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Yield, wood properties, and timber harvest at establishment of seed-tree and shelterwood regeneration systems

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Abstract

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Variation in wood properties, timber harvest and yield, on the establishment of seed-tree and shelter-tree stands as compared with clear-felling of *Pinus sylvestris,* was studied at two sites. Seed trees and shelter trees were selected on the basis of seed productivity, health and quality criteria. Pines not needed to establish seed or shelter tree stand are referred to as "indifferent pines".

The annual radial increment of seed trees was superior to that of indifferent pines, but basic density from pith to bark was lower. Shelter trees were intermediate.

Differences in wood properties and dimensions between seed trees, shelter trees and indifferent pines reflect the selection criteria used. Differences in value were related to the timber section of the tree, the amounts of pulpwood being more or less constant.

At the two sites the change from conventional clearfelling to shelter-tree stands reduced the timber harvest by 100 m^3s.u.b. ha^{-1}. The increased percentage of pulpwood, the decreased percentage of U/S logs and a decrease in mean diameter lead to a substantial reduction in value m^{-3}s.u.b. Basal area increment was reduced by 10% in a shelter-tree stand and by less than 25% in a seed-tree stand.

Keywords: Seed trees, shelter trees, wood properties, basic density, basal area increment, dimensions, timber harvest, *Pinus sylvestris.*

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Introduction

The potential for achieving a high-quality final harvest from pine stands planted at economically feasible spacings is limited (Persson, 1976, 1977; Huuri & Lähde, 1985). Only on poor sites can reasonably large volumes of U/S grade timber be produced under such conditions (Ståhl, Persson & Prescher, 1990; Uusvaara, 1991), and in general, the quality of wood produced through natural regeneration is better than that produced in planted stands (Uusvaara, 1974). This is one of the reasons why interest in natural regeneration methods has increased during recent years. Other reasons are that natural regeneration methods are less labour-intensive, require less investment capital, and are environmentally sounder. Furthermore, trees left on the site for seed production or shelter tend to produce knot-free wood in their outer annual rings. Since 1990, the area on which Scots pine has been naturally regenerated has increased considerably (Lindevall, 1994). The improvement of wood properties among trees left for additional periods has been described by Petrini (1937) and Hagner (1962). Profitability estimates have been made by Hägg (1992).

Seed trees (Anon., 1969) are the trees left in a stand to provide a source of seed for natural regeneration. Thus, the main purpose to a seed-tree stand is to produce and distribute enough seed to reforest the site adequately (Hagner, 1962).

In a shelterwood system, large stems from the old stand (referred to as "shelter trees") are left intact to provide a source of seed and shelter for the next generation of trees (Anon., 1969). For a shelterwood stand to provide shelter, its degree of closure must greatly exceed that of a seed-tree stand. Thus, a shelterwood stand generally contains many more mature trees, and is, consequently, worth much more, than a seed-tree stand. Described in another way, the shelterwood stand occupies an intermediate position between heavily thinned preharvest stands used entirely for timber production, and seed-tree stands. A good review of the biological and economic aspects of shelterwood and seed-tree management was present by Hagner (1962).

The aim of this study is to describe the wood properties, timber harvest and yield, when seed-tree or shelterwood regeneration systems are established, as compared with clear-felling. Concerning the effects on the regeneration results, no conclusions are drawn.

Material and methods

The experimental sites

The two field experimental sites, Brändan and Källsinken, are situated near Garpenberg in central Sweden at 60°16′N, 16°12′E, 175 m above sea-level. Each of the sites covers an area of 1.0 ha.

The Brändan trial is situated on a flat site of mesic-moist dwarf shrub (*Vaccinium myrtillus* L.) type and supports a mixed stand of pine and spruce. A small part of the study area is moist and contains birch in addition to the conifers. The soil is a sandy-loamy till with a 5–10 cm humus layer overlying a 15 cm thick bleached horizon. Natural regeneration in stands of this type is often inadequate.

The spatial distribution of seed trees was not a major concern. Once the seed trees had been chosen, 90 additional pines were selected as shelter trees. Trees with a high value increment, which were healthy and free of injuries, were selected in such a way that their spatial distribution complemented that of the seed trees. Thus a total of 180 trees was designated to regenerate a new stand, leaving 87 pines (referred to in what follows as "indifferent pines") which could be cut without affecting the regeneration.

The Källsinken trial is situated on a site of dry-mesic dwarf shrub (*Vaccinium vitis ideae* L.) type with Scots pine. Spruce is mixed in close to a small brook which passes through the trial. The soil is a sandy loamy moraine with a 5-cm humus layer that overlies a 15-cm-thick bleached horizon. Natural regeneration using seed trees in stands of this type generally results in dense reforestation.

In the Källsinken trial, the same procedure was applied, but the number of seed and shelter trees was reduced to 80 each, and there were 66 indifferent trees.

Table 1. *Stand characteristics at Brändan and Källsinken. Age at breast height, site quality class, total volume, number of stems, basal area and breast-height diameter*

	Brändan			Källsinken		
	Total	Pine	Spruce	Total	Pine	Spruce
Age at brh		97			107	
Sqc, $m^3ha^{-1}year^{-1}$		6.8			5.9	
V, m^3s.u.b.	287	199	88	239	197	42
N/ha	523	267	256	320	226	94
BA, m^2	30.9	20.3	10.6	23.9	19.7	4.2
DBH, cm		30.7	19.5		33.2	24.8

On both sites, 50 sample trees were selected for test sawing: 17 seed trees, 16 shelter trees and 17 indifferent pines. The trees were randomly selected from each of five diameter classes, the number of stems in each diameter class depending on basal area (Fig. 1).

