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Growth and yield in shelter stands of silver birch and Norway spruce

Tillväxt och produktion hos skärmbestånd med björk och gran

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Abstract

The growth and production in shelter stands of Norway spruce (*Picea abies* (L.) Karst.) and birches (*Betula pendula* Roth and *Betula pubescens* Ehrh.) were studied at nine areas in southern and middle Sweden (Lat. 56 – 60° N.). The spruces and birches were 25 (20 – 32) years old. Before the study was established, the stands evaluated were dense with planted spruces under self-generated birches. A birch shelter with 500 stems per hectare was created. The shelter was cut after ten years. In one stand per locality, 100 birches were left at harvesting time for further growth and development of timber quality.

The MAI 20 years after treatment for pure spruce stands was 4.71 and 4.38 m^3 ha^{-1} $year^{-1}$ for spruces growing in mixed stands. The MAI for shelter birches was 4.13 m^3 ha^{-1} $year^{-1}$ and then the MAI for spruces and birches in mixed stands was 8.1 m^3 ha^{-1} $year^{-1}$.

When the study was established the volume and biomass weight of the harvested birches was 107 m^3 ha^{-1} or 84 ton d.w. ha^{-1} when all birches was removed and 75 m^3 ha^{-1} or 44 ton d.w. ha^{-1} when a shelter of 500 birches ha^{-1} was left. The harvested wood could be used as biofuel. Timber could be harvested in stands where 50-100 birches ha^{-1} in the shelter are left. Among the remaining 100 birches per hectare in shelters examined 30 years after establishment of the study the standing volume ranged between 54 and 67 m^3 ha^{-1}.

Key words. Birch, MAI, mixed stands, Norway spruce, shelter, timber

CONTENT

Sammanfattning

Huvuddelen av skogsbestånden i de nordiska länderna är blandskogar som innehåller olika andelar av tall och gran med inslag av lövträd. De vanligast förekommande blandskogsformerna med lövträdsinblandning är gran och björk. Under perioden 1950 till 1975 var skogsbrukets inställning att lövträden som etablerats på hyggen som planterats med tall eller gran skulle röjas bort för att minska konkurrensen. Huvudsakligen användes motor-manuell röjning, men en betydande andel blev behandlade med herbicider.

Efter 1975 när behandling av lövträdsbestånd med herbicider på skogsmark förbjöds återstod motor-manuell röjning. Andelen oröjda ungskogsbestånd ökade efter förbudet och lövträdsstammarna blev grövre och därmed blev röjningen mer arbetskrävande och kostsam. Därför startades studier och praktiska försök med s.k. mekaniserad röjning. Metoden innebar att ett traktorburet röjningsdon som innehöll slagor vilka krossade stammarna och kunde grensla barrträdsplantorna utan att skada dem. Metoden fungerade praktiskt väl utan nämnvärda skador på tall- och granplantorna. Trots det var metoden inte tillräckligt effektiv och kostnadsbesparande utan används inte i dagsläget.

Under 1980-talet startades försök med nya skötselformer av ungbestånd av blandskogar med lövträdsinblandning. I första hand var det bestånd med björk och gran som studerades. Försök startades i Norge, Finland och Sverige. Studierna koncentrerades till 15–20-åriga bestånd där röjning inte hade utförts i tid. I en doktorsavhandling från 1988 (Tham, 1988) redovisades resultat från en studie av blandskogar av björk och gran där 1 500-2 000 björkar per hektar hade lämnats i en s.k. skärm. Studien visade att björkbeståndet hade ökat beståndets totala produktion med ca 100 m^3 per hektar jämfört med ett bestånd där björken hade röjts bort helt

Olika skötselmetoder (”Kronobergsmetoden”, ”Skärmmetoden”) av blandskog introducerades under senare delen av 1980-talet i Norge (Braathe, 1988), Finland (Mielikäinen, 1985) och Sverige. Metoderna utgår från en tidig röjning (10 årsåldern) av björken till en skärm innehållande 2 000-2 500 björkar per hektar. I skärmmetoden som praktiserades i Norge och Sverige finns flera steg utöver det ovan nämnda. I en senare röjning/gallring (15–20-årsåldern) minskas antalet björkar till 500-800 stammar per hektar. Björkbeståndet slutavverkas vid 35–40-års ålder. I den s.k. Kronobergsmetoden var det huvudsakliga syftet att använda björken som ett skydd mot frostskador på granen. Senare skulle björken avverkas. Metoden modifierades senare och är idag liktydig med skärmmetoden.

I dagens skogsbruk sköts huvuddelen av blandbestånd med en skärm av björk över granen på normala och bördiga marker. I vissa fall kan man rekommendera att 50-100 björkar per hektar

i skärmen lämnas kvar tills beståndet är ca 60 år med ett antal björkar med hög virkeskvalitet som kan skördas som fanérvirke.

I denna rapport redovisas resultat från en försöksserie som etablerades 1983-1984 med försök utlagda på lokaler i södra och mellersta Sverige (Tham, 1987). Försöksserien anlades på nio lokaler (Figur 1). Medelåldern var 25 år för både björk och gran (Tabell 1). Bestånden var täta (>10 000 stammar per hektar). I den här rapporten redovisas resultat från några av de ingående behandlingarna, i första hand de behandlingar som har praktisk betydelse och är principiellt viktiga för att bedöma metodens inverkan på framtida produktion i blandbestånd skötta med björkskärm över gran.

Följande behandlingar har analyserats:

- Kontroll (ogallrat bestånd)
- Gran utan björkinblandning
- Gran med en björkskärm bestående av 500 björkar per hektar

Parcellstorleken var 750 m^2 med en fem meter bred ”kappa” runt parcellen.

Vid anläggningen avverkades i medeltal 107 m^3 björk per hektar i de rena granparcellerna. I skärmparcellerna var gallringsuttaget 75 m^3 per hektar. Efter tio år (1993-1994) avverkades björkskärmen på alla lokaler. En parcell med björkskärm sparades på alla lokaler. I parcellen sparades 100 björkar per hektar. Anledningen var att få möjligheter att studera de kvarstående björkarnas tillväxt och kvalitetsutveckling under ytterligare 20 år. Försöken har mätts in vart femte år sedan starten och den senaste mätningen skedde efter 20 år (2003-2004).

Den avverkade björken kan antingen lämnas på marken eller skördas för bioenergiändamål. Björkens biomassa för den avverkade björken vid försökets start var 84 ton per hektar när all björk avverkades och 44 i parceller där 500 björkar sparades.

Vid den senaste revisionen 20 år efter försökets start var den totala produktionen i rena granbestånd 208 (117-289) och 198 (112-276) m^3 per hektar i skärmbestånd. Den totala produktionen av björk var 161 (66-245) m^3 per hektar. Den kvarstående björkskärmen med 100 björkar per hektar innehöll 38 (17-56) m^3 per hektar. Den årliga medeltillväxten var 4,71 och 4,38 m^3 per hektar och år för ”rena” granbestånd och gran i skärmbestånd. Den totala årliga medeltillväxten i skärmbestånden (gran + björk) var 8,1 m^3 ha^{-1} år^{-1}.

