REGENERATING NORWAY SPRUCE UNDER THE SHELTER OF BIRCH ON GOOD SITES MIGHT INCREASE THE BIOFUEL SUPPLY IN SWEDEN*

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ABSTRACT

In conventional forest management the fast-growing hardwoods such as birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) are cleaned when they start to compete with the conifers. In general, the naturally regenerated birch trees of minimal energy value are removed when they are 2–4 m high and start to suppress the understorey of Norway spruce (*Picea abies* (L.) Karst.). Today with increasing interest in utilising biomass for fuel, mixed forest with a shade-tolerant main species and a fast-growing species combined could be an important supply of biofuel and also an important ecological site for maintaining biodiversity.

An experiment was established 1983–85 on eight localities in central and southern parts of Sweden (lat. 58°–61° N). The stands were 20–30 years old when the experiment was started and consisted of dense, even-aged, self-propagated birch sheltering young Norway spruce either planted or self-propagated. All stands were growing on moist or mesic sites with high site indices. Thinning regimes included (1) thinning of the birch overstorey to create a shelter of 500 stems/ha (shelter) and (2) total removal of the birch overstorey (no-shelter). The treatments were replicated at each locality. The shelter was to be cut when the stand was 35–40 years old.

When the experiments started the mean diameter of trees on all plots was 60 mm for birch and 45–49 mm for Norway spruce. The amount of birch biomass removed at first treatment was 40.6 ± 3 (range 13.7–64.5) tonnes dry weight (dw)/ha for shelter plots and 70.0 ± 6 (range 34.9–142.7) tonnes dw/ha for no-shelter plots. In 1997 when all birch trees on shelter plots were cut, the amount of birch biomass removed was 45.3 ± 5 (range 13.6–109.3) tonnes dw/ha. Total amount of birch biomass during the period was 85.9 ± 7 (range 40.9–145.3) tonnes dw/ha for shelter plots and 72.7 ± 7 (range 34.9–142.7) tonnes dw/ha for no-shelter plots. The remaining Norway spruce stands have produced 32.9 (10.9–48.6) tonnes dw/ha growing under a birch shelter compared with 37.9 (5.0–63.4) tonnes dw/ha for pure spruce stands.

Keywords: biofuel; mixed forest; pre-commercial thinning; *Betula pendula*; *Betula pubescens*; *Picea abies*.

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INTRODUCTION

Biofuels in Sweden

Total energy supply in Sweden 1997 was 477 TWh. The percentage bioenergy fuel was 19% (Fig. 1). The use of biofuel in Sweden 1997 (91 TWh) is presented in Fig. 2. Wood fuels and wood are used in sawmills, district heating plants, pulp and paper industry, and in dwelling houses. This supply covers 49% of total use of biofuels.

For centuries, broad-leaved tree species have been used for fuelwood production. Although modern fuel systems based on oil or electric power are dominant today, there has been an increase in the use of fuelwood over the last decade or so. About 50% (53%) of biofuel production is based on wood fuel (Fig. 3).

But intensively cultured *Salix* species grown on short-rotation basis, and slash utilisation, are also important. For production on a commercial basis, large areas are required. Today about 15 000 ha of abandoned farmland are cultivated in *Salix* species. These areas are located south of latitude 60°N.

Another potential fuelwood resource is the harvest of alder (*Alnus glutinosa* (L.) Gaertn. and *Alnus incana* (L.) Moench.), aspen (*Populus tremula* L.), or birch growing on abandoned

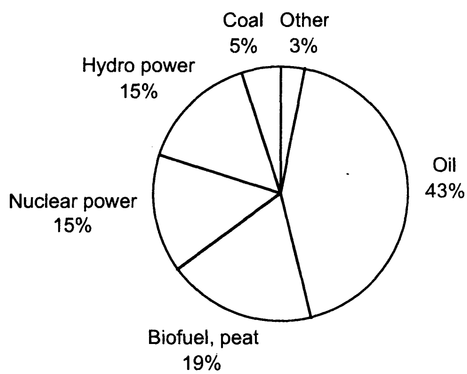

FIG. 1–Total energy use in Sweden in 1997 (Anon 1999)