All trees were cross-calipered at breast height (1.3 m). Sample trees were marked and their bark thickness measured. Two 4.5-mm increment cores were obtained from the south and east sides of each sample tree. Sample trees were felled, and their total height and the height to the first dead and live branch were measured. Any stem injuries were also recorded. A butt log was cut from each selected tree at 5.1 m, and two additional logs of 4.1 m length were taken from 10 trees in each trial. For estimating basic density, disks were removed at 5 m height from the butt log and at 9.0 m and 13.0 m height from the second and third logs, respectively. Each log and disk was assigned a number based on trial and tree type. When logs were crosscut, assortment limits were not considered. Finally, a standardized follow-up of crosscutting pattern was carried out, utilizing the possibility of rotating individual logs to estimate assortment limits.

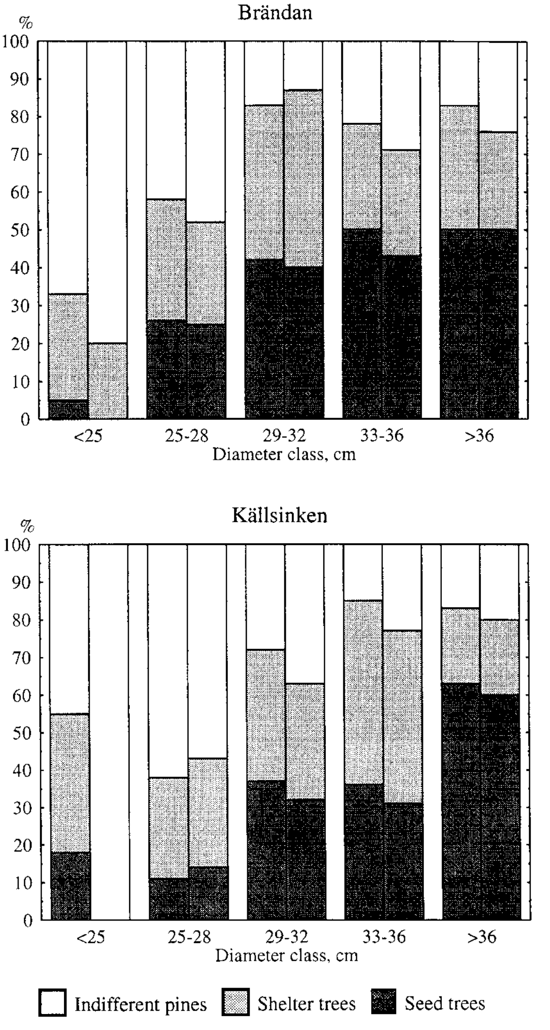

Fig. 1. Proportions of the total volume in each diameter class accounted for by seed trees, shelter trees and indifferent pines. Total values and sample tree values.

Analysis of samples

Volumes were calculated for 1.0-ha areas, Jonson's (1929) table being used for estimating standing volume. Sample tree volumes were calculated according to Brandel (1990: Function 100–01).

The estimated basal area increments for seed trees, shelter trees and all trees were calculated using two methods. First, the basal area increment was directly calculated using Persson's (1992) growth simulator (Table 9, Function 2). Then relative annual volume increment was calculated using Eriksson's (1993) function

$$Reliv = (\ln N/(0.4472 + 0.1520 \ln N))^3$$

where N = number of trees ha^{-1}. The assumption that relative basal area increment was directly proportional to the relative volume increment seemed reasonable, because the estimates were based on a short times-span late in the rotation (Eriksson, pers.comm.). Thus total basal area increment could be estimated as a percentage of the increment achieved in the original stand.

Increment cores were used for measuring annual increment. Basic density was calculated from measurements made on increment cores and disks using the water-displacement method as described in Olesen (1971) and the TAPPI Standard (1989), respectively. The increment cores were cut into sections, five annual rings thick, from the bark to annual ring 50, thereafter into 10-year sections. The basic density of the whole cross-section was determined as the weighted mean value of the core segments, where the weighting factor for a given segment was set equal to the proportion of the total cross-sectional area that it accounted for.

At the Swedish University of Agricultural Sciences (SUAS) sawmill at Garpenberg, all logs were export-graded according to number of knots and visual defects. The sawing patterns were limited to three dimensions for central yield: 50 × 100 mm, 63 × 125 mm and 75 × 150 mm. Central yields were dried to 14% moisture, planed and export-graded. Planing was carried out to obtain exact dimensions, necessary for obtaining reproducible results from stress grading. After planing, the dimensions were 45 × 95 mm, 58 × 120 mm and 70 × 145 mm, respectively. Export gradings were carried out separately for number and type of knots, as well as for defects.

Logs and sawn goods were graded according to the export grading rules (Anon., 1976). Results of the two classifications made, according to knot frequency and type as well as defects, were combined, and downgrading was performed according to "worst fault". To compensate for the predetermined length of logs, any defects occurring within 0.5 m of a log end were not included in analyses.

The sawn timber was graded according to strength in a SUAS strength grading machine of type Cook-Bolinder At-Gs (Cook Bolinders Ltd., England). Grading is based on the fact that the load required to cause a certain deflection of the timber has a known relation to the modulus of elasticity, thereby indicating the suitability of the timber for structural uses. Based on the weakest 100 mm long lengthwise section, the entire piece was assigned one of the following grades, presented according to decreasing strength: T30, T24, T18 and reject. The principles for machine stress grading were described by Brundin (1981).

