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Crop plans and yield predictions for Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth & *Betula pubescens* Ehrh.) mixtures

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Abstract

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In young Norway spruce (*Picea abies* (L.) Karst.) stands containing an even-aged component of self-propagated birches (*Betula pendula* Roth and *B. pubescens* Ehrh.) the forest manager has the choice of removing all broad-leaved trees or of accepting a mixed stand of Norway spruce under a birch shelter. Results of stand growth simulations show that the total stand yield will be higher if the broad-leaved trees are retained. The spatial distribution pattern of trees had little influence on the outcome of the growth simulation.

The simulations also showed that spruce yields will be similar, regardless of whether the spruce is grown in pure stands or is grown under a birch shelter (either 600 birches ha^{-1}, all removed at age 25, or 1 200 birches ha^{-1}, removed in two steps at age 20 and 30).

The simulations showed that the highest total yield was obtained when a shelter of 2 000 birches ha^{-1} was left after the pre-commercial thinning, then thinned at age 20 and finally all birch was removed at age 30. The birch shelter can produce ca. 100 m^3 ha^{-1} in middle Sweden if it is composed of *B. pendula*. The corresponding yield for a shelter of *B. pubescens* will be 80 m^3 ha^{-1} or less. Although height growth of the spruce will be suppressed by the birch shelter, the growth rate will increase once the shelter has been removed.

Estimates of biomass production were made for both Norway spruce and birch. Mean annual dry matter production increases from 1.4 tonne ha^{-1} yr^{-1} with a shelter of 600 birches, to 2.4 tonne ha^{-1} yr^{-1} for 3 000 birches. All yield estimates refer to age 20. The harvesting cost, based on manual felling and tractor extraction, was estimated at ca. 40 SEK/MWh (200 SEK/ton dry matter). By comparison, a commercially harvested *Salix* plantation costs about 24 SEK/MWh. However, the cost of establishing and maintaining a *Salix* plantation is ca. 35 SEK/MWh, while no such costs are incurred in the production of fuelwood under the birch shelterwood system.

Keywords: growth simulator, mixed stand, yield table, dry matter production, crop planning, silviculture prescriptions, Sweden.

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Contents

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Introduction

When stands are clear-felled, large amounts of nutrients are released (Wiklander, 1989). Thus new stands established on clear-felled sites are unable to use all of the available nutrient supply, which can result both in leaching (Rosén & Lundmark-Thelin, 1986) and in an increase in the growth of grasses, shrubs and broad-leaved trees.

Following 20–30 years of clear-felling in Sweden, there has been a marked increase in the broad-leaved tree component of young forests, while the number of conifers per unit area has decreased substantially (Hägglund, 1985). Similar trends have been observed in all the Nordic countries. Consequently, foresters must now decide how these new stands, which contain numerous broad-leaved trees together with conifers, should be managed, in order to provide maximum yield under existing conditions.

Interest in factors influencing the yield of mixed (conifer/hardwood) stands has resulted in many studies in which the yields of two species in mixture have been compared. Lappi-Seppälä (1930) found that the total yield of a mixture of birch and Scots pine (*Pinus sylvestris* L.) was higher than that obtained when the two species were grown as monocultures in the same relative proportions. The growth of spruce in a stand can be stimulated by increasing the stand's proportion of birch (Jonsson, 1962; Tham, 1989). In forestry, however, it is more pertinent to compare a mixed stand with pure stands of the most highly productive species in the mixture concerned. In the Nordic countries, mixed stands of Norway spruce and birch have been compared with monocultures of Norway spruce by Frivold (1982), Mielikäinen (1985) and Agestam (1985). Mielikäinen (1985) found that the yield obtained from a mixture of Norway spruce and silver birch (*B. pendula*) was greater than that obtained in a pure Norway spruce stand. However, the total yield in a mixture of Norway spruce and pubescent birch (*B. pubescens*), was not greater than that obtained in a pure spruce stand. Neither Frivold nor Agestam distinguished between silver and pubescent birch in their investigations, which provided no evidence that mixed birch/spruce stands have a higher total yield than pure spruce stands.

In their juvenile stage, broad-leaved trees such as birch and European aspen (*Populus tremula* L.) grow more rapidly in height than do conifers. Rapid height growth, together with the development of suckers, necessitates repeated early cuttings if serious competition between suckers and conifers is to be avoided. In the study by Mielikäinen (1985), in which a mixture of Norway spruce and silver birch achieved a higher total yield than Norway spruce alone, the silver birch was approximately seven years younger than the Norway spruce. Norway spruce, which is shade-tolerant (Ståhlfelt, 1931), can survive in the understorey of a dense canopy of broad-leaved trees (Tham, 1987). Thus one management option in young, even-aged, mixed stands of Norway spruce and self-propagated birch, is to grow them together during the first decades of the rotation. This management method exploits the differences in growth rhythm between the two species: The birch, which is a pioneer species, will dominate the spruce early in the rotation, and after the birch is removed, spruce alone will form the mature stand. According to the results of a yield prediction study (Tham, 1988), the total yield is greater when a shelter of between 500–800 birches ha^{-1} is left, than when all broad-leaved trees are removed.

The density of naturally regenerated birch trees on a clear-felled area after felling and soil scarification is greater than 800 ha^{-1}. For example, Björkbom (1972) reported 25 000 birch seedlings ha^{-1} after soil scarification. To avoid serious competition between the birch and spruce, it is necessary to reduce the number of birches. If the density of birch is reduced to 500–800 ha^{-1} before the spruce reaches 1–2 m in height, the birch sprouts must be cut several times (Andersson & Björkdahl, 1984), to prevent the suckers from overtopping the Norway spruce seedlings. Instead of reducing the density of birch to the recommended 500–800 stems ha^{-1} in one precommercial thinning, the birch thinning could also be carried out in two steps (Johansson, 1983; Brunberg & Johansson, 1984). At the first precommercial thinning, the density of birch is reduced to 2 500–3 000 stems ha^{-1}. A second thinning to 500–800 stems ha^{-1}

can then be made when the Norway spruce is 1.5–2 m tall.

There are several good reasons for thinning the birches in two steps, the most important being that birch helps to protect the Norway spruce plants against frost. If fuelwood is desired, the birch removed at the second precommercial thinning can be utilized under current market conditions. It is even possible to profit from early thinnings if the birches are sold as fuelwood instead of pulpwood (Tham & Josefsson, 1986). The utilization of hardwood biomass as an energy source, using tops and branches together with the stem, has generally been restricted to *Salix* spp. and other fast growing species subjected to intensive silvicultural regimes, including irrigation and fertilization. However, if naturally regenerated and naturally grown broad-leaved trees were to be used for biomass production, the cost of establishment would be very low, and the product could have commercial value even though the yield per hectare would be less than that of *Salix* spp. A mean annual yield of 3.9 tonne ha^{-1} yr^{-1} of dry matter was reported for planted birch by Frivold & Borchgevink (1981). The plantation in question contained 43 000 silver birches per hectare and the rotation was six years. A mean annual yield of 5 tonne ha^{-1} yr^{-1} of dry matter (stems and branches) was reported by Ferm et al. (1985) for naturally regenerated birch stands, the rotation being 15 years. Intensively managed plantations of grey alder (*Alnus incana* (L.) Moench) can produce up to 11 tonne ha^{-1} yr^{-1} dry matter of woody biomass (stems and branches) when fertilized and irrigated (Rytter, 1990).

If the birch shelter is sufficiently dense, it might prevent the sprouting of birch stumps (Andersson, 1984). This may be advantageous, since it is considered easier to perform a precommercial thinning in two steps rather than to cut suckers repeatedly. However, it is not known how dense the shelter needs to be to prevent sprouting. Measurements of irradiance in young broad-leaved stands indicate that as many as 250 000–1 000 000 stems per hectare are needed (Johansson, 1989). Silver and pubescent birch, which are clearly light-demanding species, need early and heavy thinnings to keep their crown-base height at or below half the tree length. It is recommended that the first thinning in pure birch stands be made between 15–25 years of age (Helms, 1897; Hauch & Opperman, 1898; Schotte, 1913; Wahlgren, 1914; Lehonkoski, 1939; Löken, 1954; Fries, 1964; Raulo, 1981).

There is no optimal way of managing a forest stand. Different conditions and expectations indicate that there are several options open to the forest manager.

This study aims at identifying the variation in yield of Norway spruce and birch in relation to thinning method and thinning programme. This paper presents results which may be useful in practice when thinning stands of Norway spruce in admixture with broad-leaved trees.

Material and methods

A stand-growth simulation model developed by Tham (1986) was used to predict yield in mixed stands of Norway spruce and birch. The growth predictions are based on the growth of the individual trees. The data upon which the growth functions are based were obtained from managed permanent plots. Individual tree growth in stands of mixed Norway spruce and birch is estimated using basal area and height growth functions for each species separately (Tham, 1989). The individual tree growth models are distance-dependent, the number, size and proximity of neighbours being expressed as size-ratio competition indices. The competition indices were calculated using a basal area factor angle gauge to define competitors. To obtain starting values for the individual tree growth model, each tree is assigned a diameter and a height. The diameters are predicted using a diameter-distribution model for Norway spruce and birch (Tham, 1988*a*). The height of the individual trees is obtained from the relationship between diameter and height (Näslund, 1936; Fries, 1964). For estimating the coefficients in the functions, all trees measured for diameter and height from the plots in an investigation made by Tham (1988*a*) were used. The calculated heights from the diameter–height function are randomly varied according to the standard deviation. The spatial position of the trees on the 'simulation plot' is calculated by means of the homogeneous Poisson point process in the plane, called a 'Poisson process' or a 'Poisson forest' (Tomppo, 1986). When calculating the spatial position of Norway spruce, a square spacing was assumed.