På tre lokaler studerades de kvarlämnade björkarnas dimensioner och kvalitetsutveckling studerades. Den visuella kvalitetsbedömningen baserades på timmerutbyte med en toppdiameter som var $\geq$ 18 cm i topp. Alla björkar hade hög timmerkvalitet. Timmerlängderna varierade mellan fyra och femton meter. Timmervolymerna varierade mellan 0,13 och 0,79 m^3 per träd. Den höga kvaliteten beror på beståndshistoriken med ett tätt bestånd vid starten och att man kunde välja 100 bland de 500 stammarna efter tio år. Under tioårsperioden danades björkarna av granbeståndet.

Introduction

On forest land, broadleaves are mostly established spontaneously after clear cutting or after natural catastrophes such as forest fire or windthrow. The spontaneous establishment of the broadleaf stand may take between 10 and 20 years to complete. Parts of the open area of a moist site are easily colonized by naturally seeded broadleaved species, such as birch and alder (*Alnus incana* Moench and *Alnus glutinosa* (L.) Gaertner) followed by Norway spruce (*Picea abies* (L.) Karst.). Birches grow throughout Sweden (Johansson, 1996). In Sweden, there are two species used commercially: silver (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.). Downy birch is widespread over Sweden while silver birch mainly grows in the middle and south of Sweden. Most of the birch resources grow in mixed stands (Johansson, 2003). The birch admixture is found in stands dominated by Scots pine (*Pinus* sylvestris L.) or Norway spruce. Birches are not suppressed as easily as other broadleaved pioneer species. Dominant birches in a mixed stand maintain their vitality during the rotation period, producing a better stem quality than birches growing in pure stands (Hynynen, 2010).

Nordic countries generally have cold springs and autumns. Norway spruces planted on moist sites might be damaged by frost and unsuitable growing conditions. In these areas, broadleaved species grow well but the growth and survival of softwoods is low. When a dense stand of broadleaves is established, the growing conditions for Norway spruces improve. The site becomes drier and the risk of frost damage decreases (Odin et al., 1984; Lundmark and Hällgren, 1987; Langvall and Ottosson Löfvenius, 2002). In young to middle-aged stands, the birch stems are taller and thicker than the spruces. Later on the spruce stems grow taller and compete with the birches. Depending on the stem density, strong competition can decrease the growth and survival of some of the birches. Without management, some of the birches do not survive and the stand becomes an almost pure spruce stand.

From the 1950s, when the management of forest stands focused on clear felling of mature stands in Nordic countries, problems with large numbers of naturally regenerated broadleaves arose. From 1950 to 1975, these areas were mostly cleaned using herbicides (Johansson, 1985; 1988). When the use of herbicides on forest land was forbidden, manual cleaning methods, such as cutting with brush saws, were the only feasible techniques. Later on, mechanized cleaning was introduced (Freij and Johansson, 1991). However, in the middle of the 1980s, the management of a mixture of hardwoods and softwoods started. Up to 25 years ago, the management of mixed stands has been based on stands which have never been cleaned Another way to make a mixed stand is to clean the broadleaved stand when the broadleaves have established and grown to 1.5 – 2 m in height. Then, an understory of planted and/or naturally regenerated Norway spruces is established. Mixed stands are currently managed using this method, which is routinely part of the management of young stands (Drössler, 2010).

There are several types of mixed stands recognized in forest management (Johansson and Lundh, 1991). There are two distinct methods for establishing a shelter stand:

1. The shelter forest can be established through a combination of planting and natural regeneration. Generally, one of the species is planted and the other species is established by natural seeding or vegetative regeneration by sprouts or suckers.
2. Sometimes, two species are planted together on farmland. This type of shelter stand is expensive and requires great effort and a good knowledge of species, planting techniques, risks from grazing, plant development etc. (Johansson, 2013).

Many different species mixtures are used in shelter stand management. Some of the most common mixtures are:

- Norway spruce/Scots pine
- Norway spruce/alder
- Norway spruce/aspen
- Norway spruce/birch
- Scots pine/birch
- Birch/alder
- Birch/aspen
- Norway spruce/beech
- Norway spruce/oak
- Mixtures of noble species

To manage shelter stands, the use of stratified mixtures composed of a shade-tolerant, late-succession species in the lower stratum and an early succession species in the upper stratum has been recommended (Assmann, 1970; Kelty, 1997). The most frequently used mixture is Norway spruce and silver birch. The natural relationship between mainly silver birch and Norway spruce makes it possible to combine those tree species in a shelter stand with the likelihood of producing a good ecological combination. At present, managed shelter stands of Norway spruce/birch can occasionally be seen on specific sites and at specific places. In some cases, sparse alder stands used for fuel wood will be colonized by Norway spruce. Managed shelter stands of Norway spruce and alder are currently not common in Sweden. Furthermore, an analysis on the economics of the management of shelter stands of birch and spruce showed that the method is profitable (Valkonen and Valstra, 2001).

At least two methods for managing mixed stands have been introduced in Nordic countries:

The shelter method

This method is common in Finland (Mielikäinen, 1985), Norway (Braathe, 1988; Frivold and Groven, 1994) and Sweden (Johansson, 2003; 2013). It was introduced in Sweden by Tham (1988) with some modifications being developed (Johansson and Lundh, 1991). The same technique has been used for the management of birch and Norway spruce in Finland and Norway. There are many starting points with unmanaged stands of birch and Norway spruce, but the principal aim is to create an initial mixed stand with an optimal density of birch. The shelter method involves two or three steps:

1. When the spruce are 1.5 – 2 m high, the density of birch is reduced by cleaning to 600 – 800 stems ha^{-1}.
2. The “birch shelter” is clear felled when the birch is 30 – 35 years old and the breast height diameter is about 160 mm.
3. With the present increased interest in biodiversity on forest land and the possibility of increasing the proportion of high-quality timber, a “third step” is included in which 50 – 100 stems ha^{-1} are left after the second step (Johansson and Lundh, 2006).

The modified third step is interesting for two reasons. First, the stand will not create as much shade as when only spruce is left. Second, the remaining birch stems will produce high quality timber.

The Kronoberg method

This method was introduced in southern Sweden, primarily in order to avoid frost damage to Norway spruce plants and to minimize the number of sprouts established after a complete removal of the birch stand in one step (Johansson, 1983). The method is divided into three steps as described below:

If the density of birch is very high and there is a risk of decreased growth of the spruce, birch trees growing close to the spruce plants must be cut before the first step.

