development

In order to compare the development of the Scots pine stands on peatland sites of this material (all the sample plots) to those growing on upland sites, the model for dominant height growth ($I_{Hdom(5)}$) (Varmola 1993) and the model of the growth percent of the five years dominant height (P_H) (Vuokila and Väliaho 1980) were applied:

$$\ln(I_{Hdom(5)}) = -3.3460 + 0.270265 \times \ln(H_{dom}) + 0.01 + 1.18076 \times \ln(H_{100} - H_{dom}) + 0.0125849 \quad (2)$$

$$P_H = -0.40006 + 434.52 \times (1/(H_{dom}^{0.4} \times T^{1.1})) - 124.51 \times (1/H_{dom}^{0.4} \times T^{1.1})^2) \quad (3)$$

where H_{dom} is tree dominant height (m), H_{100} is H_{dom} at the stand age of 100 years (Hägglund's site index estimate in this data) and T is the biological age of the stand. Models 2 and 3 were used to simulate the development of the dominant height during the last monitoring period (between stand ages 25–33 years).

For black spruce, comparative growth and yield models that are directly valid for Finnish conditions were not available. Payandeh and Haig (1994) presented a model based on stand age and site index for predicting the stand dominant height for naturally established black spruce growing on pristine peatland sites in northeastern Ontario. This model was applied to our stands to enable a comparison between the productivity of our stands to that of the Canadian stands. According to the temperature sum, the climatic conditions of the area where the modelling data came from appears to correspond approximately to conditions in southern Finland. The model formula is:

$$H_{dom} = 15.24 \times S^{0.84} / (1 + e^{(6.16-0.972\ln(A)-0.009\ln(S))}) \quad (4)$$

where H_{dom} is stand dominant height (m), A is stand age (years), and S is site index (stand dominant height at the age of 50 years).

Statistical analysis

Based on the latest measurements (1998), the influence of fertilisation treatments on the plotwise stand characteristics (mean annual height and volume increment, mean annual mortality, and diameter distributions (Weibull parameters)) and the differences between tree species were studied based on the split-plot ANOVA model. The main factor was the tree species, and the sample plot factors were the fertilisation treatments: 0, P, PK, NP and NPK. The analyses were also done for the following treatment combinations: P+PK and NP+NPK, P+NP and PK+NPK. Multiple comparisons between main effect means, if significant, were made by Tukey's test. All the analyses were done using the GLM procedure included in SAS software (SAS 1992).

The effect of inter-tree competition on the stand productivity was examined plotwise by calculating a coefficient of variation (CV) of tree height for each sample plot and by checking the possible dependence of this variation measure on the stand basal area.

Results

Mortality

By the time point of the last survey (1998), the total cumulative mortality defined as stem number in the Scots pine stands (59%) was clearly higher than that in black spruce stands (21%) (Fig. 2). In the Scots pine sample plots the high mortality frequency occurred in two phases. During the initial years after planting, a heavy damage caused by snow blight (*Phacidium infestans*) was observed, causing an increase in Scots pine mortality (Päivänen 1983). Moose damage may be the reason for the loss of young Scots pines between the years 1982 and 1991, when the trees were around 3 m high. In contrast, the mortality rate of black spruce was more even over time.

Stand development

Excluding the stand basal area, all the stand characteristics were significantly (at risk level 5%) greater for the Scots pine than black spruce stands (Table 1). The Scots pine stands had reached the mean height of two meters at age of 13 years, and black spruce stands reached this height at the age of 16 years (Fig. 3). At the biological age of 32 years the dominant height was ca 10.4 m (s = 0.7) for Scots pine and 7.1 m (s = 0.9) for black spruce.