Birch, which is naturally regenerated, was randomly distributed without considering spacing. The spatial pattern has little influence on the results of the growth simulation. The maximum standard error is 0.3% of the mean volume per hectare when the simulation is repeated ten times (Tham, 1988*b*). The following steps were included in each growth simulation;

- Set numbers of spruce and birch.
- Assign the spatial position of each tree.
- Set initial values of basal area and maximum diameter.
- Assign a diameter to each tree.
- Estimate the height of each tree based on its diameter.
- Set initial age.
- Set site index, altitude and region.
- Set thinning regime.
- Estimate the basal area and height growth for each tree for the desired number of five-year periods.
- For each five-year period calculate the basal area, volume and woody biomass per hectare and the dominant height for each species. A flow diagram describing the basic principles of the model is presented in Fig. 1.

The problem of edge bias in simulated plots, due to the lack of competition for border trees, is solved by means of a routine developed by Monserud & Ek (1974). The plots are duplicated and placed around the original 'simulation plot' so that border trees compete with border trees on the opposite side of the plot. The growth functions are based on permanent sample plots and are valid for middle Sweden in mixed, 15- to 50-year-old Norway spruce—birch stands. Separate growth functions are used for silver and pubescent birch. The stand growth simulation model has been described in detail by Tham (1988*b*). In the present study, the growth simulator has been expanded so that it can also estimate woody biomass, using the following functions for spruce and birch (Marklund, 1988).

To construct generally applicable regression functions for Sweden, Marklund (1987) used stratified random sampling from the compartment register of the Swedish Forest Service. The compartments were grouped into classes by geographical region, dominating species, stand age and site index. In each selected compartment a cluster of four sample plots was laid out at random. On each plot, sample trees were selected by a stratified random procedure. On sample plots, two sample trees per diameter class of the dominating species, and one sample tree per diameter class of the other species, were drawn at random. A detailed description of the material and the method used is given by Marklund (1987).

Norway spruce

Stem over bark

$$\ln(dw) = 7.469(d/[d+14]) + 0.0289\,h + 0.6828\ln(h) - 2.1702$$

Living branches including needles

$$\ln(dw) = 10.9708(d/[d+13]) - 0.0124\,h - 0.493\ln(h) - 1.2063$$

Dead branches

$$\ln(dw) = 3.6518(d/[d+18]) + 0.0493\,h + 1.0129\ln(h) - 4.6351$$

Birch

Stem over bark

$$\ln(dw) = 8.0420(d/[d+7]) + 0.0531\,h + 0.3897\ln(h) + 0.1018\ln(t) - 3.5194$$

Living branches including leaves

$$\ln(dw) = 10.2806(d/[d+10]) - 3.3633$$

Dead branches

$$\ln(dw) = 11.2872(d/[d+30]) - 0.3081\,h + 2.6821\ln(h) - 6.6237$$

Abbreviations

d = diameter over bark at breast height, cm
h = tree height, m
t = tree age at breast height, years
dw = dry weight, kg/tree
ln = natural logarithm

The biomass of these tree components is estimated for single trees and expressed in terms of dry weight (105°C, 48 h). Values for the individ-

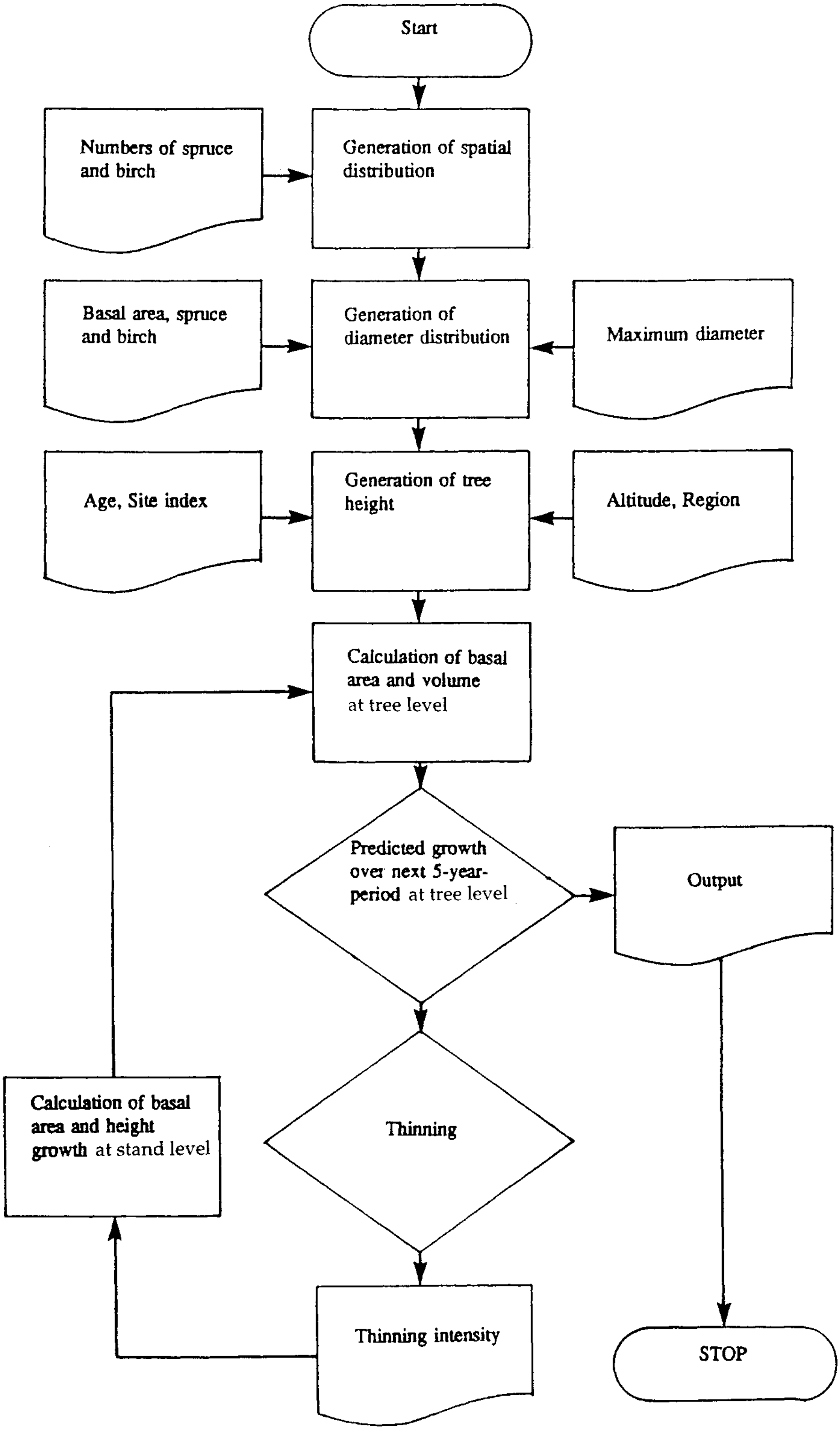

Fig. 1. Flow diagram for the growth simulation model.

ual trees are then summed, and the dry weight is given as total yield for each of the two species in the stand.

The yield prediction concerning the removal of birch in two steps was made using birch densities of 1 200, 2 000, 2 500 and 3 000 stems ha^{-1} in the shelter. The first simulated thinning occurred at 20 years of age, and the final harvest of birch was assumed to occur ten years later.

When the birches are left as a shelter instead of being cut in precommercial thinnings, the cutting of the birch shelter represents the first commercial thinning. It is necessary to use strip-roads for extracting the birch wood from the stand. Thus if the birch-shelter is removed at age 20, many Norway spruce must be prematurely removed at this time (20 years earlier compared with the no-shelter option), to allow the forwarders to pass. Consequently, to compare the shelter and no-shelter options, the shelter option had to be modified to take the effects of the strip-road into account. In the present study, growth was simulated for stands both with and without strip-roads. In the simulation the strip-roads, 4 m wide and 25 m apart (Fig. 2), were in the stand at the time of the first thinning. For instance, when the yield of a pure Norway spruce stand was to be predicted, the strip-roads were made at age 40, in connection with the first thinning in the Norway spruce stand. When, on the other hand, the yield of the birch-shelter option was simulated, the strip-roads were made at age 20, i.e. when the first thinning in the birch-shelter was performed.

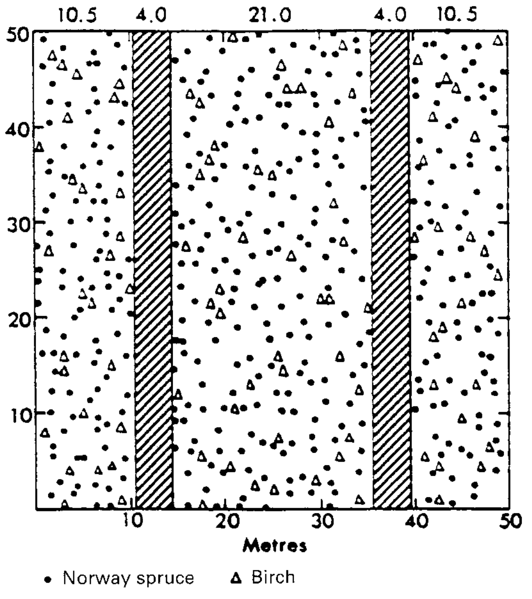

Fig. 2. The spatial distribution of Norway spruce (*Picea abies* (L.) Karst.) and silver birch (*Betula pendula* Roth) in a simulated plot with strip-roads.