To estimate the optimal values of crosscutting options, a standardized program was used to evaluate the stems of the sample trees. This program was developed by SkogForsk (APTUPP; Lidén, 1992), with dimensions and prices based on local price lists valid on 15 December 1992. Pulpwood was priced at 210 SEK m^{-3}s.u.b. for log lengths from 3.0 m to 5.5 m. The program performed an optimal bucking for each tree, with respect to diameter, taper, quality, crook, defects and damage, using the assortment limits and prices chosen.

Results

The standing volume of the pines was approximately equal at the two sites, i.e. 199 m^3s.u.b. at Brändan and 197 m^3s.u.b. at Källsinken. The proportion of the total standing volume represented by seed trees, shelter trees and indifferent pines was 39%, 35% and 26%, respectively, at both sites.

Fig. 1 shows the percentage of the total volume in each diameter class accounted for by each of the tree types, together with the corresponding percentages for sample trees. Large diameter classes were dominated by seed trees, intermediate diameter classes by shelter trees and small diameter classes by indifferent pines.

Mean values for various properties for each of the tree types in the two trials are given in Table 2, together with the amounts of pulpwood and timber for the three types of tree. Note that these values are based on 50 sample trees from each trial. Timber volumes were higher for seed trees than for the other two types, whereas pulp volumes did not vary much between tree types.

In Fig. 2, the basic density levels at 1.3 m, 5 m, 9 m and 13 m height are presented. Basic density decreased upwards in the bole. Indifferent pines tended to have a higher basic density than the other two tree types. Note that measurements

Table 2. *Stem volumes, age at breast height, breast-height diameter, total height, height of first live branch and first dead branch, taper, and timber and pulp wood volumes. Mean values and total values for the three tree types at Brändan and Källsinken based on 50 sample trees at each site*

	Brändan				Källsinken			
Type of trees	Seed trees	Shelter trees	Indiff. trees	Mean	Seed trees	Shelter trees	Indiff. trees	Mean
Stem volume, m^3	0.95	0.85	0.69	0.83	1.03	0.95	0.82	0.93
Age, BH, years	84	85	85	85	104	104	104	104
DBH, cm	34.3	32.3	29.5	32.0	35.3	33.5	31.7	33.5
Height, m	23.1	22.8	21.7	22.5	23.1	23.7	22.1	23.0
Height to first live branch, m	12.7	13.2	12.5	22.5	12.7	13.6	12.8	13.0
Height to first dead branch, m	7.1	7.1	6.8	7.0	8.6	8.8	8.4	8.6
Taper 1.3–5 m, cm/m	1.9	1.6	2.4	2.0	1.6	1.7	1.8	1.7
Timber, m^3s.u.b.	11.5	9.1	6.4	9.0	14.6	11.7	10.1	12.2
Pulpwood, m^3s.u.b.	3.6	2.8	3.5	3.3	2.1	2.1	2.8	2.3

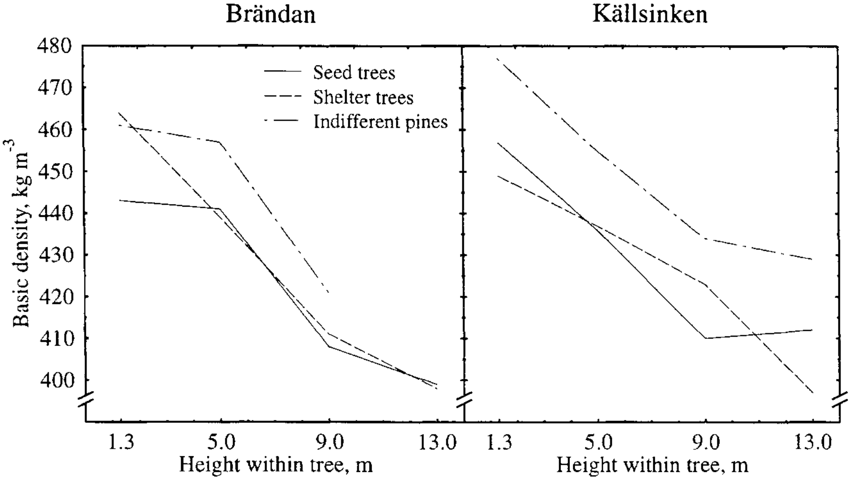

Fig. 2. Basic density (kg m^{-3}) at 1.3 m, 5 m, 9 m and 13 m. Mean for seed trees, shelter trees and indifferent pines at the Brändan and Källsinken sites. 1.3 m values based on 50 increment cores/site. 5.0 m values based on 50 disks/site. 9.0 m and 13.0 m values based on 10 disks/site.

were made on an increment core at the 1.3 m level on disks at the other levels.

In Fig. 3, basic density variation from bark to pith in a 5-year section is presented for the three tree types, together with corresponding mean annual radial increments. Annual radial increments for the three tree types are described in Fig. 4. Note that the annual radial increment (Fig. 4) and the basic density variation (Fig. 3) were each measured on a separate increment core taken at breast height.

The external quality of butt logs of sample trees, judged on the basis of export grading rules, and the quality of main yields are presented (Fig. 5) together with the estimated values of the three tree types. For main yields from seed trees at Källsinken, the low percentage of U/S quality should be noted. A standardized follow up of crosscutting was utilized to estimate optimal value of the sample trees (Fig. 5).