Although at the time of planting (1969) the black spruce stock was about 10 cm taller than Scots pine (Päivänen 1983), the mean annual height growth has been greater for Scots pine than for black spruce, resulting in significant differences in stand heights (Fig. 3). During the latest monitoring period (between stand ages 25–33 years), the mean annual height growth of pine was 38 cm (s = 4.7 cm) and that of black spruce 20 cm (s = 1.5 cm). Correspondingly, the average annual increase in dominant height was 47 cm (s = 13.1) for pine and 26 cm (s = 12.5) for black spruce.

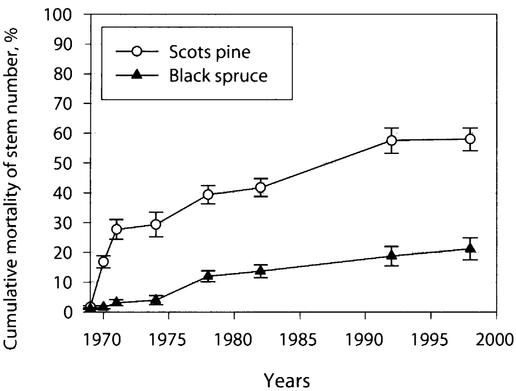

Fig. 2. The average cumulative mortality of the planted Scots pines and black spruces. Standard error of the mean represented by error bars.

Kuva 2. Kuolleisuuden keskimääräinen kehitys mänty- ja mustakuusikoealoilla. Keskiarvon keskivirheet esitetty virhepylväinä.

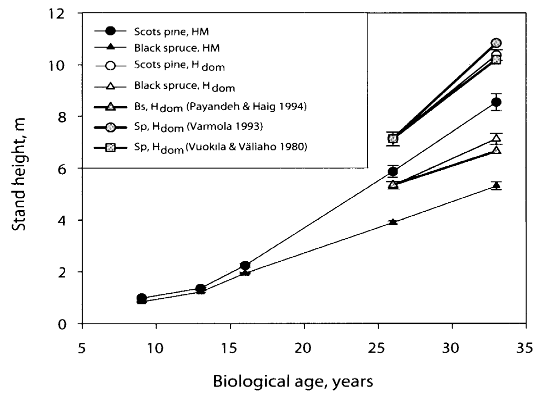

Fig. 3. The average development of the measured mean height (HM, black symbols) and the measured dominant height (H_{dom}, white symbols) of Scots pine and black spruce stands by increasing biological age. As a comparison, the thick lines with grey symbols depict the dominant height development simulated by growth and yield models at the ages of 26 and 33 years (measurement years 1991 and 1998).

Kuva 3. Mitatun keskipituuden (HM, mustat symbolit) ja valtapituuden (Hdom, valkoiset symbolit) keskimääräinen kehitys mänty- ja mustakuusikoealoilla. Vertailuna on lisäksi esitetty eräillä kasvu- ja tuotosmalleilla simuloidut valtapituuden kehitykset ajanjaksona, jolloin puuston biologinen ikä on ollut 26–33 vuotta (mittausvuodet 1991–1998).

The mean stand volume in 1998 was 45 m^3 ha^{-1} (s = 11.6) for Scots pine and 26 m^3 ha^{-1} (s = 2.9) for black spruce (Table 1). Correspondingly, the annual mean volume increment in 1991–1998 was 3.3 m^3 ha^{-1} (s = 0.9) for Scots pine and only 1.5 m^3 ha^{-1} (s = 0.4) for black spruce. Applying Hägglund's (1976) model, the site index for Scots pine, i.e. the estimated stand dominant height at stand age of 100 years, turned out to be 23 m.

At the biological stand age of 32–33 years, both the location of the peak of the diameter distributions (parameter b, $p < 0.001$) and the shape of the distribution (parameter c, $p = 0.05$) differed significantly between the two tree species (Fig. 4). The mean value of parameter b was 6.4 (s = 1.3) for black spruce stands and 11.2 (s = 0.9) for pine stands. The mean value of parameter c was 3.5 (s = 0.5) for black spruce and 4.9 (s = 1.3) for pine. The average range of DBH distribution was 10 cm for black spruce and 14 cm for Scots pine (Fig. 4).