1. The birch stand is cleaned when the birches are 3 – 4 m high. After cleaning, the remaining birch stand consists of 3000 – 4000 stems ha^{-1}. The Norway spruce stand is not cleaned.
2. When the birches are 6 – 9 m tall, the stand is cleaned again. After cleaning, the density of birch should be 1000 – 1500 stems ha^{-1}. The diameter at breast height is about 50 mm.
3. The birch shelter is felled 5 years later. The birches are now 20 – 25 years old, 8 – 12 m tall and have a diameter at breast height of 80 mm. The mean height of Norway spruce is 3 – 4 m. The spruce stand should be thinned (leaving 2000 – 2500 stems ha^{-1}).
4. Alternatively, instead of clear felling the birch stand at this stage, 600 – 800 birch may be left for 10 – 15 years. When the birch is then clear felled, the mean diameter at breast height will be around 165 mm.

When managing this type of stand, it is important that the birch stands are not too dense when the spruce is established. According to Braathe (1988), the spruces experience too much competition if the birch density is more than 1200 stems ha^{-1} and the birch is taller than 3 m. In that case, he estimated a 30 % decrease in spruce height increment.

In 1988, a report was published dealing with the production of birch in a shelter stand of birch and Norway spruce (Tham, 1988). The main result showed an increase in the yield production by about 100 m^3 wood of birch. These figures were based on older experiments with mixed birch and Norway spruce where the birch density was reduced to between 1 500 and 2 000 stems ha^{-1}. The above mentioned results were published at a time when costs for cleaning and other silvicultural actions increased rapidly. Furthermore, the cheaper method to reduce the number of broadleaves, using a chemical treatment, was forbidden in Sweden in 1983. Thus, a realistic method to reduce the number of broadleaves had to be used. The main interest at first was in methods of reducing the cleaning costs in conifer stands. However, it soon became obvious that the efficient management of mixed stands could increase profits for the owner as well as wood quality in the stand. Since then, shelter stands of birch and Norway spruce have been established on many sites in Sweden. The management of these stands has focused on a robust reduction in the number of hardwood stems.

Objectives

The main objective was to estimate volume and biomass production in experimental plots with managed shelter stands of birch and Norway spruce, then compares the growth of spruces in pure and shelter stands. Production was measured in terms of volume and biomass. A second aim was to estimate the timber volume of the remaining 100 birch stems ha^{-1} on some of the shelter plots.

Material and methods

Study site

This study is based on an experiment started in 1983 – 84 (Tham, 1987). Trials were established at nine sites in central and southern Sweden, Figure 1. During the period 1983 – 1985, all types of treatments were carried out. The mean age of the spruce stands was 25 ± 3 (20 – 32) years and 25 ± 4 (21 – 32) years for birch stands at the start of the experiment. The stands were dense, even-aged, self-regenerated birches sheltering young Norway spruce on moist or mesic sites of high site quality class, Table 1.

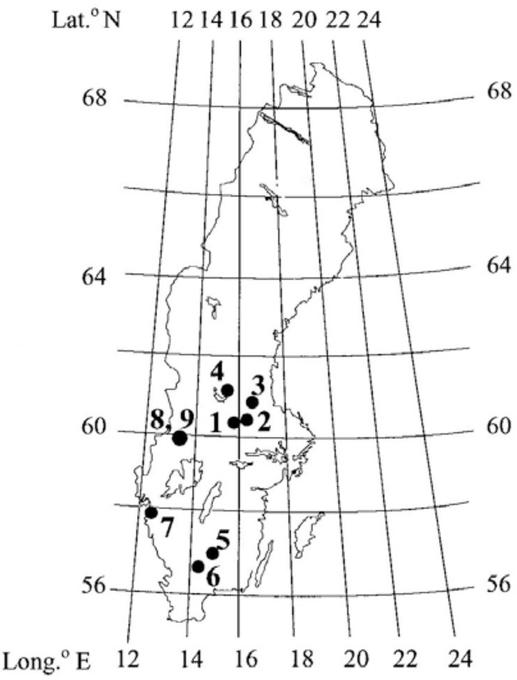

Figure 1. Location of the nine shelter stands

Table 1. Main stand characteristics of the shelter stands

Area no.	Lat. N.	Long. E.	Alt., m	Age, years, spruce, birch	Site index (spruce)[1)], H_{100} m	Site conditions[1)]
1	60° 23’	15° 52’	160	25, 23	25 – 27	Fresh dwarf-shrub type (Low herbs)
2	60° 31’	16° 14’	185	36, 32	28	Fresh dwarf-shrub type (Low herbs)
3	60° 28’	16° 05’	150	20	31	Fresh dwarf-shrub type (Tall herbs)
4	60° 59’	15° 38’	335	20, 24	25 – 27	Fresh dwarf-shrub type (Tall herbs)
5	56° 49’	14° 41’	170	27, 29	30 – 35	Fresh dwarf-shrub type (Low herbs)
6	56° 38’	14° 15’	150	27, 21	31 – 34	Moist without a field layer
7	57° 54’	12° 15’	110	24, 27	23 – 31	Fresh dwarf-shrub type (Low herbs)
8	60° 03’	13° 23’	170	29, 26	30 – 31	Fresh dwarf-shrub type (Low herbs)
9	60° 03’	13° 23’	170	22, 22	28 – 30	Moist peat land

1. Hägglund and Lundmark (1977)

Characteristics of study stands

The experiment included:

- Control (no thinnings).
- Pure spruce stands (total removal of birches at the start of the study).
- Shelter stands (the birch overstory was thinned to create a shelter of 500 stems ha^{-1}).

Each plot had an area of 750 m^2 with a buffer strip of 5 m. Site conditions and site index estimations were based on site factors as described by Hägglund and Lundmark (1977). The index refers to the expected dominant height at 100 years of age for Norway spruce as there are no site index curves that have been formally validated for mixed stands in Nordic countries.

When starting the experiment, most of the chosen stands were too densely populated (>10000 stems ha^{-1}) but most of the planted spruces were still alive. Self-thinning caused by strong competition from birch, amounted to 15 % by total stem number. Before the initial treatment, the number of stems per hectare was recorded, Table 2. Diameter at breast height (DBH), mm, for spruces and birches taller than 1.3 m was also recorded. The difference (range of distribution (R)) between the highest and lowest value of basal area within an area should not exceed a value calculated by the formula: R = k x g, where g = mean of basal area (m^2 ha^{-1}) and k = constant (0.113 – 0.326 depending on the number of parcels in the area). Parcels representing control were not included in the restriction of basal area. After the initial thinning of the stands, the mean number of spruce stems per hectare in pure stands was 4608 ± 2772 (880 – 12280) and 4924 ± 2075 (1667 – 12040) in shelter stands; there were 500 ± 8 (493 – 507) birches per hectare, Table 2.

All birches in no shelter stands were cut with a mean volume of 107 (64 – 161) m^3 ha^{-1} and a DBH of 56 (31 – 96) mm. In shelter stands, most of the birches were cut, with a mean volume of 75 (5 – 140) m^3 ha^{-1} and a DBH of 52 (34 – 80) mm, making up 91 % of stand production.