In Fig. 6, the variation in dimensions for main yields and the results of the machine stress grading for structural purposes is described for the main yields from the butt log. The major part of the main yields fulfils requirements for the highest grade for structural purposes.

Alternative methods of regeneration felling

In practice, given the present stands, three options are available for regeneration felling: to

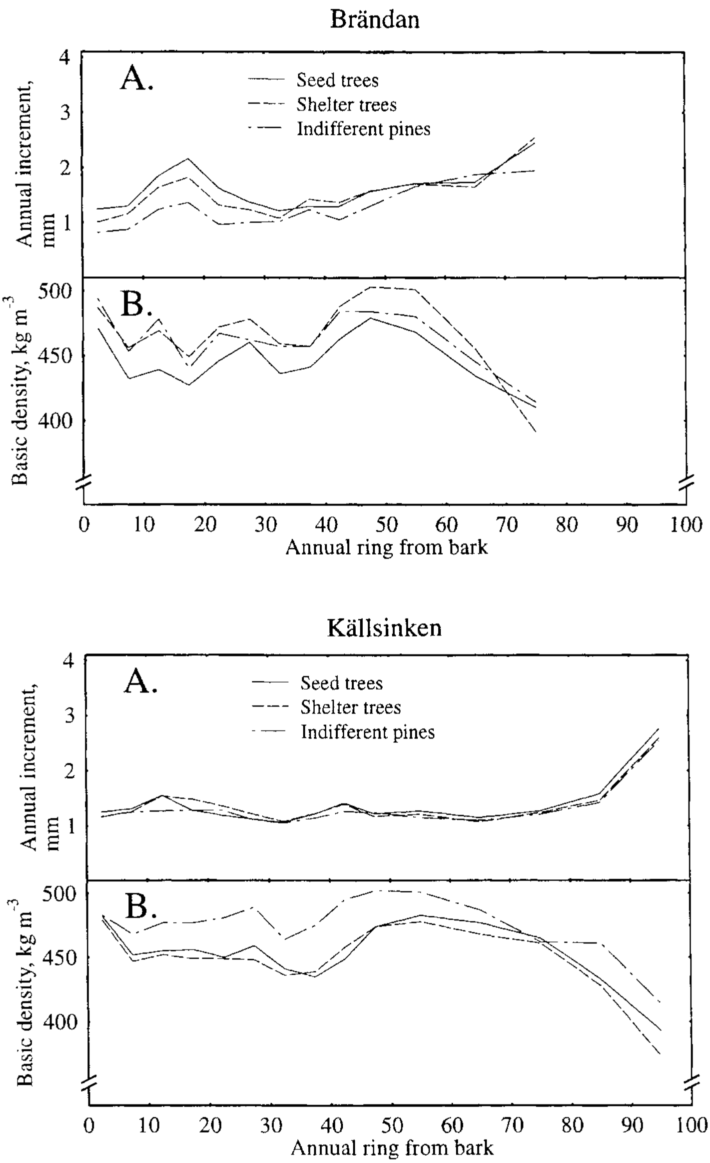

Fig. 3. Basic density (kg m^{-3}) (A) and mean annual radial increment (mm) (B) from bark to pith for seed trees, shelter trees and indifferent pines at Brändan and Källsinken. Values based on assessment of increment cores sections of 5 annual rings from the bark to annual ring 50 and thereafter of 10 year sections.

clear-fell and plant (i.e. all trees are removed); to create a shelterwood (i.e. indifferent pines are removed); and to form a seed tree stand (i.e. remaining and shelter trees are removed). The following tables present mean values for the three regeneration methods, called clear-felling, seed trees and shelter trees. The values presented could be regarded as a description of the potential timber harvest. Total volumes in different DBH classes are presented in Table 3. Clear-felling yields higher volumes and larger dimensions than does felling to create seed-tree stands or shelterwoods.

The proportional distributions of export grades for the main yields of butt logs are presented in Table 4. The differences in the percentage of logs given a U/S grade at Källsinken are not reflected in the export grading of main yields.

From the results of the crosscutting follow-up and the volume estimates made, the values and yields obtained from different regeneration-