Results

The simulated plots were ca. 2 500 m^2 in area. For each simulation and tree, new coordinates were randomly assigned. The spatial distribution pattern had little influence on the results of the growth simulation. The maximum difference between the runs in mean volume per hectare was 1.6 m^3 f ha^{-1} when the simulation was repeated three times (Table 1).

The long-term growth of a mixed stand, when the birch-shelter is removed in two steps, was predicted for shelters with 0, 1 200, 2 000, 2 500 and 3 000 silver birches ha^{-1}. The birch were pre-commercially thinned to the desired number before 15 years of age. The birch-shelter was thinned for the first time at age 20 years, and at age 30 years all birches were removed. The Norway spruce was thinned at ages 40 and 45. The total yield at each of the birch densities is shown in Table 2. At age 20, mean diameter at breast height (dbh over bark; corresponding to mean basal area) for the birch-shelter with 1 200 stems ha^{-1} was 9.8 cm. Corresponding values for 2 000, 2 500 and 3 000 stems ha^{-1} were 9.0, 8.1 and 7.9 cm respectively. The mean dbh for each of the four birch-shelters at age 30 was 13.8, 11.7, 10.6 and 10.1 cm respectively. The relationship between the number of birches in the shelter, and standing volume before thinning at age 20, is shown in Fig. 3.

Table 1. *Mean and range of the volume yield (m^3 ha^{-1}) at different stand ages when the initital spatial distribution of trees is simulated three times*

Age	Mean volume	
15	0.7	(0.7–0.7)
20	5.2	(5.2–5.2)
25	21.9	(21.8–22.1)
30	56.7	(56.4–57.0)
35	119.2	(118.9–119.6)
40	198.2	(197.8–198.9)
45	250.7	(249.9–251.4)
50	301.0	(300.0–301.6)

Table 2. *Total yield (m^3 ha^{-1}) of Norway spruce and silver birch for shelters of four different birch densities and a pure spruce stand*

Birch density, no./ha	Volume birch removed at age 20	Volume birch removed at age 30	Yield at age 50		
			Birch	Spruce	Total
0	–	–	–	299.6	299.6
1 200	36.5	47.1	83.6	303.3	386.9
2 000	48.5	54.7	103.2	290.6	393.8
2 500	50.4	56.0	106.3	280.9	387.2
3 000	57.4	58.5	115.9	269.2	385.1

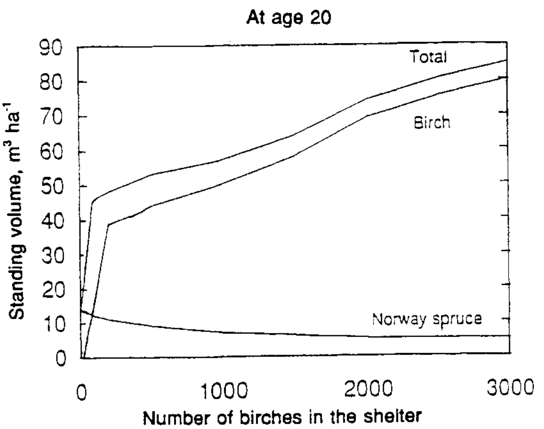

Fig. 3. Relationship between the number of birches in the shelter and standing volume at age 20 before thinning.

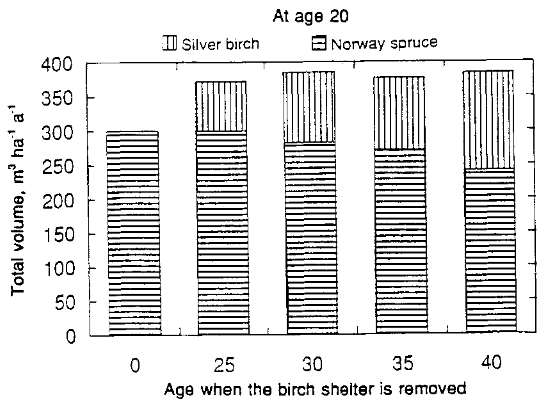

Fig. 4. Total yield (m^3 ha^{-1}) of Norway spruce (*Picea abies* (L.) Karst.) and silver birch (*Betula pendula* Roth) in relation to the time of removal of the birch shelter, for the first 50 years of the rotation.

When 1 200 birches in the shelter were removed in two steps, there was no difference in the yield of Norway spruce after 50 years, regardless of the presence or absence of a birch shelter. In this option, the birch produced, ca. 80 m^3 ha^{-1}, was a real surplus, since the yield of Norway spruce, ca. 300 m^3 ha^{-1}, was unchanged. The shelter was thinned at age 20 and totally removed at age 30.

The highest total yield, ca. 394 m^3 ha^{-1}, is produced with the option 2 000 birches together with Norway spruce. The birch proportion of the yield has increased and the yield of Norway spruce, in absolute terms, has decreased from 300 to 290 m^3 ha^{-1}, compared with the former options with 1 200 birches in the shelter.

Predictions of the long-term growth of Norway spruce in stands with a birch shelter kept for 25, 30 and 35 years are given in Fig. 4. In stands where the birch shelter had been removed at 25 years of age, there was no difference in the yield of Norway spruce after 50 years between this stand, and a stand lacking a birch shelter. The highest total yield was obtained when the birch shelter was kept for 35 years. The yield of silver birch increased from 70 to 140 m^3 ha^{-1} in this simulation, although the yield of Norway spruce decreased during the first 50 years of the rotation, from 300 to 240 m^3 ha^{-1}. The mean dbh (corresponding to mean basal area) of the birch in the shelters was calculated at 15.2 cm at 25 years of age, 16.7 cm at age 30 and 17.9 cm at age 35.

The influence of strip-roads on the long-term growth of Norway spruce is demonstrated in Table 3. There was no difference in the yield of Norway spruce between the options 'strip-roads' and 'no strip-roads', when the stand consisted of 1 936 Norway spruce ha^{-1}. When birch was mixed with 1 600 spruce ha^{-1}, the total yield was 14 m^3 ha^{-1} lower when the birches were cut using strip-roads, as compared with the option 'no strip-roads'. There was a small difference in the intensity of spruce thinning carried out in connection with the strip-road thinning, between the stand with 1 600 stems ha^{-1}

Table 3. *Total yield (m^3 ha^{-1}) of Norway spruce and silver birch in stands with strip-roads made in connection with the birch shelter cutting. Total yields of Norway spruce in stands where the birch shelter was removed without making strip-roads are given in parentheses*

Norway spruce density, no./ha		Volume birch removed at age 25	Volume spruce removed at age 25	Yield at age 50 Norway spruce
Pure spruce	1 600	–	–	300 (301)
Mixed stand	1 600	73	3	283 (297)
Pure spruce	1 936	–	–	298 (299)
Mixed stand	1 936	80	4	299 (301)

(19% of the volume removed), and the stand with 1 936 stems ha^{-1} (17% removed). However, the 1 280 stems remaining after the 1 600 stem stand had been thinned, were too few to compensate adequately for the loss of growth that occurred in connection with the removal of stems to make way for the forwarding machines.

The estimates of dry-matter production were made for both Norway spruce and birch. The complete yield tables, with estimates of volume as well as dry matter production for all silvicultural options evaluated, are given in Appendix 1. The total aboveground dry-matter production of the birch in unthinned stands at different shelter densities, is demonstrated in Fig. 5. The mean annual dry-matter production ranged from 1.4 tonne ha^{-1} yr^{-1} with a shelter of 600 birches, to 2.4 tonne ha^{-1} yr^{-1} for 3 000 birches. All yield estimates are for 20-year-old stands. The dry-matter production of birch growing together with 1 936 spruce ha^{-1} did not differ significantly from that of a stand in which the birches grew together with 1 600 spruces. The annual increment over time for a stand with a shelter of 600 birches ha^{-1} is given in Fig. 6. The current annual increment culminated at age 30 with a dry matter production of 4.7 tonne ha^{-1} yr^{-1}. The dry-matter production of birch was about the same, regardless of whether the stand contained 1 600 spruce ha^{-1} or 1 934 spruce.

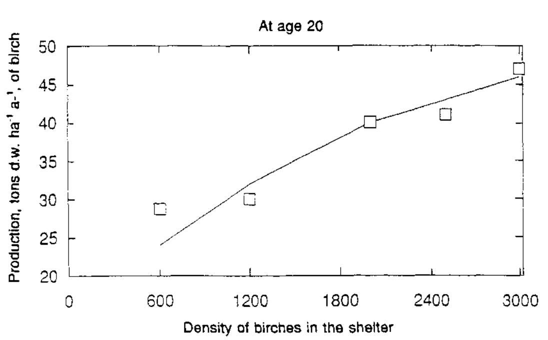

Fig. 5. Relationship between the density of the birch shelter and production of above-ground birch biomass in unthinned stands.