Estimation of growth in pure and shelter stands

The experiment has been revised once every five years over twenty years. The last revision was made in 2003 and 2004. The number of spruces was reduced by thinning operations when the experiment was revised. The birch shelter was cut ten years after the start of the experiment (1993-1994).

The slenderness of stems (h/d) was measured. The h/d ratio (height, m/DBH, cm), also called slenderness index (100xh/d), is an indicator of the level of competition (Assmann, 1970; Lanner, 1985).

When the shelter was cut, 1993-1994, 100 birches per hectare were left on one parcel of each of the localities. The main reason for that was to study the quality of the birch stems.

Volume estimations of spruce and birch were made using equations presented by Näslund (1947):

<u>spruce</u>

$$V= 0.1050 \times D^2 + 0.01968 \times D^2 \times H + 0.01478 \times D \times H^2 - 0.04585 \times H^2 - 0.006168 \times D^2 \times C \qquad (1)$$

<u>birch</u>

$$V= 0.09595 \times D^2 + 0.02375 \times D^2 \times H + 0.01221 \times D \times H^2 - 0.03636 \times H^2 - 0.004605 \times D \qquad (2)$$

where:

V = Stem volume, m^3

D = Diameter at breast height (on bark), cm

H = Stem height, m

C = Crown height (Distance between ground and the base of green crown), m

Table 2. Stand characteristics before and after treatment (1983 – 1984)

	No. of stems ha^{-1}	DBH, mm	No. of stems ha^{-1}	DBH, mm	Height, m	No. of stems ha^{-1}	DBH, mm	Volume, m^3 ha^{-1}
	Before treatment		After treatment			Removed		
				Control				
				Birch				
Mean	6262±5720	58±18	5089±4521	83±33	10.8±2.9	1380±1222	27±7	3±1
Range	2386-13000	39-75	2013-10280	45-107	7.8-13.6	373-2740	20-34	2-4
			Norway spruce					
Mean	7071±4988	59±18	5849±3090	50±6	8.4±0.4	1196±1933	15±8	0.4±0.6
Range	3520-12774	42-77	3493-9347	46-57	8.0-8.8	27-3427	10-24	0.1-1
				No shelter				
				Birch				
Mean	9784±5809	56±21				9784±5809	56±21	107±49
Range	2214±20827	31-96				2214-20827	31-96	41-199
				Norway spruce				
Mean	4921±3176	42±12	4608±2772	43±12	7.4±2.0	379±785	27±20	0.4±0.4
Range	920-12440	21-64	880-12280	21-63	4.6-12.8	0-2733	7-76	0.1-1.6
				Shelter				
				Birch				
Mean	6645±3149	58±14	500±8	107±24	12.5±2.8	6046±3367	52±13	75±34
Range	1587-13694	36-82	493-507	64-161	7.1-18.0	746-13187	35-80	5-140
				Norway spruce				
Mean	5427±3373	48±12	4924±2675	50±12	7.9±1.7	581±1066	27±16	1±1
Range	1747-12827	32-84	1667-12040	30-85	5.3-12.3	13-3280	4-64	0.1-3

During further examinations, estimations of volume were made using equations by Brandel (1990):

<u>Spruce</u>

$$V = 10^{-1.02039} \times D^{2.00128} \times (D+20.0)^{-0.47473} \times H^{2.87138} \times (H-1,3)^{-1.61803} \tag{3}$$

<u>Birch</u>

$$V = 10^{-0.89363} \times D^{2.23818} \times (D+20.0)^{-1.06930} \times H^{6.02015} \times (H - 1.3)^{-0.51472} \tag{4}$$

Where:

V = Stem volume, m^3

D = Diameter at breast height (on bark), cm

H = Stem height, m

The stand characteristics are shown in Table 3.

On three localities, an examination of the birch shelter was made ten years after the examination 2003-2004. The purpose was to study the growth of the remaining 100 shelter trees per hectare. The stem volume for birch stems was calculated using equation (4). Later, a visual classification of the timber quality of the standing birch stems was made. Based on the result of the classification, an estimation of the amount of timber was made. The length and top diameter of logs were calculated using taper equations for birch (Blingsmo, 1985). Common rules for classification of timber quality and assortments were used. The demand for different qualities of sawtimber varies between sawmills. The standard length of sawlogs is 3 m and the top diameter must be ≥ 18 cm. Different quality classes are allocated, depending on the number and size of knots together with the status of the knots. Saw products are used for manufacturing furniture or in carpentry shops. No detailed qualifications were made. The amount of timber was calculated on the part (length) of the stem, which fulfilled basic requirements for acceptance as timber.

Statistical analysis

Descriptive analysis, diagrams and t-tests were carried out using the SAS/STAT system for personal computers (SAS, 2006) and Microsoft Excel 2010. A significance level of $p \leq 0.05$ was used throughout the study.

Results

Stand characteristics 20 years after treatment

Mean DBH and height of Norway spruces and birches in control stands were higher for birches, 124 ± 76 mm and 16.1 ± 6.1 m than for spruces 70 ± 15 mm and 11.5 ± 2.5 m, Table 3. The differences between DBH means for spruces growing in pure and shelter stands were small, being 132 ± 25 and 129 ± 26 mm, and between height, being 14.6 ± 2.2 and 15.1 ± 2.6 m respectively, Table 3. The slenderness index, h/d, was higher for spruces and birches in control parcels, 1.6±0.1 (1.5-1.7) and 1.7±1.0 (0.9-2.8) than in shelter and no shelter parcels.

The number of spruces per hectare in no shelter and shelter stands was 32.7 % and 33.7 % respectively by stem numbers before treatment, Tables 2 and 3. The h/d ratio was 1.11 ± 0.13 (0.91 – 1.35) for spruces growing in pure stands and 1.19 ± 0.26 (0.98 – 2.24) in shelter stands. There were no significant differences. The h/d ratio was lower 0.86 ± 0.06 (0.79 – 0.94) for the 100 shelter birches than for spruces.

Table 3. Stand characteristics 20 years after treatment (2003 – 2004)

	No. of stems ha^{-1}	DBH, mm	Height, m	h/d[1]	No. of stems ha^{-1}	DBH, mm	Height, m	h/d[1]
				Control				
	Norway spruce					*Birch*		
Mean	4049±572	70±15	11.3±2.5	1.6±0.1	2542±2181	124±76	16.1±**6.7**	1.7±1.0
Range	3667-4707	57-86	8.4-13.8	1.5-1.7	1013-5040	39-186	10.7-23.5	0.9-2.8
				No shelter				
	Norway spruce							
Mean	1610±475	132±25	14.6±2.2	1.1±1.0				
Range	973-2067	95-171	10.3-18.3	0,9-1.3				
				Shelter				
	Norway spruce					*Birch*		
Mean	1654±671	129±26	15.1±2.6	1.2±0.3	106±7	226±38	19.3±3.3	0.9±0.1
Range	827-280	85-179	10.2-20.2	1.0-2.2	93-120	160-263	14.7-23.6	0.8-0.9

1) Slenderness (h/d)

Total production of Norway spruces and birches, 20 years after establishment

Most of the thinning removal was derived from thinning that occurred when the stands were examined. The mean total production of spruces in pure and mixed stands was 207.9 ± 72.3 (117-289) and 197.8 ± 46.5 (112-276) m^3 ha^{-1} respectively. The difference between the treatments was not statistically significant. Figure 2 shows the variation in spruce yield between areas. Most of the birches had been cut when the stands were examined after 10 years (1993-1994). The mean total production of birch was 161.0 ± 51.5 (66 – 245) m^3 ha^{-1}. For shelter stands, the total production of Norway spruce and birch was 350 m^3 ha^{-1}.