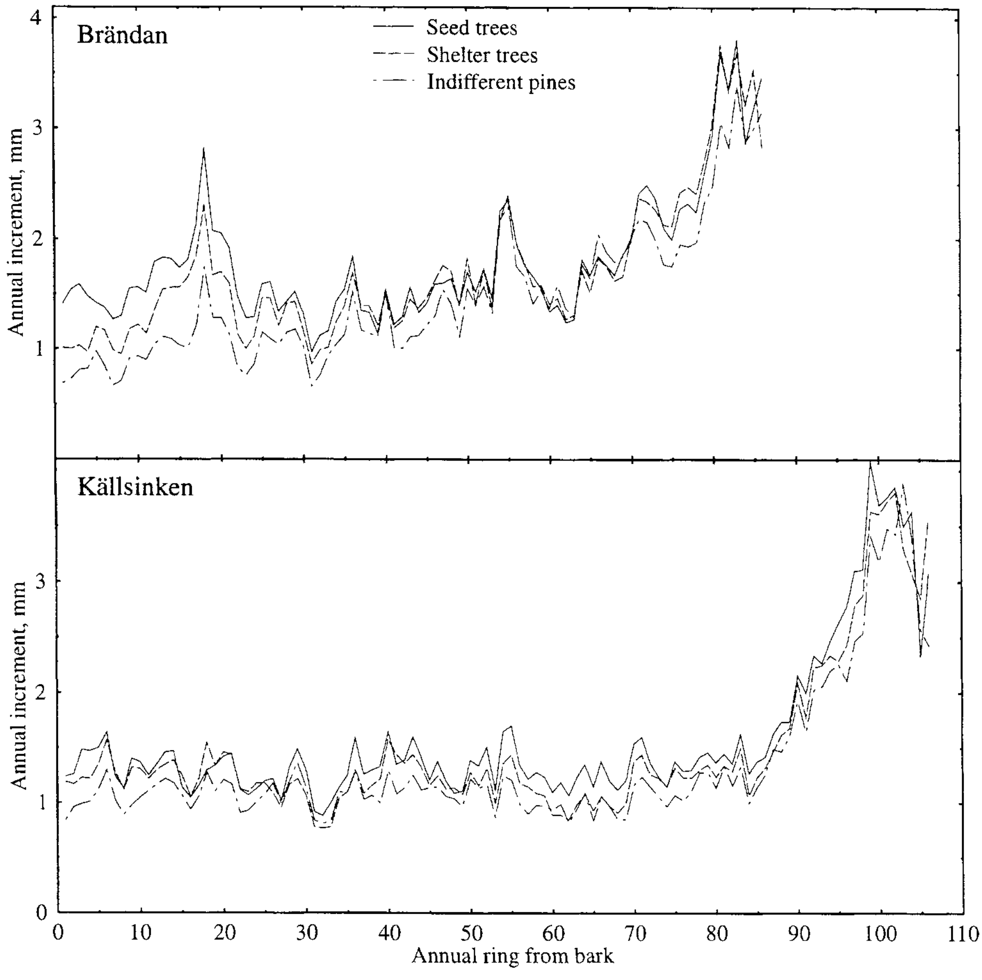

Fig. 4. Annual radial increment (mm) from bark to pith for seed trees, shelter trees and indifferent pines at Brändan and Källsinken. Values based on assessments of increment cores.

felling methods were calculated (Table 6). The low percentage of U/S obtained when bucking (Table 5), compared with values presented in Table 4, can be ascribed to the fact that the whole trunk was evaluated in the crosscutting follow-up.

The predicted yield increment for seed and shelter trees within the next 10 year period is important when different regeneration methods are compared. Table 6 shows values obtained when the growth simulator presented by Persson (1992) was used to estimate yield increment. Table 7 gives the corresponding values obtained when the relative volume increment function developed by Eriksson (1993) was used. In both tables, the values obtained when assuming that the original stand was left uncut were included for comparison (i.e. all trees). It is of interest to note that, while the predicted yield increment for seed trees is within 75% of that produced by the original stand, the annual radial increment is less than 3 mm on average.

Discussion

For regeneration purposes, seed-tree stands and shelter-tree stands are biologically possible options on most dry and mesic pine sites in central Sweden (Hagner, 1962). The limits are set by requirements concerning the regeneration period (5–10 years; Swedish Forestry Act of 1979, National Board of Forestry 1994), by the perils of natural regeneration in practice and by the revenue from different methods. This study dealt primarily with evaluation of the short-term

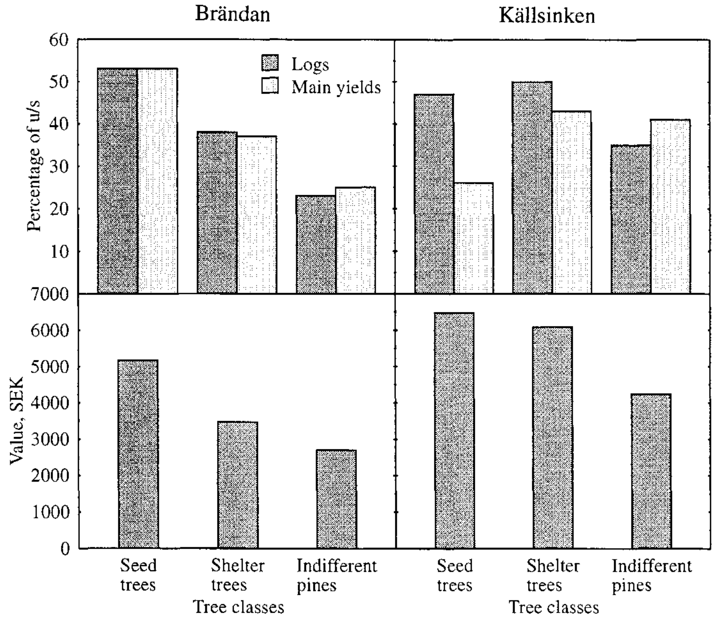

Fig. 5. Per cent butt logs and main yields of U/S quality as determined by export grading rules (Anon., 1976) for seed trees, shelter trees and indifferent pines at Brändan and Källsinken. Estimated values (SEK) of the sample trees are also presented.