In Scots pine stands the positive correlation between the CV of tree height and the stand basal area, which increased from 0.31 to 0.45 during the latest monitoring period (between stand ages 25–33 years), indicated increasing variation in tree sizes (heights) during the development of the stand (trees were growing and canopy was closing). For black spruce stands the correlation coefficient described above was negative and even decreased from –0.19 to –0.37 during the monitoring period.

Model simulations

For Scots pine, Varmola's (1993) model of stand dominant height growth (Eq 2) produced an overestimation of 46 cm (+4.4%) for H_{dom}. In contrast, the model of dominant height growth percent (Eq 3) presented by Vuokila and Väliaho (1980) underestimated by H_{dom} about 18 cm (–1.7%) for the simulation period (between stand ages 25–33 years). However, most of the stands studied by Vuokila and Väliaho (1980) were established by sowing and only a minority by planting. The smallest bias was obtained when the value of H_{100} was set at 23 m, which is the same as the site index (H_{100}) obtained by the Hägglund's (1976) intercept method.

The model applied (Eq 4) showed that the

Table 1. The mean stand characteristics of Scots pine and black spruce stands at the stand age of 33 years (1998) by the fertilisation treatments, and the results of split-splot ANOVA modelling of the effects of fertilisation treatments and tree species. N = stem number, ha^{-1}; G = stand basal area, m^2 ha^{-1}; DgM = stand basal area mean diameter, cm; HM = stand median height, m; H_{dom} = stand dominant height, m (the mean height of 100 thickest trees ha^{-1}); V = stand volume, m^3 ha^{-1}; I_V = mean annual volume increment in 1991–1998 m^3 ha^{-1} $yr.^{-1}$; Weibull parameters: b = the location parameter (describes the location of the peak of the DBH distribution, cm) and c = the shape parameter (describes the shape of the DBH distribution).

Taulukko 1. Keskimääräiset männyn ja mustakuusen metsikkötunnukset 33 vuoden iällä (1998) lannoituskäsittelyittäin sekä osaruutukokeen lannoituskäsittely- ja puulajivaikutusten testitulokset split-plot ANOVA -mallin mukaan. N = runkoluku, ha^{-1}; G = metsikön pohjapinta-ala, m^2 ha^{-1}; DgM = pohjapinta-alan mediaaniläpimitta, cm; HM = metsikön keskipituus, m; H_{dom} = metsikön valtapituus, m (100 paksuinta puuta, ha^{-1}); V = metsikön tilavuus, m^3 ha^{-1}; I_V = keskimääräinen vuotuinen tilavuuskasvu jaksolla 1991–1998 m^3 ha^{-1} $a.^{-1}$; Weibull-parametrit: b kuvaa läpimittajakauman huipun sijaintia ja c kuvaa läpimittajakauman muotoa.

	Fert. treat.	N	DgM	G	HM	H_{dom}	V	I_V	b	c
Pinus sylvestris	0	1273	11.95	10.97	7.89	9.91	52.36	3.86	11.26	4.04
	P	760	11.40	9.75	8.01	10.53	26.81	2.11	11.30	4.82
	NP	1046	11.42	7.91	7.97	10.72	39.60	2.93	10.40	4.31
	PK	932	12.01	10.41	9.34	10.16	54.00	4.03	11.82	6.63
	NPK	1065	12.31	10.53	8.74	10.51	51.92	3.95	11.21	4.93
	Average	1015	11.82	9.91	8.39	10.37	44.93	3.34	11.20	4.95
Picea mariana[*)]	0	2566	7.27	8.66	5.38	6.93	28.87	1.80	6.34	3.70
	P	2205	7.49	7.59	5.19	7.51	25.51	1.57	6.23	3.12
	NP	2338	7.25	6.46	5.10	7.70	21.42	1.02	6.61	4.04
	PK	1882	7.25	7.54	5.47	6.76	26.92	1.67	6.18	3.04
	NPK	2281	7.57	8.14	5.40	6.76	27.59	1.58	6.54	3.53
	Average	2254	7.36	7.68	5.31	7.13	26.06	1.53	6.38	3.49