The mean standing volume for pure spruce stands was 159.0 ± 33.3 (119-200) and 150.7 ± 26.4 (103-189) m^3 ha^{-1} for shelter spruce stands. The volume differs between localities and within stands, Figure 2.

The mean standing volume of birch shelter with 100 birches ha^{-1} was 38.1 ± 17.0 (17.4 – 56.4) m^3 ha^{-1} and the mean DBH 226 ± 38 (160 – 263) mm.

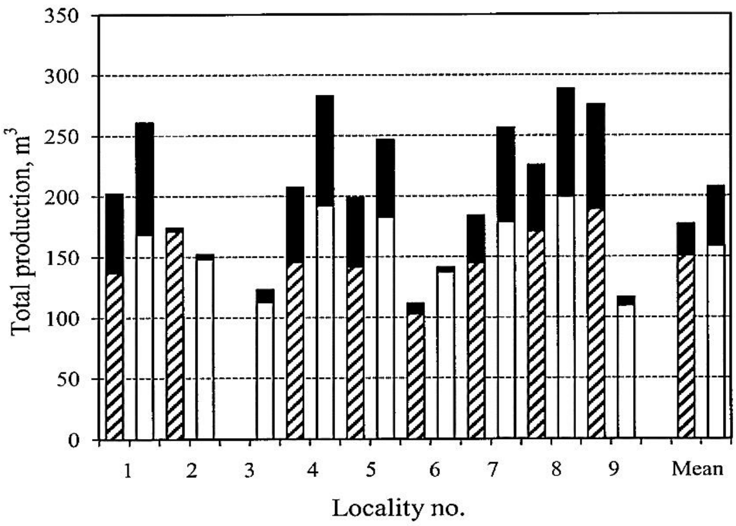

Figure 2. Total production, m^3 ha^{-1} of Norway spruce in 40-45-year-old mixed stands. Standing volumes in shelter stands ▨, no shelter stands □ and thinned removal ■. Revised 2003-2004.

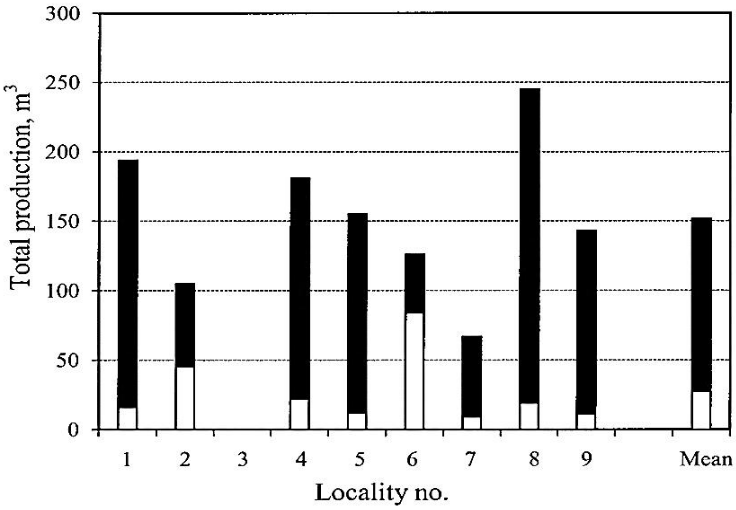

Figure 3. Total production, m^3 ha^{-1} of birch in 40-45-year-old mixed stands. Standing volume □ and thinned removal ■. Revised 2003-2004.

Mean annual increment for spruces and birches

The mean annual increments for pure and shelter spruce stands were 4.71 ± 1.66 (2.72 – 7.07) and 4.38 ± 1.35 (2.18 – 6.72) m^3 ha^{-1} $year^{-1}$, Figure 4. The difference between means was not statistically significant. The mean annual increment for birches ranged between 1.51 and 6.13 m^3 ha^{-1} $year^{-1}$ with a mean of 4.13 ± 1.50, Figure 5. The mean annual increment for shelter stands was 8.5 (4.4 for spruces and 4.1 for birches) m^3 ha^{-1} $years^{-1}$.

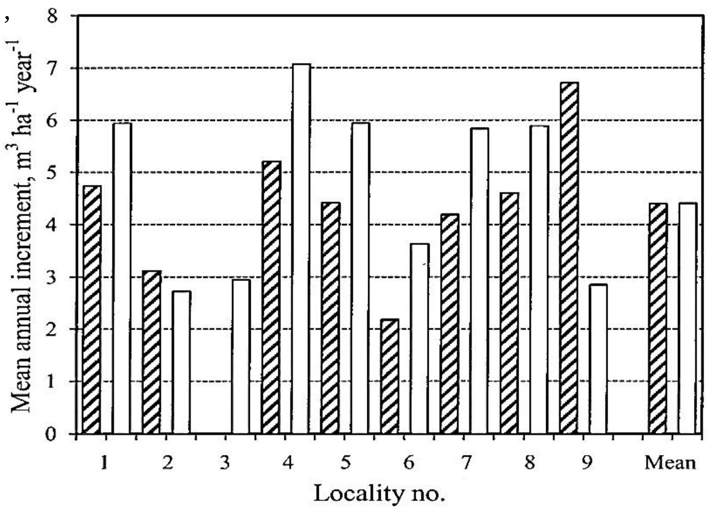

Figure 4. Mean annual increment, m^3 ha^{-1} $year^{-1}$ of Norway spruce in shelter stands no shelter stands