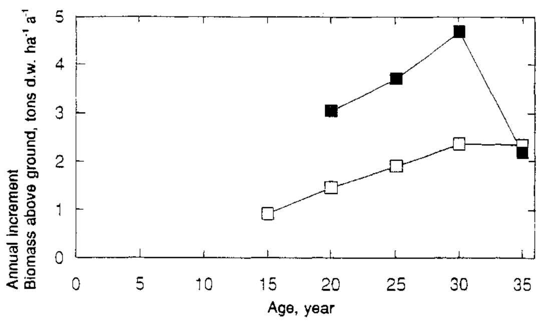

Fig. 6. Annual increment for a Norway spruce stand containing 600 birches ha^{-1}. □ Mean annual increment, ■ current annual increment.

Discussion

Simulations of long-term growth in this study of evenaged mixed stands of birch and Norway spruce with shelters of 1 200, 2 000, 2 500 and 3 000 birches ha^{-1} indicated that at a density of 1 200 stems ha^{-1}, the shelter does not reduce the growth of Norway spruce. According to the thinning schedule for planted pure silver birch (Oikarinen, 1983), the option with 1 200 birches ha^{-1} (Appendix, Yield table 2) is thinned too early. A pure stand with a dominant height of 12 m should be thinned when the basal area is 13 m^2 ha^{-1}, according to Oikarinen's thinning schedule. In the present example with 1 200 stems in the shelter, where the basal area of the birch was 9.3 m^2 ha^{-1}, it would have been possible to have waited five years before thinning. Here the forester must choose between thinning and promoting the yield of spruce, or not thinning and promoting the yield of birch. When the basal area of the Norway spruce is also taken into account, both species together reach the recommended 13 m^2 ha^{-1}, and the stand is due to be thinned. However, the spruces were severely suppressed by the birches, their dominant height being only 3.5 m, whereas the birches were 12 m tall. Birch growth was not influenced by the understorey. Thus, if desired, the 1 200 birches could be kept until 25 years of age, which would result in a 50-year yield of 110 m^3 ha^{-1} of birch and 260 m^3 ha^{-1} of spruce (Tham, 1988). By contrast, the corresponding 50-year yield in the case where the birch was thinned after 25 years, was 80 m^3 ha^{-1} of birch and 300 m^3 ha^{-1} of Norway spruce. The options 2 000 and 2 500 birches ha^{-1}, having a basal area of 12 and 13 m^2 ha^{-1} respectively, are just due for thinning. The option with 3 000 birches in the shelter has a basal area of 15 m^2 ha^{-1}, which is outside the recommendations in the thinning schedule for this dominant height.

To estimate the maximum basal area obtainable in natural birch stands, the basal area of birch was plotted against dominant height (Fig. 7). The data are from 20–30-year-old experimental stands of self-propagated birch, established in young Norway spruce regenerations. A detailed description of the experiment is given by Tham (1987). The lines in the figure represent the recommended basal area before and after thinning in Oikarinen's (1983) thinning schedule. As is shown in the figure, stands with higher basal areas, exceeding the

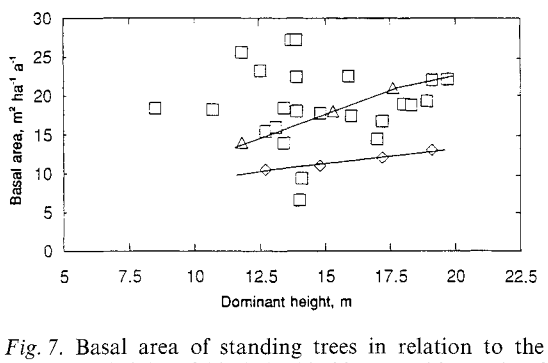

Fig. 7. Basal area of standing trees in relation to the dominant height of birch in 20–30 year old stands of Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth & *Betula pubescens* Ehrh.). ◇ Basal area after thinning[1], △ Basal area before thinning[1], □ Basal area of birch in experiment[2].

recommended level, also occur. If the stands are too dense, there is a risk that the height of the live crown will exceed half the tree height, resulting in decreasing tree growth.

The strategy of growing the birch shelter for more than 25 years is based on the assumption that the extra yield of birch, together with lower harvesting costs, will more than compensate for the loss in spruce yield. The mean diameter of the birches increases from 15.2 to 17.9 cm if the shelter is kept until 35 years of age. It would also be advantageous if at least some birch could be sold as timber instead of pulpwood. To be classified as timber, the top-diameter of the log must be 16 cm and the length at least 3 m. There are no taper-functions available for birch, but an estimate based on Cernold's tables for pine (Anon, 1977), indicates that the diameter at breast-height must be at least 18 cm to make it theoretically possible for the diameter 3 m above ground to be 16 cm. If the birch shelter is kept until age 35, about 25 per cent of the birches would probably reach timber size. It is, however, not realistic to expect that all such birches would be of timber quality, which depends mostly on the number and size of the branches.

The height of the live crown correlates with the diameter-height relationship, which in turn is a function of stand density. If a large number of birches of timber quality is desired, it would be better to start with a denser birch-shelter, thin it and allow the remaining trees to grow more than 30 years. According to the thinning schedule, the final felling of birch can be delayed until 40 years of age, but this will lead to a decrease in the yield of Norway spruce. If it is desirable to keep birch longer than 40 years, a thinning that removes all birch which does not meet timber quality requirements, as well as some Norway spruce, is recommended.

The finding that the presence of strip-roads should not decrease yield in stands above a certain density has also been demonstrated by other investigators. Elfving (1984) found no significant differences in yield between selective thinning and row thinning in planted Scots pine. Pine is more sensitive to corridors compared with spruce (Isomäki, 1986), but corridors up to 3.5 m do not influence the total yield of a stand. Pukkala (1988) reported that in pine stands, the gaps had to be wider than 3 m to enhance growth. However, it should be stressed that effects on growth in these studies refer to the reduction in between-tree competition resulting from the removal of trees. The effect of the strip-road or gap is the biological one with respect to the distribution of trees. Another important factor is the damage to roots and soil caused by vehicles driving on the strip-road. Up to 70% of the roots in a thinning stand are present in the humus layer, and a 10 cm deep track can damage many of them (Wästerlund, 1992). Strip-road effects should be examined not only for distance, but also as regards the area between the 10 cm deep tracks, which is correlated with growth.

The predicted mean annual dry matter production, between 1.4 and 2.4 tonne ha^{-1} yr^{-1}, is low compared with that reported by Frivold & Borchgevink (1981). Johansson (1991) reported wide variation in dry-matter production for birch, related to age. The density of birch in these studies exceeded 40 000 ha^{-1}. Stands simulated in the present study were not as dense, since they were pre-commercially thinned to a density of 3 000 birches ha^{-1} or less. A 20-year-old stand with 4 700 birches ha^{-1} and a mean dry-matter production of 2.35 tonne ha^{-1} yr^{-1} (Mård & Tham, 1990) is more similar to one simulated here. Since the stands in the present study are not as dense, the mean diameter is greater, and the corresponding harvesting cost lower, compared with completely unmanaged stands.

The harvesting costs for common species of broad-leaved tree are reported and discussed by Johansson (1991). Using these cost estimates—even though these cases were based on clear-felling rather than on the shelterwood system simulated here—the following generalization of harvesting costs can be made: The harvesting cost, assuming manual felling and tractor extraction, would be ca. 40 SEK/MWh (200 SEK/tonne dry matter), which is higher compared with the cost incurred when commercially harvesting *Salix* plantations, i.e. 24 SEK/MWh. On the other hand, the cost of establishing and maintaining a *Salix* plantation is ca. 35 SEK/MWh, whereas there is no corresponding cost involved in low-intensity shelterwood management. It is interesting to note that the precommercial thinning, from 30 000–40 000 birches ha^{-1} down to 3 000–2 000 birches ha^{-1}, which decreases the thinning cost from 375 SEK/tonne dry matter to 200 SEK/tonne dry matter, is desirable as long as the cost of the precommercial thinning is lower than 3 000 SEK ha^{-1}. In this study, however, the main reason for such a precommercial thinning was to promote the growth of the suppressed Norway spruces.

The yield tables are based on the assumption that the Norway spruces in the stand need nine years to reach breast height. If the time needed to reach breast height increases by six years or more, owing to the presence of the birch shelter, the surplus in volume yield obtained from a mixed stand would approximate the volume yield of a Norway spruce stand undergoing normal development both before and after it has reached breast height. This stresses the importance of investigating the development of Norway spruce from the seedling stage to breast height in young plantations containing broad-leaved trees.

Conclusions

There are various silviculture crop plans which are feasible for young, mixed stands of Norway spruce and self-propagated birch. The results of this study, which simulated stand development and yield in such stands, show that yield is improved when a birch shelter is present rather than when it is totally removed.

The simulations showed that the yield obtained by leaving a shelter of 600 birches, removed at age 25, is similar to that obtained with a shelter of 1 200 birches removed in two steps. The first birch thinning should be made at age 20 and the second, final, thinning at age 30.