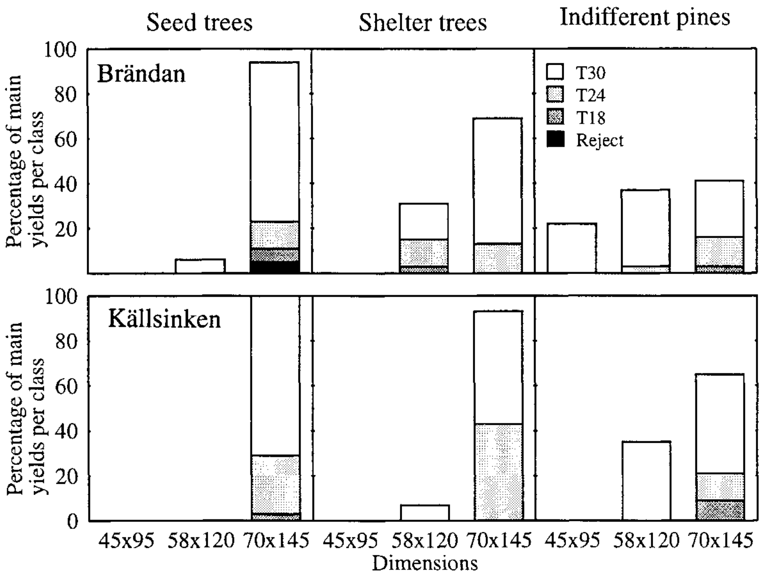

Fig. 6. Relative proportions of the various strength classes for three dimension classes of main yields from seed trees, shelter trees and indifferent pines at Brändan and Källsinken. Main yields were classified as either T30, T24, T18 or reject, based on weakest lengthwise 100-mm section as described by Brundin (1981).

effects on the wood properties, timber harvest and yield of seed- and shelter-trees stands.

Only two experimental sites were evaluated; however, their silvicultural histories rendered both of them suitable for either of the alternatives to clearfelling. As argued by Eriksson (1993), a prerequisite for establishing seed- or shelter-tree stands is that the stand has a sufficient number of trees suitable as seed trees. This can be achieved by establishing a sawtimber stand and opening it up, leaving stems with large cone-producing crowns at the last thinning.

Table 3. *Volumes (m^{-3}s.u.b.) of Scots pine removed in different breast-height diameter classes for three regeneration methods, i.e. clear felling, seed trees and shelter trees, at Brändan and Källsinken*

	Brändan						Källsinken					
DBH class	Total	−24	25–28	29–32	33–36	37+	Total	−24	25–28	29–32	33–36	37+
Regeneration method												
Clear felling	199	6	27	59	67	40	197	2	11	47	79	58
Seed trees	122	6	23	37	35	21	120	2	10	34	48	26
Shelter trees	54	5	11	16	17	5	51	2	6	18	16	9

Table 4. *Proportional distributions of export grades for butt logs (log) and main yields (m.y.) (U/S, V, VI -) at Brändan and Källsinken*

Export grading class	Brändan			Källsinken		
	U/S	V	VI-	U/S	V	VI-
Clear felling						
log	38	56	6	44	48	8
m.y.	39	55	6	37	50	13
Seed trees						
log	30	63	6	42	52	6
m.y.	31	67	2	42	49	9
Shelter trees						
log	23	65	12	35	59	6
m.y.	25	75	–	41	50	9

The layout and design of the study do not permit a detailed analysis of the relationship between cutting levels and wood properties. Since the sample material is limited to two stands at lat. 60°N and altitude 175 m, both of them having high site quality indices, generalisations could prove to be misleading when applied to other regions. In spite of these limitations, it is our opinion that some general conclusions can be drawn from this study.

To the casual observer, the two experimental sites chosen for this study would seem to be very similar: indeed, they have similar mean heights, standing volumes of pine (200 m^3s.u.b.) and basal areas (20 m^2), and both stands contain some Norway spruce (*Picea abies* (L.) Karst.). However, the stands differ in terms of site quality class (6.8 m^3 and 5.9 m^3 respectively). Though apparently small, this difference reflects a dissimilarity in forest type that may substantially influence the survival, growth and quality of the succeeding generation. Differences between forest types have been treated by Hagner (1962) and Uusvaara (1991). Hägg (1992) evaluated the profitability of using shelter trees when the risk of failure is high.

The Brändan site consists basically of a pine stand with an understorey of Norway spruce. If left to itself, it is likely that this stand would gradually become pure spruce. Our conclusion is that the natural regeneration of Scots pine on this site would be difficult in spite of an abundance of suitable seed trees. At least twice during the rotation there has been a substantial reduction in tree number (cf. Fig. 4, annual rings 15–20 and 50–60 from bark) which resulted in an increase in the annual radial increment. Windbreak or windthrow during winter storms are the probable causes of these reductions.

The Källsinken site is basically a pine site, except for the area bordering the stream, which

Table 5. *Estimated total value of optimally bucked Scots pine trees and estimated amounts of pulpwood and timber, separated into special-, U/S- and V-log, for three regeneration felling methods at Brändan and Källsinken*

Regeneration method	Brändan Clear felling	Brändan Seed trees	Brändan Shelter trees	Källsinken Clear felling	Källsinken Seed trees	Källsinken Shelter trees
Timber, m^3s.u.b.	145	83	34	165	99	46
Pulpwood, m^3s.u.b.	54	34	19	32	22	12
Special logs, $m^3$to	–	–	–	7.7	6.2	–
U/S logs, $m^3$to	23.8	8.5	2.7	40.8	22.4	9.8
V log, $m^3$to	94.5	59.1	25.3	86.3	52.6	27.1
Total value, SEK	61 200	33 300	14 600	76 000	46 700	19 200
Value, SEK/m^3	307	285	276	386	386	331

Table 6.