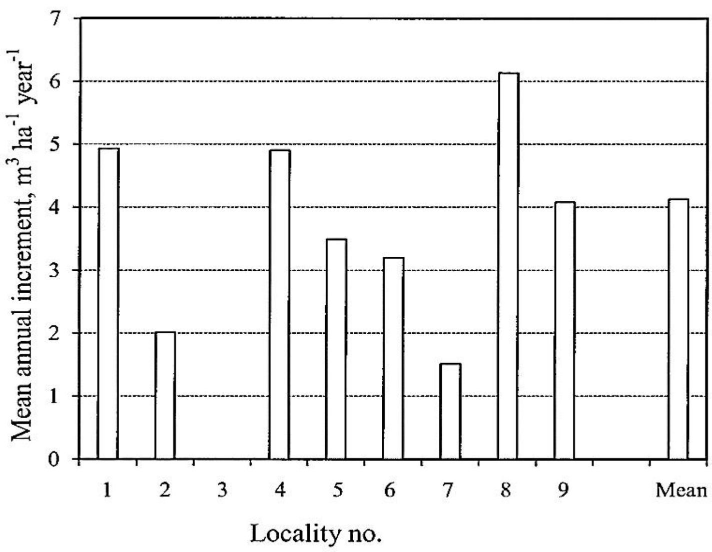

Figure 5. Mean annual increment, m^3 ha^{-1} $year^{-1}$ of birch in shelter stands

Timber quality of shelter birch stems 30 years after treatment

The mean DBHs for birch shelters in localities 1, 2 and 4 were 313 ± 25 (285 – 350), 274 ± 35 (228 –323) and 279 ± 95 (207 – 293) mm respectively. The mean stem volumes were 0.633 ± 0.123 (0.468 – 0.793), 0.543 ± 0.156 (0.371 – 0.821) and 0.501 ± 0.172 (0.231 – 0.841) m^3, Table 4. The standing volumes were 67.1 (locality no. 1), 57.6 (locality no. 2) and 53.6

(locality no. 4) m^3 ha^{-1}. Based on the visual classification of shelter birches in three localities, all of the stems seemed to fulfill the quality requirements for sawtimber. With a minimum top diameter of logs (18 cm), the range of sawtimber lengths of the revised birch stems was: 9 to 14 meters (area no. 1), 4 to 15 meters (area no. 2) and 6 to 14 meters (area no. 4). The timber log volumes ranged between 0.468 and 0.793 m^3 $tree^{-1}$ (locality no. 1), 0.371 and 0.821 m^3 $tree^{-1}$ (locality no. 2) and 0.231 and 0.841 m^3 $tree^{-1}$ (locality no. 4). The mean slenderness figures (h/d) for birch stems in localities 1, 2 and 4 were 0.75 ± 0.04 (0.70 – 0.82); 0.90 ± 0.14 (0.65 – 1.05); 0.80 ± 0.07 (0.68 – 0.91) respectively, Table 4.

Table 4. Stand characteristics for a 30 year-old birch shelter stems in three areas

Stem no.	DBH, mm	Height, m	Volume, m^3	h/d	DBH, mm	Height, m	Volume, m^3	h/d	DBH, mm	Height, m	Volume, m^3	h/d
		Locality no 1				Locality no. 2				Locality no. 4		
1	350	24.5	0.793	0.70	244	25.2	0.461	1.03	207	17.9	0.231	0.86
2	302	23.5	0.597	0.78	253	24.2	0.465	0.96	240	21.8	0.375	0.91
3	288	20.5	0.468	0.71	323	27.8	0.821	0.86	361	24.7	0.841	0.68
4	343	24.4	0.765	0.71	286	18.6	0.413	0.65	278	23.4	0.520	0.84
5	306	23.2	0.600	0.76	255	26.8	0.536	1.05	275	22.2	0.479	0.81
6	285	21.2	0.480	0.74	317	25.8	0,725	0.81	293	21.9	0.522	0.75
7	301	24.7	0.632	0.82	288	23.4	0.550	0.81	286	21.5	0.491	0.75
8	328	25.0	0.735	0.76	228	23.2	0.371	1.02	293	22.8	0.548	0.78
Mean	313 ± 25	23 ± 2	0.633 ± 0.123	0.75±0.04	274 ± 35	27 ± 3	0.543 ± 0.156	0.90±0.14	279 ± 45	22 ± 2	0.501 ± 0.172	0.80±0.07

Discussion

Selection of stands and stand age

The aim was to find mixed stands of Norway spruce and birch distributed between southern and northern Sweden. There were no stands found in the eastern part of Sweden as mixed stands contained other species together with birch, such as oak (*Quercus robur* L.), alder (*Alnus* spp.), European aspen (*Populus tremula* L.) and sallow (*Salix caprea* L.) (Tham, 1987). As one criterion was that the stand should grow on rich sites (site index $H_{100} \geq 28$ m for spruce), no stands were found in northern Sweden. The evaluated stands were 20 – 30 years old and had not been managed. Before treatment, the number of trees per hectare was high, resulting in strong competition between individuals and species. Initially, this strong competition caused self-thinning of the birches. The growth rate may have been reduced initially. Ideal stand ages for creating a shelter stand are 10-15 years. At that age, the risk of frost damage to spruce seedlings is avoided.

Stand characteristics 20 years after treatment

When the experiment started, there was no damage to branches or leaders on remaining spruces after treatments of the stands (Tham, 1987). At each of the examinations, no studies were made of the stem characteristics of spruce and birch trees growing in pure and shelter stands. DBH for shelter spruces was lower, 129 mm, than for pure spruce stands, 132 mm. Height was not negatively affected by the shelter, being 15.1 m in shelters and 14.5 m in pure spruce stands. According to Lanner (1985), the growth of a tree's diameter decreases with increasing number of stems while height is not affected. Trees are more slender when there is competition. Spruces growing under a shelter were affected by competition, with lower MAIs than in pure stands. Spruces growing in shelter stands had a lower MAI, being 4.4 with a range of 2.2 to 6.7, than spruces growing in pure stands, with an MAI of 4.7 (2.7 – 7.1). The MAI for spruces in shelter stands was 93.6 % by pure spruce stands. However, the MAI for the shelter stands (birch + spruces) was 8.1 m^3 ha^{-1} $year^{-1}$ higher, than that of pure spruce stands. An indication of competition is given by the h/d ratio (height, m/DBH, mm), where a low ratio, ≤ 1, indicates little competition (Assmann, 1970; Lanner, 1985). A high h/d ratio might increase the risk of snow breakage of the spruces. In the present study, the h/d for pure spruces was 1.1 and 1.2 for spruces in shelter stands. In a study of six 20 – 33 year old mixed stands of spruce and birch growing in southern Sweden, the MAI for pure spruce stands (1.5 – 5.1) was, as a mean, 36 % greater than for spruces growing in shelter stands (0.4 to 4.5) and the MAI for shelter stands (2.3 – 7.8) was 24 % greater than for pure spruce stands (Klang and Ekö, 1999). The relative branch diameter (m^{-1} per stem) was not significantly affected by densities of 180, 290, 390, 890, 2200 and 3220 birches ha^{-1} in the shelter (Klang and Ekö, 1999). Neither were there significant differences in the h/d ratio between pure spruce stands and spruces growing in shelter stands. In a study of a mixed stand of Norway spruces and birches growing in northern Sweden 19 years after establishment the MAI was lower, being 1.87 and 1.78 m^3 ha^{-1} $year^{-1}$ for spruces growing under a shelter with 300 and 600 birches ha^{-1}, than in pure stands at 2.43 m^3 ha^{-1} $year^{-1}$ (Bergqvist, 1999). The DBH was significantly larger for pure spruces than for sheltered spruces. Small differences in height growth were found but sheltered spruces grew faster than spruces in pure stands. Bergqvist (1999) reported lower h/d for pure spruces (0.83) than for spruces under the shelter (0.98 and 0.90, respectively) for densities of 600 and 300 birches ha^{-1}.