The highest total yield was obtained by leaving a shelter of 2 000 birches ha^{-1} after the precommercial thinning, then thinning the shelter at age 20 and finally removing it at age 30. Compared with the first option, the spruce yield was 10 m^3 ha^{-1} lower, while the birch yield was 20 m^3 ha^{-1} higher. A silver birch shelter can produce about 100 m^3 ha^{-1} in middle Sweden. The corresponding yield of pubescent birch will be 80 m^3 ha^{-1} or less.

The height growth of Norway spruce will be suppressed by the birch shelter, but if it is removed, the spruce will grow more rapidly. In this study only the first 50 years were considered. Thus the possibility cannot be excluded that other options, such as a 3 000 ha^{-1} shelter of birches, could give as high a spruce yield as the pure-stand option on a longer rotation.

The effect of strip-roads on the long-term growth of Norway spruce was negligible. In practice, however, growth reductions might occur owing to damage caused by vehicles driving on the strip-roads.

The cost of producing bioenergy from self-regenerated birch should be at approximately the same level as those incurred in energy forestry with *Salix* plantations. Although the harvesting costs are higher for the birch-shelter option, the costs for establishment and maintenance are lower.

To produce timber-quality birch trees, it is necessary to begin with a dense shelter and to thin it in two steps. To meet the buttlog diameter requirement of sawmills, it would be necessary to keep the birch shelter for at least 35 years.

References

Agestam, E. 1985. En produktionsmodell för blandbestånd av tall, gran och björk i Sverige. (Summary: A growth simulator for mixed stands of pine, spruce and birch in Sweden.) *Swedish University of Agricultural Sciences, Department of Forest Yield Research, Report No. 15.* 150 pp. Garpenberg.

Andersson, S.-O. 1984. Om lövröjning i plant- och ungskogar. *Sveriges Skogsvårdsförbunds Tidskrift 82*(3–4), 69–85.

Andersson, S.-O. & Björkdahl, G. 1984 Om björkstubbskottens höjdutveckling i ungdomsskedet. *Sveriges Skogsvårdsförbunds Tidskrift 82*(3–4), 61–67.

Anon. 1977. *Praktisk Skogshandbok*, 8th ed. Sveriges skogsvårdsförbund. 463 pp. Stockholm. (In Swedish.)

Björkbom, J.C. 1972. Stand changes in the first 10 years after seedbed preparation for paper birch. *U.S.D.A., Forest Service Research Paper N.E. 288.* 10 pp.

Brunberg, T. & Johansson, A.H. 1984. Granföryngring under lågskärm. *Forskningsstiftelsen Skogsarbeten. Resultat 15.* Stockholm. (In Swedish.)

Elfving, B. 1984. Nya resultat om stickvägsgallring. *Skogen 10*, 32–33. (In Swedish.)

Ferm, A., Kauppl, A. & Rinne, P. 1985. The potential of birch for biomass production. IEA/FE, Programme Group 'B'–Biomass Growth and Production. *Canadian Forestry Service, Report No. 2,* 58.

Fries, J. 1964. Vårtbjörkens produktion i Svealand och södra Norrland. (Summary: Yield of Betula verrucosa Ehrh. in Middle Sweden and Southern North Sweden.) *Studia Forestalia Suecica 14.* 303 pp. Stockholm.

Frivold, L.-H., 1982. Bestandsstruktur og produksjon i blandningsskog av björk *(Betula verrucosa* Ehrh., *B. pubescens* Ehrh.) and spruce (*Picea abies* (L.) Karst.) in South East Norway. *Scientific Reports of the Agricultural University of Norway 18.* 108 pp. Ås.

Frivold, L.H. & Mielikäinen, K. 1990. The effects of hardwoods on softwood growth in mixed stands in Fennoscandia. (In: B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades (eds.) The Silvics and Ecology of Boreal Spruces.) 1989 IUFRO Working Party S1.05–12 Symp. Proc., Newfoundland, 12–17 Aug. 1989. *Forest Canadian Information. Report N-X-271,* 75–82.

Frivold, L.-H. & Borchgevink, I. 1981. Biomasseproduksjon av lavlandsbjørk *(Betula verrucosa* Ehrh.*)* i en 6-årig førsøksplantering i Ås, Norge. *Scientific Reports of the Agricultural University of Norway 60*(12), 17.

Hauch, L.A. & Oppermann, A. 1898. *Haandbog i skovsbrug.* Copenhagen 1898–1902. (In Danish.)

Helms, J. 1897. Birken paa Tisvilde-Frederiksvaerk Distrikt. *Tidskrift for skovvaesen 9:B,* 189–270. (In Danish.)

Hägglund, B. 1985. Introduction. (In: B. Hägglund & G. Peterson, eds.) Broadleaves in Boreal Silviculture–an obstacle or an asset? *Swedish University of Agricultural Sciences, Department of Silviculture, Report 14,* 1–5.

Isomäki, A. 1986. Linjakäytävän vaikutus reunapuiden kehitykseen. (Summary: Effects of line corridors on the development of edge trees.) *Folia Forestalia 678,* 30.

Johansson, A.H. 1983. Skärmmetoden–biologisk och säker metod till rimliga kostnader. *Skogen 4,* 30–36. (In Swedish.)

Johansson, T. 1989. Irradiance within canopies of young trees of European aspen (*Populus tremula* L.) and European birch (*Betula pubescens* Ehrh.) in stands of different spacings. *Forest Ecology and Management 28,* 217–236.

Johansson, T. 1991. Odling av lövträd på åkermark för energiändamål. Bioenergi. *Utveckling och Miljö 36,* Vattenfall. Vällingby. (In Swedish.)

Jonsson, B. 1962. Om barrblandskogens volymproduktion. (Summary: Yield of mixed coniferous forest.) *Meddelanden från statens skogsforskningsinstitut* 50(8), 1–143. Stockholm.

Lappi-Seppälä, M. 1930. Untersuchungen über die Entwicklung gleichaltriger Mischbestände aus Kiefer und Birke. *Communicationes Instituti Forestalis Fenniae 15,* 1–243.

Laasasenaho, J. 1976. Taper curve and volume functions for pine, spruce and birch. (Seloste: Männyn, kussen ja koivun runkokäyrä- ja tilavuusyhtälöt.) *Communicationes Instituti Forestalis Fenniae 108,* 74.

Lehonkoski, N.A. 1939. Känner du ditt björkbestånd? *Skogsbruket 9,* 229–243. (In Swedish.)

Löken, A. 1954. Björkeskogbruk i nedre Savolax. *Tidskrift for Skogsbruk,* 387–391. (In Swedish.)

Marklund, L.G. 1987. Biomass functions for Norway spruce (*Picea abies* (L.) Karst.) in Sweden. (Sammanfattning: Biomassafunktionen för gran i Sverige).

Swedish University of Agricultural Sciences, Department of Forest Survey, Report 43. 127 pp. Umeå.

Marklund, L.G. 1988. Biomassafunktioner för tall, gran och björk i Sverige. (Summary: biomass functions for pine, spruce and birch in Sweden.) *Swedish University of Agricultural Sciences, Department of Forest Survey. Report 45.* 71 pp. Umeå.

Mielikäinen, K. 1985. Koivousekoituksen vaikutus kuusikon rakenteeseen ja kehitykseen. (Summary: Effect of an admixture of birch on the structure and development of Norway spruce stands.) *Communicationes Instituti Forestalis Fenniae 133,* 79 pp.

Monserud, R.A. & Ek, A.R. 1974. Plot edge bias in forest stand growth simulation models. *Canadian Journal of Forest Research 4,* 419–423.

Mård, H. & Tham, Å. 1990. Thinning of birch in mixed stands of Norway spruce (Picea abies (L.) Karst.) and birch (Betula pendula Roth & B. pubescens Ehrh.). (In: Å. Tham & H. Mård (eds.) Changes to forest management and silvicultural techniques necessitated by forest energy production). *Swedish University of Agricultural Sciences, Department of Forest Yield Research, Report 27,* 153.

Näslund, M. 1936. Skogsförsöksanstaltens gallringsförsök i tallskog. Primär bearbetning. (Zusammenfassung: Die Durchforstungsversuche der forstlichen versuchsanstalt Schwedens im Kiefernwald. Primärbearbeitung). *Meddelande från statens skogsforskningsinstitut 29* (1), 169 pp. Stockholm.

Oikarinen, M. 1983. Etelä-Suomen viljeltyjen rauduskoivikoiden kasvatusmallit. (Summary: Growth and yield models for silver birch (*Betula pendula*) plantations in southern Finland. *Communicationes Instituti Forestalis Fenniae 113,* 1–75.

Pukkala, T. 1988. Effect of spatial distribution of trees on the volume increment of a young Scots pine stand. *Silva Fennica 22*(1), 1–17.

Raulo, J. 1981. *Björkboken.* (Transl. by F. Bergman 1987). Skogsstyrelsen 1987.

Rosén, K. & Lundmark-Thelin, A. 1986. Hyggesbruket och markvården. Sveriges lantbruksuniversitet. *Skogsfakta Konferens 9,* 42–49. (In Swedish.)

Rytter, L. 1990. Biomass and nitrogen dynamics of intensively grown grey alder plantations on peatland. *Swedish University of Agricultural Sciences, Department of Ecology and Environmental Research. Report 37,* 20.

Schotte, G. 1913. Svenska skogsträd, 5. Björk och al. *Skogsvårdsföreningens Folkskrifter 36.* (In Swedish.)