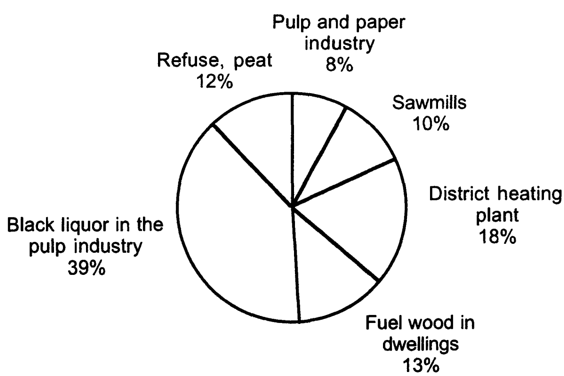

FIG. 2–Use of biofuel, peat, etc., for energy purposes in 1997 (Anon 1999)

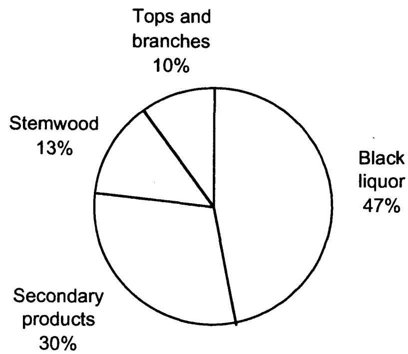

FIG. 3–Types of wood-based fuels in 1990 (Anon 1997)

farmland (Johansson 1992, 1998, 1999a,b,c, 2000). Ongoing research shows that annual production of 4–6 tonnes dw/ha or more is realistic. This concept is based on small-scale plots (0.5–1.0 ha). The farmer could supply his farm and some neighbours with energy for heating. Today we have no official figures of potential area for this type of fuelwood utilisation but a very rough figure indicates areas of 50 000–100 000 ha throughout Sweden. Mostly these areas are localised on poorer farmland sites and the specific areas utilised are small, 0.1–1.0 ha.

Nowadays we have a debate about nuclear fuel in Sweden and for how long we should continue to use it.One nuclear power station in southern Sweden closed in late 1999.

The Swedish Government proposes to invest 5–7 billion SEK for 3 years in a research programme including technical, economic, and biological factors important for starting, on a large scale, the commercial use of biomass for energy supply. The aim is to increase the percentage bioenergy supply when the supply of nuclear and oil fuels decreases successively during the first decades in 2000.

Mixed Stand Management

To manage mixtures of forest stands, the use of stratified mixtures composed of shade-tolerant, late-succession species in the lower stratum and early succession species in the upper stratum has been recommended (Assmann 1970; Kelty 1992). The natural relationship between birch and Norway spruce makes it possible to combine them in a mixed stand, and the ecological combination is good.

The Swedish definition of mixed stands including broad-leaved species (mixed coniferous-broad-leaved stand) is "type of stand where the total percentage broad-leaved species is 30–70% of the growing stock". In Table 1, forest statistics for Sweden are presented. The growing stock for different regions differs depending on actual sites and the species present.

The management and the potential of mixed coniferous-broad-leaved stands are presented here. More specifically, the mixed stands described consist of young Norway spruce with a shelter of birch. Generally, management of mixed stands including broad-leaved species demands intense and careful silviculture methods. Otherwise growth will decrease—especially in the understorey species, mostly Norway spruce, but also in the shelter species.

TABLE 1–Growing stock (million m^3) on forest land by tree species within regions during the period 1993–97 (Anon 1999).

Species Lat.	Northern Sweden –64°N	 61–64°N	Central Sweden 58.5–61°N	Southern Sweden 55–58.5°N	Total
Scots pine	279	260	297	244	1080
Norway spruce	179	340	299	434	1252
Pendula birch	3	9	22	34	68
Pubescent birch	81	64	34	38	217
European aspen	4	8	13	11	36
Common alder	–	1	6	14	21
Grey alder	1	5	3	1	10
Other species	3	5	8	52	68
Total	550	692	682	828	2752

Most mixed stands have been established spontaneously. Parts of a clearfelled area on a moist site are easily colonised by broad-leaved species, such as birch and alder. As the area is usually frost-prone and the site is moist, planted Norway spruce or Scots pine (*Pinus sylvestris* L.) are damaged by frost and the unsuitable growing conditions. The growth of broad-leaved species is high, but for the softwoods the growth is low as is the survival rate. Later on when a dense stand of hardwoods is established the growth conditions for Norway spruce will be better. The site will be drier and the risk of frost will have decreased.