Current dimensions and estimated increment after ten years for seed trees, shelter trees and "all pines". Abbreviations N = number of trees, BA = basal area, MAI = mean annual radial increment, BAI = basal area increment, CAI = current annual radial increment

	Brändan Age Brh 90 years				Källsinken Age Brh 100 years			
Regeneration method	N	Volume, m^3s.u.b.	BA, m^2	MAI 0–90, mm/year	N	Volume, m^3s.u.b.	BA, m^2	MAI 0–100, mm/year
Seed trees	90	78	7.8	1.84	80	79	7.7	1.75
Shelter trees	180	150	14.7	1.79	160	154	14.6	1.70
"All pines"	267	210	20.3	1.72	226	211	19.7	1.67
	Brändan Age Brh 100 years				Källsinken Age Brh 110 years			
	Volume, m^3s.u.b	BA, m^2	BAI, m^2/year	CAI 91–100, mm/year	Volume, m^3s.u.b	BA, m^2	BAI, m^2/year	CAI 101–110, mm/year
Seed trees	115	10.8	0.31	2.95	114	10.5	0.29	2.95
Shelter trees	198	18.4	0.37	2.00	200	18.1	0.35	1.95
"All pines"	265	24.4	0.41	1.55	262	23.5	0.38	1.60

Table 7. *Estimated relative volume increment (RELIV), basal area increment (BAI) and volume after ten years for seed trees, shelter trees and "all pines". Reliv shows the yield increment of seed trees and shelter trees as a fraction of an idealized stand*

Regeneration method	Brändan			Källsinken		
	RELIV	BAI, m^2/year	Vol., m^3	RELIV	BAI, m^2/year	Vol., m^3
Seed trees	0.630	0.32	121	0.610	0.29	121
Shelter trees	0.741	0.38	201	0.722	0.34	203
"All pines"	0.800	0.41	265	0.775	0.37	264

contains spruce as well. Pine seedlings are already established in the stand openings. The potential for natural regeneration with pine is high. An analysis of annual ring dynamics (Fig. 4) suggests that no serious losses due to windbreak have occurred in the stand. Furthermore, there is an abundance of suitable seed trees.

The differences between the stands, in terms of their site characteristics and silvicultural management histories, are reflected in differences in stem volume and taper (Table 2) as well as in timber and pulp volumes and total value (Table 5). However, the site differences in basic density (Fig. 2), quality classes of logs (Fig. 5) and strength grades (Fig. 6) were small. The low percentage of the main yields that was of U/S quality for seed trees at Källsinken (Fig. 5) could not be attributed to any visible defects on the surfaces or cross-sections of butt logs. In view of the even development of annual radial increment at Källsinken, the timber quality of this site should be considered superior to that of the Brändan site (Fig. 3).

Differences in wood properties between the tree types (i.e. seed trees, shelter trees and indifferent pines) are simply an effect of the selection criteria used and of variation in wood properties within each site. If there are no differences in selection criteria, there will be no differences between culled and retained trees in a given stand. Similarly, if variation in wood properties is negligible, differences between tree types will be small. In our study, superior seed production and good health were the criteria used in selecting seed trees. Shelter trees were chosen among stems with a high value increment, in such a way as to create a good spatial distribution. The criteria and methods used for selecting seed and shelter trees are similar to those used by the present owners, Assi Domän AB (cf. Anon., 1991) except that the number of shelter trees in our study (160–180) was lower than the number recommended by the present owners (200–400). The fact that seed trees were chosen before shelter trees may have influenced the outcome of the study, and may have reduced differences between these two tree types. It should be noted that, in practice, shelterwood management will not be the two-stage process used in the present investigation.

In our study, the selection criteria are reflected in differences in dimensions between seed trees, shelter trees and indifferent pines (Table 2). Trees with a small diameter were never used as seed trees and were rarely used as shelter trees. Large-diameter trees were chosen as seed or shelter trees unless they were growing too close to another main stem or were seriously affected by injuries. Thus indifferent pines have a lower mean diameter than shelter trees and seed trees. The differences between seed trees and shelter trees can be similarly explained. Differences in selection cannot be related to variation in age or seedling growth, since breast-height age was identical for the three types of tree.

Basic density decreased upwards in the bole (Fig. 2) and from bark to pith (Fig. 3). On both sites, seed trees had a lower basic density than indifferent pines for all density assessments made. Shelter trees tended to have an intermediate basic density. These findings agree closely with results from other Scots pine studies, as summarized by Hakkila (1979) and Ståhl & Ericson (1991), and for the genus *Pinus*, as summarized by Zobel & van Buijtenen (1989).

Although the decrease in annual radial increment observed when moving from juvenile to mature wood corresponded to an increase in basic density, it is doubtful whether radial growth and density development are interdependent. The period required for the gradual transformation from juvenile to mature wood seems to be predetermined (Zobel, 1981), the process being governed by hormone and carbohydrate levels (Menyialo, 1985). By contrast, the change in annual radial increment reflects the gradual increase in the crown, which is followed by increased competition after crown closure.

Generally, the annual changes in radial increment are not reflected by changes in basic density. For example, the variation in annual increment during the latest 50 years cannot be used to determine the annual variation in basic density during the same period (Fig. 3). That density and annual increment are well correlated among trees, but not within them (i.e. between annual rings), may seem contradictory at first. However, it should be noted that radial increment and density development both are related to annual weather conditions. Thus a comparison within one or more years would reveal a negative correlation between radial increment and basic density (cf. Persson, 1976) whereas in a comparison between different periods, this effect would be obscured.