Ståhlfelt, M.G. 1935. Der Einfluss der Durchforstung auf die Funktion der Nadeln und auf die Ausbildung der Baumkrone bei der Fichte. (Sammanfattning: Gallringens inverkan på barrfunktion och kronbildning hos granen.) *Svenska Skogsvårdsföreningens Tidskrift,* 149–176. (In German.)

Tham, Å. & Josefsson, R. 1986. Björk och gran i blandning—några resultat från ett försök i Södra Sverige. In: *Bioenergi 86. Del 5,* 41–49. Svebio. Stockholm. (In Swedish.)

Tham, Å. 1987. Gran och björk i blandning. Gallring i unga bestånd, försöksuppläggning och utgångsläge. (Summary: Mixed spruce and birch. Thinning in young stands, experimental design and initial position.) *Swedish University of Agricultural Sciences, Department of Forest Yield Research, Report 20,* 79.

Tham, Å. 1988*a*. Structure of mixed *Picea abies* (L.) Karst. and *Betula pendula* Roth and *Betula pubescens* Ehrh. stands in South and Middle Sweden. *Scandinavian Journal of Forest Research 3,* 355–370.

Tham, Å. 1988*b*. *Yield prediction after heavy thinning of birch in mixed stands of Norway spruce (*Picea abies *(L.) Karst.) and birch (*Betula pendula *Roth &* Betula pubescens *Ehrh.).* (Sammanfattning: Produktionsförutsägelser vid kraftiga gallringar av björk i blandbestånd av gran (*Picea abies* (L.) Karst.) och björk (*Betula pendula* Roth & *Betula pubescens* Ehrh.). *Swedish University of Agricultural Sciences, Department of Forest Yield Research, Report 23.* 36 pp.

Tham, Å. 1989. Prediction of individual tree growth in managed stands of mixed *Picea abies* (L.) Karst. and *Betula pendula* Roth & *Betula pubescens* Ehrh. *Scandinavian Journal of Forest Research 4,* 491–512.

Tomppo, E. 1986. Models and methods for analysing spatial patterns of trees. *Communicationes Instituti Forestalis Fenniae 138.* 65.

Wahlgren, A. 1914. *Skogsskötsel.* Stockholm. 732 pp. (In Swedish.)

Wiklander, G. 1989. Kvävebelastning och urlakning. *Kungl. Skogs- och Lantbruksakademien. Rapport 35,* 77–83. (In Swedish.)

Wästerlund, I. 1992. Extent and causes of site damage due to forestry traffic. *Scandinavian Journal of Forest Research 7,* 135–142.

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Appendix 1

Yield Table 1. *1 936 Norway spruces per hectare without birch shelter, between 15–50 years*

		Stand after thinning				Removed			Total yield			Annual increment: Current		Annual increment: Mean
	Age, years	Dom. height, dm	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha[a]	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	Basal area, m^2/ha	Volume, m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume, m^3sk/ha
Spruce	15	16.3	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.406	0.0	0.0	0.1
Birch	15	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.406	0.0	0.0	0.1
Spruce	20	32.2	1 936	4.8	12.5	0	0.0	0.0	4.8	12.5	16.303	0.9	2.3	0.6
Birch	20	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 936	4.8	12.5	0	0.0	0.0	4.8	12.5	16.303	0.9	2.3	0.6
Spruce	25	51.7	1 936	12.9	38.8	0	0.0	0.0	12.9	38.8	45.936	1.6	5.3	1.6
Birch	25	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 936	12.9	38.8	0	0.0	0.0	12.9	38.8	45.936	1.6	5.3	1.6
Spruce	30	71.1	1 936	21.5	79.8	0	0.0	0.0	21.5	79.8	82.487	1.7	8.2	2.7
Birch	30	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 936	21.5	79.8	0	0.0	0.0	21.5	79.8	82.487	1.7	8.2	2.7
Spruce	35	93.4	1 936	30.2	138.3	0	0.0	0.0	30.2	138.3	123.434	1.7	11.7	4.0
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 936	30.2	138.3	0	0.0	0.0	30.2	138.3	123.434	1.7	11.7	4.0
Spruce	40	116.3	1 544	29.7	165.6	392	7.5	41.8	37.2	207.4	161.577	1.4	13.8	5.2
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 544	29.7	165.6	392	7.5	41.8	37.2	207.4	161.577	1.4	13.8	5.2
Spruce	45	132.9	1 236	27.1	172.4	308	6.9	43.7	41.5	257.9	187.520	0.9	10.1	5.7
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 236	27.1	172.4	308	6.9	43.7	41.5	257.9	187.520	0.9	10.1	5.7
Spruce	50	146.5	1 236	31.0	214.6	0	0.0	0.0	45.3	300.1	210.860	0.8	8.4	6.0
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Total			1 236	31.0	214.6	0	0.0	0.0	45.3	300.1	210.860	0.8	8.4	6.0

[a] Forest m^3.

Yield Table 2. *1 936 Norway spruces and 1 200 birches per hectare without birch shelter, between 15–50 years. The birches are removed in two steps*

		Stand after thinning				Removed			Total yield			Annual increment		
												Current		Mean
	Age, years	Dom. height, dm	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	Basal area, m^2/ha	Volume, m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume, m^3sk/ha
Spruce	15	16.6	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.407	0.0	0.0	0.1
Birch	15	102.5	1 200	5.2	23.5	0	0.0	0.0	5.2	23.5	14.667	0.0	0.0	1.6
Total			3 136	5.4	24.5	0	0.0	0.0	5.4	24.5	17.074	0.0	0.0	1.6
Spruce	20	33.3	1 936	2.4	6.2	0	0.0	0.0	2.4	6.2	8.641	0.4	1.1	0.3
Birch	20	122.0	344	2.8	15.7	856	6.5	36.5	9.3	52.2	30.348	0.8	5.7	2.6
Total			2 280	5.2	22.0	856	6.5	36.5	11.7	58.5	38.990	1.3	6.8	2.9
Spruce	25	54.5	1 936	7.5	23.1	0	0.0	0.0	7.5	23.1	25.151	1.0	3.4	0.9
Birch	25	144.3	344	3.9	26.3	0	0.0	0.0	10.5	62.8	37.064	0.2	2.1	2.5
Total			2 280	11.4	49.5	0	0.0	0.0	17.9	86.0	62.215	1.2	5.5	3.4
Spruce	30	81.9	1 936	16.1	64.8	0	0.0	0.0	16.1	64.8	59.299	1.7	8.3	2.2
Birch	30	0.0	0	0.0	0.0	344	5.2	47.1	11.7	83.6	46.264	0.2	4.2	2.8
Total			1 936	16.1	64.8	344	5.2	47.1	27.8	148.4	105.563	2.0	12.5	4.9
Spruce	35	106.5	1 936	23.3	115.7	0	0.0	0.0	23.3	115.7	92.864	1.4	10.2	3.3
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	11.7	83.6	46.264	0.0	0.0	2.4
Total			1 936	23.3	115.7	0	0.0	0.0	35.0	199.4	139.128	1.4	10.2	5.7
Spruce	40	136.3	1 540	26.3	163.2	396	6.6	40.9	32.9	204.1	144.298	1.9	17.7	5.1
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	11.7	83.6	46.264	0.0	0.0	2.1
Total			1 540	26.3	163.2	396	6.6	40.9	44.6	287.7	190.562	1.9	17.7	7.2
Spruce	45	149.3	1 236	25.4	176.0	304	6.4	44.7	38.5	261.6	176.947	1.1	11.5	5.8
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	11.7	83.6	46.264	0.0	0.0	1.9
Total			1 236	25.4	176.0	304	6.4	44.7	50.2	345.2	223.211	1.1	11.5	7.7
Spruce	50	162.6	1 236	29.8	222.0	0	0.0	0.0	42.8	307.6	203.352	0.9	9.2	6.2
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	11.7	83.6	46.264	0.0	0.0	1.7
Total			1 236	29.8	222.0	0	0.0	0.0	54.5	391.2	249.616	0.9	9.2	7.8

Yield Table 3. *1 936 Norway spruces and 2 000 birches per hectare without birch shelter, between 15–50 years. The birches are removed in two steps*