Effect of tree species (whole plot factor)
Puulajivaikutus (pääruutufaktori)

		DgM	G	HM	H_{dom}	V	I_V	b	c
df = 1	F	243.4	2.85	176.55	149.25	262.11	363.4	252.64	5.86
	p_{value}	0.0001	0.1669	0.0002	0.0003	0.0001	0.0001	0.0001	0.0527

Effect of fertilisation (sub-plot factor)
Lannoitusvaikutus (osaruutufaktori)

		DgM	G	HM	H_{dom}	V	I_V	b	c
df = 4	F	0.91	3.16	0.58	0.71	0.49	0.60	0.21	0.72
	p_{value}	0.4920	0.0638	0.6856	0.6030	0.7449	0.6712	0.9291	0.5999

Interaction
Yhdysvaikutus

		DgM	G	HM	H_{dom}	V	I_V	b	c
df=4	F	0.28	3.38	0.35	0.56	0.07	0.09	0.70	2.32
	p_{value}	0.8830	0.0587	0.8398	0.6956	0.9897	0.9849	0.9291	0.1275

[*)] the black spruce layers are not included in the stand characteristics
mustakuusen taivukkaat eivät sisälly metsikkötunnuksiin

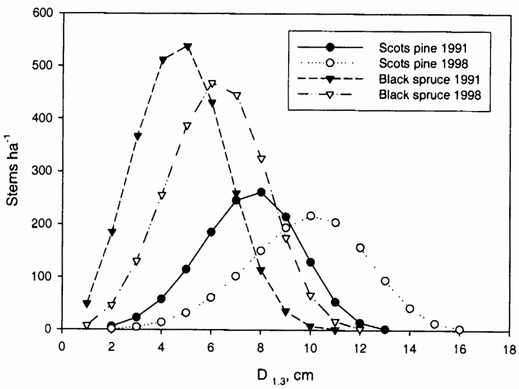

Fig. 4. The average smoothed DBH distributions for planted Scots pine and black spruce stands in the study field at the ages of 26 and 33 years (measurement years 1991 and 1998).

Kuva 4. Männiköiden ja mustakuusikoiden keskimääräiset tasoitetut läpimittajakaumat metsiköiden ollessa 26 ja 33 vuoden ikäisiä (mittausvuodet 1991 ja 1998).

black spruce stand development of our sites seems to correspond to that of the Canadian stands on sites with a site index about 11 m (stand dominant height at the age of 50 years).

Occurrence of black spruce layers

The number and height of the layers varied largely between the individual trees and stands. Most of the planted black spruces (63%) had at least one layer. On average, the number of layers exceeding the breast height (1.3 m) was 1540 per hectare, representing on average 22% of the total stem number of layers (Table 2). Some of the tallest layers reached the size of the parent tree. The layers seemed to affect the growth of parent trees, as the stand dominant height was negatively correlated ($r = -0.8$, $p = 0.011$) with the number of layers (Fig. 5). Based on a preliminary analysis, one sample plot turned to be an outlier and was eliminated from this calculation.

Effects of fertilisation

According to the ANOVA model the fertilisation treatments or treatment combinations did not have any significant impact on the measured stand characteristics or on the stand structure of either species (Table 1). In addition, the treatments had no effect on the annual mean height growth or mortality.

Discussion

The much slower height growth of black spruce than that of pine during 29 years experiment may indicate the differences in the ecology of these two tree species, for example in their ability to utilise the site's potential. It is unclear how a "better choice" of the black spruce provenance could have affected the growth of trees. In this study only one provenance of black spruce was available and we do not have any evidence that the provenance in question was the most appropriate for our study site. It is known that black spruce has significant genetic variability in growth rate (Morgenstern 1978). This is, however, the only experiment in Finland where the growth and development of black spruce has been followed with successive surveys from establishment to the stage of young stand treatment.