In the present study, the birch shelter was cut 10 – 13 years after the experiment was started. It is possible that if the rotation period had been extended by at least five years, resulting in greater production. However the stands grew quickly (4.1 (1.5 – 6.1) m^3 ha^{-1} $year^{-1}$) considering the strong competition that existed before the experiment started. The h/d ratio for birches was 0.96 ± 0.11 (0.81 – 1.18). In a study by Klang and Ekö (1999), the MAI was 3.0 (1.5 – 5.3) m^3 ha^{-1} $year^{-1}$ and in a study in northern Sweden, MAI was 3.26 and 1.88 m^3 ha^{-1} $year^{-1}$ for densities of 600 and 300 birches ha^{-1} (Bergqvist, 1999). MAI for planted silver birches growing on farmland in Finland was 6.0 – 9.3 m^3 ha^{-1} $year^{-1}$ (Oikarinen, 1983). These birch seedlings were genetically improved and therefore grew faster than the naturally regenerated birches in the present study.

The utilization of harvested birches

The volume of the harvested birches at the establishment of the study was 107 m^3 ha^{-1} in pure spruce stands and 75 m^3 ha^{-1} in shelter stands. The birches harvested can be used as biofuel. In the present study, the biomass quantity of the harvests at the start of the experiment was estimated to be 84 ton d.w. ha^{-1} in no shelter stands and 44 ton d.w. ha^{-1} in shelter stands, using an equation reported by Johansson (1999). However, logging of the birches in a young stand must be done carefully without damaging the remaining stems and their roots. When removing the harvest, valuable nutrients are lost in the stand. As management of mixed stands should be carried out on rich sites, this reduction of nutrients may be acceptable.

Timber quality of birch shelter stems

The evaluation of birch stems for the sheltered stand resulted in a good establishment and growth of the birches. The timber quality for the remaining 100 birches per hectare of the primary birch shelter might be acceptable as timber. The birches have grown in dense stands together with spruces and the birch stems were naturally pruned. At the start of the experiment, the percentage length between ground and the base of living crown and birch tree height was 41 % (Tham, 1987). In the shelter stands, the birch stems were free of living branches on 5.1 m (41 %) of the stem height (mean stem height = 12.5 m). In the study, 9 to 10 years later, at three areas, the percentage of stems without living branches ranged between 50 % and 65 %. A general recommendation when managing birches is that the percentage stem with green crown should be at least 50 %. However, a visual inspection of standing birch stems is only an indicator of quality. The stems must be felled and a careful check, based on the criteria for different timber classes, carried out. The average number of birch trees without defects was higher in shelter stands (50 %) than in no shelter stands (37 %) in a study on six mixed stands in southern Sweden (Klang and Ekö, 1999). The h/d ratio at the three studied localities was low: 0.75, 0.90 and 0.80 for 100 birches ha^{-1} remaining in the shelter. A high ratio indicates a better use of the stem for timber with an increased recovery by sawmill compared to stems with a lower h/d.

Conclusions

When managing mixed stands for creating a birch shelter stand above Norway spruces, it is important to clean the birch stand early (10 years old) to about 2000 stems ha^{-1} and then thin the stand to 500 birches ha^{-1} five to ten years later. Shelter stands should be established on rich soils for fast growth. Sheltered stands of Norway spruce and birch produce more than pure stands of spruces. The MAI for spruces in sheltered stands is lower than in pure stands. The mean diameter of sheltered spruces is lower than for pure spruces. Height was not affected by the shelter. If 100 birches ha^{-1} are left for 10 – 20 years, then when the 35 – 40 year old shelter is cut, some of the birches will produce timber of high quality.

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References

Assmann E. 1970. The principles of forest yield study. Oxford. Pergamon Press.

Bergqvist, G. 1999. Wood volume yield and stand structure in Norway spruce understory depending on birch shelterwood density. Forest Ecology and Management 122, 221-229.

Blingsmo, K. R. 1985. Avsmalningsfunksjoner og -tabeller for bjørk. Summary: Taper functions and tables for birch. Norwegian Forest Institute. Research paper 10, 35 pp.

Braathe, P. 1988. Utviklingen av gjenvekst med ulike blandingsforhold mellom bartrær og løvtrær – II. Summary: Development of regeneration with different mixtures of conifers and broadleaves – II. Norwegian Forest Institute. Research paper 8, 50 pp.

Brandel, G. (1990). Volume functions for individual trees, Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula pendula* and *Betula pubescens*). Department of Forest Yield Research. Report 26, 72 pp. Garpenberg. Swedish University of Agricultural Sciences.

Drössler, L. 2010. Tree mixtures - a common feature of southern Sweden. Forestry 83(4), 433-441.

Frej, J. and Johansson, T. 1991. Kombinationsröjning. (Combined cleaning operations) Skogsarbeten. Resultat nr 14, 4 pp. In Swedish.

Frivold, L. H. 1982a. Bestandsstruktur og produksjon i blandingsskog av bjørk (*Betula verrucosa* Roth, *B. pubescens* Ehrh.) og gran (*Picea abies* (L.) Karst.) i Syd-øst-Norge. Summary: Stand structure and yield of mixed stands of birch (*Betula verrucosa* Roth, *B. pubescens* Ehrh.) and spruce (*Picea abies* (L.) Karst.) in South East Norway. Meldinger fra Norges Landbrukshøgskole 61 (18), 1-108.

Frivold, L. H. 1982b. Blandingsskogens status i europeisk skogbruk. Summary: Status of mixed forest in European forestry. Tidskrift for Skogbruk 90, 250-261.

Frivold, L. H. 1986. Seed regeneration of birch and spruce in clear cut areas in east Norwegian lowlands, in relation to vegetation types and moisture. Norwegian Forest Research Institute. Report 39 (4), 67-84.

Frivold, L. H. and Groven, R. 1996. Yield and management of mixed stands of spruce, birch and aspen. Norwegian Journal of Agricultural Sciences. Supplement no. 24, 17-24, 17-24.

Frivold, L. H. and Frank, J. 2002. Growth of mixed birch – coniferous stands in relation to pure coniferous stands at similar sites in south-eastern Norway. Scandinavian Journal of Forest Research 17, 139-149.

Frivold, L. H. and Kolström, T. 1999. Yield and treatment of mixed sands of boreal tree species in Fennoscandia. In: Olsthoorn, A. F. M., Bartelink, H. H., Gardiner, J. J., Prezsch, H., Hekhuis, H. J. and Franc, A. (Eds.). Management of Mixed-species Forest: Silviculture and Economics, 37-45.