		Stand after thinning				Removed			Total yield			Annual increment: Current		Annual increment: Mean
	Age years	Dom. height, dm	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	No. of stems, no./ha	Basal area m^2/ha	Volume, m^3sk/ha	Basal area, m^2/ha	Volume m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume m^3sk/ha
Spruce	15	16.3	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.407	0.0	0.0	0.1
Birch	15	102.8	2 000	7.3	31.8	0	0.0	0.0	7.3	31.8	19.959	0.0	0.0	2.1
Total			3 936	7.5	32.8	0	0.0	0.0	7.5	32.8	22.366	0.0	0.0	2.2
Spruce	20	31.7	1 936	2.1	5.4	0	0.0	0.0	2.1	5.4	7.838	0.4	0.9	0.3
Birch	20	127.6	600	3.8	21.2	1 400	8.8	49.4	12.6	70.6	40.858	1.1	7.8	3.5
Total			2 536	5.9	26.6	1 400	8.8	49.4	14.7	76.1	48.696	1.4	8.7	3.8
Spruce	25	50.6	1 936	6.6	19.4	0	0.0	0.0	6.6	19.4	21.977	0.9	2.8	0.8
Birch	25	148.0	600	5.1	33.4	0	0.0	0.0	13.9	82.9	48.609	0.3	2.4	3.3
Total			2 536	11.6	52.8	0	0.0	0.0	20.5	102.3	70.586	1.1	5.2	4.1
Spruce	30	77.5	1 936	15.0	57.3	0	0.0	0.0	15.0	57.3	54.725	1.7	7.6	1.9
Birch	30	0.0	0	0.0	0.0	600	6.5	55.2	15.3	104.7	57.677	0.3	4.4	3.5
Total			1 936	15.0	57.3	600	6.5	55.2	30.4	161.9	112.403	2.0	11.9	5.4
Spruce	35	101.0	1 936	21.8	102.0	0	0.0	0.0	21.8	102.0	85.494	1.4	8.9	2.9
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	15.3	104.7	57.677	0.0	0.0	3.0
Total			1 936	21.8	102.0	0	0.0	0.0	37.2	206.7	143.171	1.4	8.9	5.9
Spruce	40	128.4	1 564	25.4	149.6	372	6.4	37.6	31.8	187.2	137.257	2.0	17.0	4.7
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	15.3	104.7	57.677	0.0	0.0	2.6
Total			1 564	25.4	149.6	372	6.4	37.6	47.1	291.9	194.935	2.0	17.0	7.3
Spruce	45	140.8	1 240	25.1	165.6	324	6.3	41.4	37.7	244.6	171.015	1.2	11.5	5.4
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	15.3	104.7	57.677	0.0	0.0	2.3
Total			1 240	25.1	165.6	324	6.3	41.4	53.1	349.3	228.693	1.2	11.5	7.8
Spruce	50	155.8	1 240	29.4	210.7	0	0.0	0.0	42.1	289.7	197.040	0.9	9.0	5.8
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	15.3	104.7	57.677	0.0	0.0	2.1
Total			1 240	29.4	210.7	0	0.0	0.0	57.5	394.4	254.717	0.9	9.0	7.9

Yield Table 4. *1 936 Norway spruces and 2 500 birches per hectare without birch shelter, between 15–50 years. The birches are removed in two steps*

		Stand after thinning				Removed			Total yield			Annual increment: Current		Annual increment: Mean
	Age, years	Dom. height, dm	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	Basal area, m^2/ha	Volume, m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume, m^3sk/ha
Spruce	15	16.5	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.408	0.0	0.0	0.1
Birch	15	102.8	2 500	7.6	32.0	0	0.0	0.0	7.6	32.0	20.069	0.0	0.0	2.1
Total			4 436	7.8	33.0	0	0.0	0.0	7.8	33.0	22.477	0.0	0.0	2.2
Spruce	20	31.4	1 936	2.1	5.3	0	0.0	0.0	2.1	5.3	7.740	0.4	0.9	0.3
Birch	20	113.5	508	2.6	14.0	1 992	10.5	56.6	13.1	70.6	40.542	1.1	7.7	3.5
Total			2 444	4.7	19.3	1 992	10.5	56.6	15.1	75.9	48.282	1.5	8.6	3.8
Spruce	25	49.5	1 936	6.8	19.9	0	0.0	0.0	6.8	19.9	22.917	0.9	2.9	0.8
Birch	25	126.1	508	3.5	21.9	0	0.0	0.0	14.0	78.4	45.501	0.2	1.6	3.1
Total			2 444	10.3	41.7	0	0.0	0.0	20.8	98.3	68.418	1.1	4.5	3.9
Spruce	30	78.0	1 936	16.7	63.2	0	0.0	0.0	16.7	63.2	62.021	2.0	8.7	2.1
Birch	30	0.0	0	0.0	0.0	508	4.5	38.6	15.0	95.2	52.711	0.2	3.3	3.2
Total			1 936	16.7	63.2	508	4.5	38.6	31.7	158.4	114.732	2.2	12.0	5.3
Spruce	35	101.6	1 936	23.8	111.0	0	0.0	0.0	23.8	111.0	94.579	1.4	9.5	3.2
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	15.0	95.2	52.711	0.0	0.0	2.7
Total			1 936	23.8	111.0	0	0.0	0.0	38.8	206.1	147.291	1.4	9.5	5.9
Spruce	40	128.9	1 528	26.1	152.9	408	6.6	37.9	32.7	190.8	141.540	1.8	16.0	4.8
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	15.0	95.2	52.711	0.0	0.0	2.4
Total			1 528	26.1	152.9	408	6.6	37.9	47.7	286.0	194.252	1.8	16.0	7.1
Spruce	45	143.9	1 212	25.1	165.8	316	6.3	41.4	37.9	245.2	171.857	1.0	10.9	5.4
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	15.0	95.2	52.711	0.0	0.0	2.1
Total			1 212	25.1	165.8	316	6.3	41.4	52.9	340.3	224.568	1.0	10.9	7.6
Spruce	50	157.3	1 212	29.2	209.9	0	0.0	0.0	42.0	289.3	196.829	0.8	8.8	5.8
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	15.0	95.2	52.711	0.0	0.0	1.9
Total			1 212	29.2	209.9	0	0.0	0.0	57.0	384.4	249.540	0.8	8.8	7.7

Yield Table 5. *1 936 Norway spruces and 3 000 birches per hectare without birch shelter, between 15–50 years. The birches are removed in two steps*

		Stand after thinning				Removed			Total yield			Annual increment		
												Current		Mean
	Age, years	Dom. height, dm	No. of stems, no./ha	Basal area, m²/ha	Volume, m³sk/ha	No. of stems no./ha	Basal area m²/ha	Volume m³sk/ha	Basal area h²/ha	Volume m³sk/ha	Dry matter tonne	Basal area m²/ha	Volume, m³sk/ha	Volume, m³sk/ha
Spruce	15	16.5	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.408	0.0	0.0	0.1
Birch	15	102.5	3 000	8.8	37.0	0	0.0	0.0	8.8	37.0	23.170	0.0	0.0	2.5
Total			4 936	9.1	37.9	0	0.0	0.0	9.1	37.9	25.578	0.0	0.0	2.5
Spruce	20	30.3	1 936	1.9	4.9	0	0.0	0.0	1.9	4.9	7.319	0.3	0.8	0.2
Birch	20	134.5	888	4.5	24.7	2 112	10.5	57.4	15.0	82.1	47.564	1.2	9.0	4.1
Total			2 824	6.4	29.6	2 112	10.5	57.4	16.9	87.0	54.882	1.6	9.8	4.4
Spruce	25	48.7	1 936	6.2	17.7	0	0.0	0.0	6.2	17.7	20.731	0.8	2.6	0.7
Birch	25	153.4	888	5.7	37.1	0	0.0	0.0	16.3	94.5	55.389	0.2	2.5	3.8
Total			2 824	11.9	54.8	0	0.0	0.0	22.4	112.2	76.121	1.1	5.0	4.5
Spruce	30	76.4	1 936	15.3	56.1	0	0.0	0.0	15.3	56.1	56.156	1.8	7.7	1.9
Birch	30	0.0	0	0.0	0.0	888	7.2	58.5	17.7	115.9	63.892	0.3	4.3	3.9
Total			1 936	15.3	56.1	888	7.2	58.5	33.0	172.0	120.048	2.1	12.0	5.7
Spruce	35	96.6	1 936	21.1	93.5	0	0.0	0.0	21.1	93.5	82.071	1.2	7.5	2.7
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	17.7	115.9	63.892	0.0	0.0	3.3
Total			1 936	21.1	93.5	0	0.0	0.0	38.8	209.4	145.962	1.2	7.5	6.0
Spruce	40	124.6	1 540	24.4	136.2	396	6.1	34.2	30.5	170.3	129.656	1.9	15.4	4.3
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	17.7	115.9	63.892	0.0	0.0	2.9
Total			1 540	24.4	136.2	396	6.1	34.2	48.2	286.2	193.548	1.9	15.4	7.2
Spruce	45	139.7	1 236	24.0	152.7	304	6.0	37.6	36.1	224.5	161.265	1.1	10.8	5.0
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	17.7	115.9	63.892	0.0	0.0	2.6
Total			1 236	24.0	152.7	304	6.0	37.6	53.8	340.4	225.156	1.1	10.8	7.6
Spruce	50	152.5	1 236	28.5	197.5	0	0.0	0.0	40.7	269.2	187.578	0.9	9.0	5.4
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	17.7	115.9	63.892	0.0	0.0	2.3
Total			1 236	28.5	197.5	0	0.0	0.0	58.4	385.1	251.470	0.9	9.0	7.7

Yield Table 6. *1 600 Norway spruces and 600 birches per hectare without birch shelter, between 15–50 years. The birches are removed at age 25*