Very little information is available on the growth of black spruce in Finnish peatland conditions. On one permanent sample plot with planted black spruce the dominant height was 8.2 m at the age of 30 years, thus being 2.1 m higher than the average dominant height in the stands of this study at the same age. However, this site represented the *Vaccinium myrtillus*-type site on drained peatland, which is more fertile than the site in our study. (This reference data is from the archives of the Finnish Forest Research Institute. For other characteristics of the stand in question, see sample plot number C32, Lehtonen 1993, p. 42).

Table 2. The mean characteristics of the black spruce layers.

Taulukko 2. Mustakuusen taivukkaiden puustotunnuksia. Keskiarvon keskivirheet suluissa.

Stand character	Mean	s.e.m
Stem number, $h \geq 1.3$ m (ha^{-1})	1540	(176)
Stem number, $h < 1.3$m (ha^{-1})	8515	(1872)
Basal area (m^2 ha^{-1})	1.44	(0.15)
Mean diameter (cm)	4.43	(0.15)
Volume (m^3 ha^{-1})	4.29	(0.48)
Volume growth (m^3 ha^{-1} a^{-1})	0.26	(0.04)

The height development of pine seemed to be close to the average of the Scots pine seedling stands growing on *Vaccinium vitis-idaea* type (VT) sites on mineral soil sites in southern Finland (e.g. Räsänen et al. 1985). Corresponding conclusions have also been made by Kaunisto and Päivänen (1985), who compared the average height development of the fertilised Scots pine seedling stands on drained afforested peatlands and pine plantations on mineral soil sites.

For the Scots pine stands of this study, Hägglund's (1976) site index and stand dominant height simulations applying the models of Vuokila and Väliaho (1980) and Varmola (1993) showed that the site's potential (the dominant height at the age of 100 years was 23 m) was comparable to that of upland *Calluna vulgaris* site type (CT) and *Vaccinium vitis-idaea* site type (VT) (Vuokila ja Väliaho 1980). Heikurainen et al. (1983) and Kaunisto (1985) also concluded that the growth rate of pine plantations established on oligotrophic (originally treed) pine peatland was in accordance with those of upland CT- and VT-type sites.

The average annual volume growth of Scots pine stands in this study is in accordance with the average productivity of drained cottongrass (*Eriophorum vaginatum*) sedge pine fen (TSR) (~ 3.5 m^3 ha^{-1} y^{-1}), whereas the productivity of black spruce is at the same level as the productivity of Scots pine on low-sedge pine fen (LkR) (Keltikangas et al. 1986, p. 58).

The observed differences in the development of the growth rate and stand structure between the two tree species studied here may be a consequence of the differences in both ecology and inter-tree competition.

By the time of the last inventory (1998) the canopy of our Scots pine stands was closing. The increasing variation in tree size during the development of the stand may indicate increasing asymmetric inter-tree competition for light (Weiner 1990).

In the black spruce stands, however, the competition for light may not have been as critical an issue, because the tree crowns had a narrow conical shape and the canopies were not yet closed. This assumption was supported by the finding of a decreasing negative correlation between the CV of tree height and the stand basal area. This would

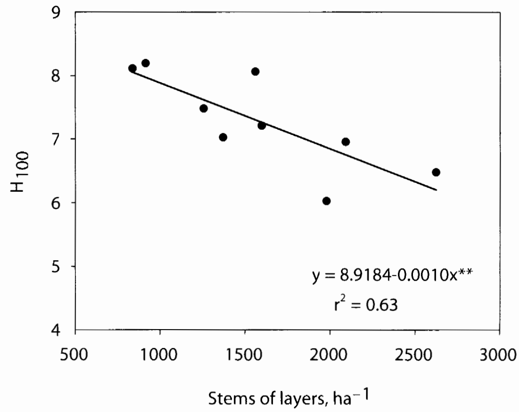

Fig. 5. The relationship between black spruce dominant height and stem number of black spruce layers in the study plots. The stars in the regression equation indicate the statistical significance (1% risk) of the regression coefficient.