There was a good correspondence between butt logs and main yields in terms of their proportional distributions among the different export grading classes (Fig. 5). Similar studies on other sites indicate that the export grading of logs often overestimates the percentage of U/S logs (Blomqvist & Orke, 1986). The discrepancy between the export grading of butt logs and of main yields for seed trees at Källsinken could not reasonably be explained by a single type of damage or injury. In general, the percentages of U/S logs and main yields were in the range of normal values for the region (Anon, 1993). Butt logs from the indifferent pines were assigned lower export grades than those from seed and shelter trees. This difference could in part be due to the smaller dimensions of the remaining pines. Seed trees and shelter trees did not differ markedly in terms of the export grade of their butt logs. The strength grading of the experimental material indicates that structural weakness is not a major problem for naturally regenerated Scots pine cut at the end of a full rotation in central Sweden (Fig. 6). The main differences between tree types can be related to differences in dimensions.

To allow different types of tree to be compared, logs were crosscut to standard lengths. This procedure also simplified sample handling. However, it was not possible to saw the timber according to optimal bucking of individual trees. To limit the effect of our use of standard lengths in the export grading of logs and main yields, assortment limits up to 0.5 m from log end were ignored. As a result, the number of U/S logs and U/S main yields was slightly overestimated, compared with standard length estimates. Nevertheless, the procedure closely mimics the trimming of sawn goods at a sawmill.

The value of whole sample trees (Fig. 5) was estimated by using the standardized follow-up of crosscutting (APTUPP). The differences in value between seed trees, shelter trees and indifferent pines can be explained largely by dissimilarities in their timber sections. Amounts of pulpwood varied little between tree types for the dimensions studied. The total amount of timber was higher for seed trees than for shelter trees or indifferent pines. Furthermore, the percentage of U/S or special timber was higher for seed trees and shelter trees than for indifferent pines. The results from the export grading of timber made when bucking closely resemble the export grading carried out for standard-length timber at the sawmill.

Alternative regeneration-felling methods

It is important to remember that in all alternative regeneration methods the removal of spruce is possible. This would increase the yield by 88 m^3 at Brändan and 42 m^3 at Källsinken. The classification into three types, i.e. seed trees, shelter trees and indifferent pines, was made to evaluate differences between them in stands suitable for regeneration. However, it is unlikely that seed trees or shelter trees would be selectively cut in these stands.

The alternative felling methods compared were clear felling and fellings leading to seed tree stands and shelter tree stands. There are large differences between them in terms of the total volumes harvested, the diameter distribution (Tables 2, 3), the percentage of high quality grades (Table 4) among the harvested stems, and the total revenue obtained (Table 5). Other considerations affecting the choice of regeneration methods, e.g. planned silvicultural treatments, labour intensity and future productivity, are not considered in the present context. To simplify, it was assumed that in a clear-felling all trees within a given area are harvested. This is a highly unlikely assumption, since present forestry regulations (Anon., 1994) restrict the number of trees removed at final felling. Nevertheless, the error introduced through this simplification should not have influenced the overall outcome of the analysis. The formation of a seed tree stand would require the removal of shelter trees, indifferent pines and all spruce. Our choice of seed trees would probably correspond well with the choice made in practice, since the selection criteria used by Assi Domän AB, the present owner of these sites, are similar to ours (Anon., 1991). The formation of a shelter tree stand would require the removal of the indifferent pines and Norway spruces. In this case, trees chosen for the shelter, as well as their spatial distribution, could differ from the choices made under practical conditions. In practice, seed and shelter trees would be selected simultaneously, whereas we made a stepwise selection. Although we do not know the degree to which these procedural deviations affected our results, they probably were of minor importance.

As indicated by Table 5, the choice of regeneration-felling method will influence both the revenue and the volumes harvested, which in turn contribute to determining the area harvested annually. If a change were made from conventional clear-felling to seed-tree or shelter-tree methods, an increase in the area logged would be required. On the other hand, a smaller area would have to be harvested once the removal and establishment of the shelter-tree stands was in balance. If the management change were made gradually, the effects of the reduction in timber harvest could be mitigated. There are two reasons for this: First, the volumes harvested when establishing a seed- or shelter-tree stand are smaller than those harvested when clear-felling and planting. Thus, for example, in our study the 100 m^3s.u.b. reduction in the pine timber harvest resulting from a change from clear-felling to shelter-tree management, would have to be compensated by an increase in the area felled. The second reason why an increase in the area logged would be required is that at least one more logging operation per rotation would be necessary, i.e. removal of the seed trees or shelter trees. Also, the quality of the timber produced could change. In our study there was a large difference in quality between the wood harvested in a final felling and that harvested in a shelterwood felling. For instance, the percentage of pulpwood increased while the percentage of U/S logs decreased. This, and a decrease in mean diameter (Table 3) will give a substantial reduction in value m^{-3}s.u.b.

The combined effects of the reduced timber harvest per unit area and reduced value m^{-3}s.u.b. should be taken into account in short-term management planning with seed-tree or shelter-tree stands as two of the options.

To make a sound decision, the productivity of the indifferent pines in a seed- or shelter-tree stand must be taken into account (cf. Tables 6, 7). In our study, two stands were used, in which a gradual decrease in stem density created conditions suitable for natural regeneration. Furthermore, the trees left on the two sites will respond well to the drastic reduction in basal area. On the basis of two independent studies (Persson, 1992; Eriksson, 1993), the reduction in basal area increment may be predicted at ca. 10% in a shelter-tree stand and nearly 25% in a seed-tree stand, compared with the original stand. This would increase the current annual radial increment from 1.55 mm to nearly 3 mm for seed trees. Thus, the selection of high-quality trees for use in seed-tree and shelter-tree stands, together with the expectation that they will grow vigorously for five to ten years, makes for an interesting management option. However, the potential advantages must be weighed against the postponed revenue,increased management costs and higher risks associated with natural regeneration.

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