		Stand after thinning				Removed			Total yield			Annual increment		
												Current		Mean
	Age, years	Dom. height dm	No. of stems no./ha	Basal area m^2/ha	Volume m^3sk/ha	No. of stems no./ha	Basal area m^2/ha	Volume m^3sk/ha	Basal area m^2/ha	Volume m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume m^3sk/ha
Spruce	15	16.7	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.406	0.0	0.0	0.1
Birch	15	108.7	600	4.2	22.0	0	0.0	0.0	4.2	22.0	13.559	0.0	0.0	1.5
Total			2 536	4.4	23.0	0	0.0	0.0	4.4	23.0	15.965	0.0	0.0	1.5
Spruce	20	33.6	1 936	2.6	6.8	0	0.0	0.0	2.6	6.8	9.132	0.5	1.2	0.3
Birch	20	137.5	600	7.6	47.2	0	0.0	0.0	7.6	47.2	29.513	0.7	5.0	2.4
Total			2 536	10.2	53.9	0	0.0	0.0	10.2	53.9	38.645	1.1	6.2	2.7
Spruce	25	55.1	1 936	7.1	22.5	0	0.0	0.0	7.1	22.5	23.647	0.9	3.1	0.9
Birch	25	0.0	0	0.0	0.0	600	10.9	80.4	10.9	80.4	44.387	0.7	6.6	3.2
Total			1 936	7.1	22.5	600	10.9	80.4	18.0	102.9	68.034	1.6	9.8	4.1
Spruce	30	72.6	1 936	12.0	45.9	0	0.0	0.0	12.0	45.9	42.333	1.0	4.7	1.5
Birch	30	0.0	0	0.0	0.0	0	0.0	0.0	10.9	80.4	44.387	0.0	0.0	2.7
Total			1 936	12.0	45.9	0	0.0	0.0	22.9	126.3	86.720	1.0	4.7	4.2
Spruce	35	99.7	1 936	22.9	110.9	0	0.0	0.0	22.9	110.9	90.197	2.2	13.0	3.2
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	10.9	80.4	44.387	0.0	0.0	2.3
Total			1 936	22.9	110.9	0	0.0	0.0	33.8	191.2	134.584	2.2	13.0	5.5
Spruce	40	125.9	1 544	26.0	156.3	392	6.6	39.5	32.5	195.9	141.024	1.9	17.0	4.9
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	10.9	80.4	44.387	0.0	0.0	2.0
Total			1 544	26.0	156.3	392	6.6	39.5	43.5	276.2	185.410	1.9	17.0	6.9
Spruce	45	138.1	1 232	25.7	171.6	312	6.5	43.3	38.7	254.5	176.113	1.2	11.7	5.7
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	10.9	80.4	44.387	0.0	0.0	1.8
Total			1 232	25.7	171.6	312	6.5	43.3	49.7	334.8	220.499	1.2	11.7	7.4
Spruce	50	149.8	1 232	30.4	218.4	0	0.0	0.0	43.5	301.3	203.935	0.9	9.4	6.0
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	10.9	80.4	44.387	0.0	0.0	1.6
Total			1 232	30.4	218.4	0	0.0	0.0	54.4	381.7	248.322	0.9	9.4	7.6

Yield Table 7. *1 600 Norway spruces and 600 birches per hectare without birch shelter, between 15–50 years. The birches are removed at age 30*

		Stand after thinning				Removed			Total yield			Annual increment		
												Current		Mean
	Age, years	Dom. height, dm	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	Basal area, m^2/ha	Volume, m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume m^3sk/ha
Spruce	15	16.3	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.408	0.0	0.0	0.1
Birch	15	111.3	600	4.2	22.1	0	0.0	0.0	4.2	22.1	13.622	0.0	0.0	1.5
Total			2 536	4.4	23.1	0	0.0	0.0	4.4	23.1	16.030	0.0	0.0	1.5
Spruce	20	33.0	1 936	2.6	6.8	0	0.0	0.0	2.6	6.8	9.229	0.5	1.2	0.3
Birch	20	138.2	600	7.4	45.9	0	0.0	0.0	7.4	45.9	28.708	0.6	4.8	2.3
Total			2 536	10.0	52.7	0	0.0	0.0	10.0	52.7	37.936	1.1	5.9	2.6
Spruce	25	53.8	1 936	7.2	22.8	0	0.0	0.0	7.2	22.8	23.985	0.9	3.2	0.9
Birch	25	165.6	600	10.5	77.2	0	0.0	0.0	10.5	77.2	48.464	0.6	6.2	3.1
Total			2 536	17.7	99.9	0	0.0	0.0	17.7	99.9	72.449	1.5	9.4	4.0
Spruce	30	74.0	1 936	12.1	48.3	0	0.0	0.0	12.1	48.3	42.897	1.0	5.1	1.6
Birch	30	0.0	0	0.0	0.0	600	13.1	114.0	13.1	114.0	62.363	0.5	7.4	3.8
Total			1 936	12.1	48.3	600	13.1	114.0	25.2	162.3	105.260	1.5	12.5	5.4
Spruce	35	90.8	1 936	17.1	81.3	0	0.0	0.0	17.1	81.3	64.533	1.0	6.6	2.3
Birch	35	0.0	0	0.0	0.0	0	0.0	0.0	13.1	114.0	62.363	0.0	0.0	3.3
Total			1 936	17.1	81.3	0	0.0	0.0	30.2	195.3	126.896	1.0	6.6	5.6
Spruce	40	119.8	1 552	23.5	140.8	384	6.0	35.9	29.5	176.7	125.974	2.5	19.1	4.4
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	13.1	114.0	62.363	0.0	0.0	2.9
Total			1 552	23.5	140.8	384	6.0	35.9	42.6	290.7	188.337	2.5	19.1	7.3
Spruce	45	132.9	1 236	24.9	162.5	316	6.2	40.9	37.1	239.3	166.654	1.5	12.5	5.3
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	13.1	114.0	62.363	0.0	0.0	2.5
Total			1 236	24.9	162.5	316	6.2	40.9	50.2	353.3	229.017	1.5	12.5	7.9
Spruce	50	144.9	1 236	30.1	210.8	0	0.0	0.0	42.3	287.6	196.601	1.0	9.7	5.8
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	13.1	114.0	62.363	0.0	0.0	2.3
Total			1 236	30.1	210.8	0	0.0	0.0	55.4	401.6	258.964	1.0	9.7	8.0

Yield Table 8. *1 600 Norway spruces and 600 birches per hectare without birch shelter, between 15–50 years. The birches are removed at age 35*

		Stand after thinning				Removed			Total yield			Annual increment: Current		Annual increment: Mean
	Age, years	Dom. height, dm	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	No. of stems, no./ha	Basal area, m^2/ha	Volume, m^3sk/ha	Basal area, m^2/ha	Volume, m^3sk/ha	Dry matter, tonne	Basal area, m^2/ha	Volume, m^3sk/ha	Volume m^3sk/ha
Spruce	15	16.4	1 936	0.2	0.9	0	0.0	0.0	0.2	0.9	2.409	0.0	0.0	0.1
Birch	15	111.1	600	4.2	22.1	0	0.0	0.0	4.2	22.1	13.584	0.0	0.0	1.5
Total			2 536	4.4	23.0	0	0.0	0.0	4.4	23.0	15.993	0.0	0.0	1.5
Spruce	20	33.1	1 936	2.6	6.8	0	0.0	0.0	2.6	6.8	9.203	0.5	1.2	0.3
Birch	20	137.1	600	7.4	45.7	0	0.0	0.0	7.4	45.7	28.576	0.6	4.7	2.3
Total			2 536	10.0	52.5	0	0.0	0.0	10.0	52.5	37.779	1.1	5.9	2.6
Spruce	25	54.1	1 936	7.2	22.8	0	0.0	0.0	7.2	22.8	24.021	0.9	3.2	0.9
Birch	25	164.7	600	10.6	77.6	0	0.0	0.0	10.6	77.6	48.736	0.6	6.4	3.1
Total			2 536	17.8	100.4	0	0.0	0.0	17.8	100.4	72.757	1.6	9.6	4.0
Spruce	30	73.7	1 936	12.1	48.2	0	0.0	0.0	12.1	48.2	42.864	1.0	5.1	1.6
Birch	30	195.0	600	13.2	115.0	0	0.0	0.0	13.2	115.0	72.946	0.5	7.5	3.8
Total			2 536	25.3	163.2	0	0.0	0.0	25.3	163.2	115.810	1.5	12.6	5.4
Spruce	35	95.2	1 936	17.3	85.7	0	0.0	0.0	17.3	85.7	66.052	1.0	7.5	2.4
Birch	35	0.0	0	0.0	0.0	600	15.1	150.3	15.1	150.3	82.557	0.4	7.1	4.3
Total			1 936	17.3	85.7	600	15.1	150.3	32.5	235.9	148.608	1.4	14.5	6.7
Spruce	40	112.2	1 548	17.4	101.0	388	4.4	25.3	21.8	126.4	88.678	0.9	8.1	3.2
Birch	40	0.0	0	0.0	0.0	0	0.0	0.0	15.1	150.3	82.557	0.0	0.0	3.8
Total			1 548	17.4	101.0	388	4.4	25.3	36.9	276.6	171.235	0.9	8.1	6.9
Spruce	45	123.3	1 236	22.4	138.0	312	5.6	34.7	32.4	198.0	141.320	2.1	14.3	4.4
Birch	45	0.0	0	0.0	0.0	0	0.0	0.0	15.1	150.3	82.557	0.0	0.0	3.3
Total			1 236	22.4	138.0	312	5.6	34.7	47.6	348.3	223.877	2.1	14.3	7.7
Spruce	50	134.1	1 236	28.6	188.0	0	0.0	0.0	38.6	248.1	174.822	1.2	10.0	5.0
Birch	50	0.0	0	0.0	0.0	0	0.0	0.0	15.1	150.3	82.557	0.0	0.0	3.0
Total			1 236	28.6	188.0	0	0.0	0.0	53.7	398.3	257.379	1.2	10.0	8.0