Kuva 5. Valtapituuden ja taivukkaiden lukumäärän vuorosuhde mustakuusikoealoilla. Regressioyhtälössä olevat tähdet ilmaisevat regressiokertoimen merkitsevyyttä (riskitaso 1 %).

indicate decreasing variation in tree size and increasing symmetric inter-tree competition for available below ground resources, primarily nutrients (Weiner 1990). Thus individual trees may reduce the growth of their neighbor trees although a visual inspection indicated that spatial distribution and crown size of the trees would leave sufficient room to grow.

One special feature of the black spruce stands is the formation of layers, whose stem numbers varied greatly between the sample plots. It was difficult to find any common variable that would explain the birth-death variation within a layer population. The nature of the layer formation process seems to be more or less random; the branches become attached to the surface moss layer due to the pressure of snow or due to the growth of *Sphagnum* (e.g. Stanek 1975). Only a few layers reached the height of the parent trees. However, the layers seemed to compete for the same growth resources (primarily nutrients) and may even reduce the growth of dominant trees (Fig. 5).

The results showing no differences in stand characteristics between refertilisation treatments might be explained by the understandably low amounts of refertilisers used. Moreover, the insufficient number of replicates and the damage done to the Scots pine stands by moose (*Alces alces*) and Scleroderris cancer (*Gremmeniella abietina)* during 1970–1980's could also have weakened the impact of fertilisation.

Conclusions

Black spruce could be used for afforestation of drained treeless peatlands in Finland — if such activity were conducive to operational scale forestry. However, its growth and production levels make that economically unfeasible. Differences in the total yield between the tree species studied could even be greater, because here the comparisons were based on the stands consisting of living trees only. However, in some special cases, for example treeless areas that resist afforestation, black spruce could be an alternative tree species. Such sites would include abandoned agricultural fields on peat, where Scots pine may become subjected to moose and vole damage and Norway spruce is sensitive to spring frost.

Cultivation of black spruce could also be suitable for e.g. decorative purposes, for example as Christmas trees (Päivänen 1971). Its short branches and shoots form a beautiful, dense and narrow conical crown. However, its growth rate for Christmas tree farming is low compared to that of other exotic alternatives (e.g. *Picea omorica* (Panc.) Purkyne and *Abies balsamea* (L.)).

An important issue for the future of our small experiment is the successful management of well-established but slow-growing black spruce stands including, for example, research on what thinning models and fertilisation programmes should be used when attempting to achieve the levels necessary to sustain at least pulp wood production.

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Tiivistelmä:

Mustakuusen ja männyn istutustaimikon kehitys karulla ojitetulla suolla

Mustakuusi on metsätaloudellisesti erittäin tärkeä puulaji Kanadassa, ja se viihtyy luontaisella levinneisyysalueella hyvin paitsi kangasmailla myös lähes kaikentyyppisillä turvemailla. Mustakuusta on koemittakaavassa istutettu myös Suomessa ojitetuille soille, mutta sen pitempiaikaista kehitystä ja kilpailukykyä suhteessa kotimaisiin puulajeihin on kuitenkin tutkittu hyvin vähän.