Hynynen, J., Niemistö, P., Viherä-Aarnio, A., Brunner, A., Hein, S. and Velling, P. 2010. Silviculture of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) in Northern Europe. Forestry 83 (1), 103-119.

Hägglund, B. and Lundmark, J. E., 1977. Site index estimations by means of site properties. Studia Forestalia Suecica 138, 38 pp.

Johansson, A. 1983. Skärmmetoden – en biologisk och säker metod till rimliga kostnader. (The shelter method – a biological and safe method in proportion to costs). Skogen 4, 14-16. In Swedish.

Johansson, K. 1992. Effects of initial spacing on the stem and branch properties and graded quality of *Picea abies* (L.) Karst. Scandinavian Journal of Forest Research 7, 503-514.

Johansson, K. 1993. Influence of initial spacing and tree class on the basic density of *Picea abies* (L.) Karst. Scandinavian Journal of Forest Research 8, 18-27.

Johansson, T. 1996. Management of birch forest In: J. Dietrichson (Ed) Silviculture for fuelwood. Proceedings from IEA Bioenergy Task XII Activity on Forest Management, Asker, Norway, September 4-6, 1995. Norwegian Journal of Agricultural Sciences, Supplement No 24, 7-20.

Johansson, T. 1988. Preventing stump regrowth with a herbicide-applying tree cutter. Weed Research 28, 353-358.

Johansson, T. 1996. Management of birch forest. In: Dietrichson, J. (Ed.) Silviculture for fuelwood. Proceedings from IEA. Bioenergy. Task XII. Activity on forest management. Asker. Norway. September 4-6 1995. Norwegian Journal of Agricultural Sciences. Supplement No. 24, 7-20.

Johansson, T. 1999. Biomass equations for determining fractions of pendula and pubescent birches growing on abandoned farmland and some practical implications. Biomass and Bioenergy 16, 223-238.

Johansson, T. 2000. Regenerating Norway spruce under the shelter of birch on good sites might increase the biofuel supply in Sweden. New Zealand Journal of Forestry Science 30 (1/2), 16-28.

Johansson, T. 2001. Björkskärm över gran. Summary: Birch shelter and Norway spruce. Swedish University of Agricultural Sciences. Department of forest management and products. Report 16, 29 pp.

Johansson, T. 2003. Mixed stands in Nordic countries – a challenge for the future. Biomass and Bioenergy 24, 365-372.

Johansson, T. 2013. Establishment and production of mixed stands planted on farmland. Swedish University of Agricultural Sciences. Department of Energy and Technology. Report 66, 27 pp.

Johansson T. and Lundh J-E. 1991. Anläggning av blandskog. (Cultivation of management of mixed forests). Skog och Forskning 2,11–8. Swedish.

Johansson, T. and Lundh, J-E., 2006. Al, asp och björk i blandskog. (Alder, aspen and birch growing in conifer forest). Swedish University of Agricultural Sciences. Department of Bioenergy. Report 12, 131 pp.

Kelty, M. J. 1992. Comparative productivity of monocultures and mixed stands. In: Kelty, M. J., Larson, B. C. and Oliver C. D. (Eds.). The Ecology and Silviculture of Mixed-species Forests, 125-141. Kluwer Academic. Dodrecht.

Klang, F. and Ekö, P. M. 1999. Tree properties and yield of *Picea abies* planted in shelterwoods. Scandinavian Journal of Forest Research 14, 262-269.

Kliger, I. R., Perstorper, M., Johansson, G. and Pellicane, P J. 1995. Quality of timber products from Norway spruce. Part 3. Influence of spatial position and growth characteristics on bending stiffness and strength. Wood Science and Technology 29, 397-410.

Langvall, O. and Ottosson Löfvenius, M. 2002. Effect of shelterwood density on nocturnal near-ground temperature, frost injury risk and budburst date of Norway spruce. Forest Ecology and Management 168, 149-161.

Lundmark, T. and Hällgren, J.-E. Hällgren, 1987. Effect on frost on shaded and exposed spruce and pine seedlings in the field. Canadian Journal of Forest Research 17, 1197-1201.

Mielikäinen, K. 1985. Effect on an admixture of birch on the structure and development of Norway spruce stands. Communicationes Instituti Forestalis Fenniæ 133, 1-79. In Finnish with English summary.

Mård, H. 1996. The influence of a birch shelter (*Betula* spp.) on the growth of young stands of *Picea abies*. Scandinavian Journal of Forest Research 11, 343-350.

Nichols, J. D., Bristow, M. and Vanclay, J. V. 2006. Mixed-species plantations: Prospects and challenges. Forest Ecology and Management 233, 383-390.

Näslund, M. 1947. Funktioner och tabeller för kubering av stående träd. Tall, gran och björk i södra Sverige samt i hela landet. Summary: Functions and tables for computing the cubic volume of standing trees. Pine, spruce and birch in southern Sweden, and in the whole of Sweden. Meddelanden från statens skogsforskningsinstitut 36 (3), 81 pp. Stockholm.

Odin, H., Magnusson, B. and Bäckström, P.-O., 1984. Effects of low shelterwood on minimum temperature near the ground. In: Pertu, K. (Ed.), Ecology and Management of Forest Biomass Production Systems. Swedish University of Agricultural Sciences. Department of Ecology and Environmental Research. Report 5, 77-99.

Oikarinen, M. 1983. Growth and yield models for silver birch (*Betula pendula*) plantations in southern Finland. Communicationes Instituti Forestalia Fennica 143, 1-75.

Olesen, P. O. 1976. The interrelation between basic density and ring width of Norway spruce. Det Forstlige Forsøgsvesen i Danmark 34, 340-359.

SAS, 2006. Version 9.1. SAS Institute Inc. Cary. NC. USA.

Tham, Å. 1987. Gran och björk i blandning. Summary: Mixed spruce and birch. Swedish University of Agricultural Sciences. Department of Forest Yield Research 20, 79 pp.

Tham, Å. 1988. Yield prediction after heavy thinnings of birch in mixed stands of Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula verrucosa* Roth and *B. pubescens* Ehrh.). Swedish University of Agricultural Sciences. Department of Yield Research. Report 23, 1-36.

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

Tham, Å. 1994. Crop plans and yield predictions for Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) mixtures. Studia Forestalia Suecica 195, 21 pp.

Vadla, K. 1992. Quality of wood with selection cutting and shelterwood cutting – a literature survey. Skogforsk. Research Paper 10, 21 pp.

Valkonen, S. and Valstra, L. 2001. Productivity and economic of mixed two-storied spruce and birch stands in Southern Finland simulated with empirical models. Forest Ecology and Management 140, 133-149.

Örlander, G. 1993. Shading reduces both visible and invisible frost damage to Norway spruce seedlings in the field. Forestry 66, 27-36.

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