Tutkimuksen tavoitteena oli vertailla istutettujen mustakuusi- ja mäntytaimikoiden kehitystä, rakennetta ja tuotosta sekä tutkia taimikkovaiheessa tehdyn lannoituksen vaikutuksia ojitetulla avosuolla. Tutkimusajanjakso käsitti n. 30 vuotta istutuksen jälkeen. Tutkimusaineisto kerättiin Juupajoen Nuijanevalle perustetulta koekentältä. Kasvupaikka on ollut alun perin lyhytkorsikalvakkanevaa (LkKaN). Koekentälle istutettiin keväällä 1969 kymmenelle satunnaistetulle 16,25 x 16,25 m kokoiselle koealalle 2 + 2 vuotiaita paljasjuurisia mustakuusen taimia ja kymmenelle vastaavalle koealalle 1 + 2 vuotiaita männyn taimia 81 kpl kullekin. Mustakuuset ovat kanadalaista alkuperää, mutta toista Suomessa kasvatettua puusukupolvea, ja männyt ovat paikallista alkuperää. Vuonna 1976 koealoille tehtiin viisi lannoituskäsittelyä kahtena toistona kullekin puulajille (P, PK, NP, NPK ja kontrolli). Puustot on mitattu seitsemän kertaa istutuksen jälkeen ja viimeinen mittaus tehtiin vuonna 1998. Metsiköitä ei ole käsitelty.

Tutkimustulokset osoittivat, että mustakuusen kehitys oli merkitsevästi mäntyä heikompaa. Puustojen ollessa biologiselta iältään noin 30 vuotiaita mustakuusimetsiköiden valtapituus oli keskimäärin noin 7,1 m, keskitilavuus 26 $m^3 ha^{-1}$ ja vuotuinen keskimääräinen tilavuuskasvu 1,5 $m^3 ha^{-1} a^{-1}$. Männiköiden vastaavat tunnukset olivat 10,4 m, 45 $m^3 ha^{-1}$ ja 3,3 $m^3 ha^{-1} a^{-1}$. Mustakuusella puiden kuolleisuus on ollut kuitenkin vähäisempää kuin männyllä. Mustakuusikoealoilla kuolleisuus oli viimeiseen mittaukseen mennessä 21 % ja männyllä 59 % alun perin istutetuista taimista.

Alkuvaiheen lannoituskäsittelyillä ei ole ollut tilastollisesti merkitsevää vaikutusta taimikoiden myöhempään kehitykseen. Tähän tosin syynä saattoi olla annettujen lannoitteiden pieni määrä, toistojen vähäinen määrä sekä männiköissä tapahtuneet hirvituhot.

Männikölle lasketun kasvupaikkaindeksin ja mallivertailujen perusteella tutkimusalueena olleen suokasvupaikan tuotoskyky sijoittui kivennäismaiden puolukkatyypin (VT) ja kanervatyypin (CT) välille. Yksiselitteistä syytä mustakuusikoiden ja männiköiden erilaiselle kehitykselle ei löydetty. Ilmeisesti puulajien erilainen ekologia selittää suurelta osin kehityksen erot. Toisaalta mustakuusikoiden männiköitä suurempi tiheys eli suurempi puiden välinen kilpailu saattoi osaltaan vaikuttaa puustojen tuotokseen.

Mustakuuselle on ominaista kyky muodostaa uusia, itsenäiseen kasvuun kykeneviä puuyksilöitä kasvullisesti emopuiden oksataivukkaista. Istutetuista puista noin 63 %:lla oli seuralaisenaan vähintään yksi taivukasalkuinen taimi. Taivukkaat näyttivät vaikuttavan negatiivisesti emopuiden kasvuun. Tutkimustulosten perusteella voidaan päätellä, että kasvun ja tuotoksen suhteen mustakuusi on tuskin kilpailukykyinen puulaji mäntyyn verrattuna käytännön metsätaloudessa Suomessa. Sen sijaan mustakuusi voi olla käyttökelpoinen puulaji kohteilla, jotka ovat osoittautuneet vaikeasti metsitettäviksi. Lisäksi mustakuusella — ainakin nuoruusvaiheessa latvukseltaan kaunismuotoisena puuna — voi Suomessa olla käyttöä esim. joulupuuna tai muissa koristetarkoituksissa.

Received 20.5.2003, Accepted 17.10.2003