Where an understorey of Norway spruce established naturally, the forester decided to "save" the softwood plants. In 1988 a report was published dealing with the production of birch in a mixed stand of birch and Norway spruce (Tham 1988). The main result showed that production was increased by about 100 m^3 of birch wood. These figures were based on older experiments with mixed birch and Norway spruce where the birch were reduced to 1500 to 2000 stems/ha.

These results were published in a period when costs for cleaning and other silvicultural actions increased rapidly. Furthermore, chemical treatment as a cheap method of reducing the number of broad-leaved species was forbidden in Sweden in 1983. Therefore a realistic and relatively cheap method to reduce the number of broad-leaved trees had to be used. Mixed stands of birch and Norway spruce since then have been established on many sites in Sweden. But the management of the stands has been focused on the elimination of hardwood stems, or at least a strong reduction in their number.

Until recently the management of mixed stands has been based on stands which have not been cleaned in time. Today an increasing interest in managing mixed stands has arisen. Spontaneous establishment of a hardwood stand may take as long as 10–20 years. Another way to form a mixed stand is to clean the hardwood stand when the plants have established and grown up to 1.5–2 m high. Then an understorey of planted and/or naturally regenerated Norway spruce can be established.

The most frequently utilised mixture is Norway spruce/birch, as birch is the most common hardwood species in Sweden (Tables 1 and 2). Today, managed mixed stands of Norway spruce/birch are now and then to be seen on specific sites and localities. In some places sparse alder stands used for fuelwood will be colonised by Norway spruces. Managed mixed stands of Norway spruce/alder are so far not common in Sweden.

TABLE 2–Percentage stems per hectare and growing stock (m^3/ha) of birch and aspen growing in mixed coniferous and broad-leaved stands. Survey period 1978–80 (Folkesson & Johansson 1981).

Cutting class*	Total number of stems/ha	Birch (%)	Aspen (%)	Growing stock (m^3/ha)	Birch (%)	Aspen (%)
B2	4181	79	13	5.7	58	5
B3	5070	81	6	20.0	77	7
C	3235	81	7	47.9	79	9

* B2= Young forest with a mean height between 1.3 and 3.0 m;
B3= Young forest with a mean height over 3.0 m;
C = Young thinning forest. Mean diameter of trees between 100 mm on bark.

In a completed project we constructed functions for biomass production based on diameter in breast height. In this case we use functions for birch (cf. Johansson 1998b).

Birch grow throughout Sweden (Johansson 1996) and two species are grown commercially—pendula (*Betula pendula*) and pubescent birch (*Betula pubescens*). Pubescent birch is widespread in Sweden and pendula birch is gown mainly in middle and southern Sweden (Table 1).

In Sweden two methods have been introduced for growing mixed stands.

The Kronoberg method

This method was introduced in southern Sweden primarily in order to avoid frost damage on Norway spruce and to minimise the number of sprouts established after the complete removal of the birch stand. The method is divided into three steps.

If the number of birch is very high and there is a risk of decrease in growth for the spruce, birch growing close around the spruce plants must be cut before the first step is made.

- The birch stand is cleaned when the trees are 3–4 m high. After cleaning the stands consist of 3000 to 4000 stems/ha. The Norway spruce stand is not cleaned.
- When the birch trees are 6–9 m high the stand is cleaned again. After cleaning the birch stocking should be 1000 to 1500 stems/ha. Diameter at breast height is about 50 mm.
- The birch shelter is felled 5 years later. Birch trees are now 20–25 years old, 8–12 m high, and have a diameter at breast height of 80 mm. The mean height of the Norway spruce is 3–4 m. The spruce stand should be thinned to 2000–2500 stems/ha.
- Instead of clearfelling the birch stand in the third step, 600–800 birch trees can be left for 10–15 years when the mean diameter at breast height will be 165 mm at clearfelling.

Comments: When managing this type of stand it is important that the number of birch stems is not too high when the spruce are established. According to Braathe (1988) competition is too high for spruce if there are more than 1200 birch stems/ha and they are more than 3 m tall. In that case he postulated a 30% decrease of height increment for the spruce.

The shelter method

This method was introduced by Tham (1988) and modified by Johansson & Lundh (1991). There are many variations in non-managed stands of birch and Norway spruce but the principal idea is to get an initial mixed stand with an optimal number of birch trees.

- When the spruce are 1.5–2 m high the number of birch is reduced to 600–800 stems/ha.
- The "birch shelter" is clearfelled when the trees are 30–35 years old and the breast height diameter is about 160 mm.
- Today, with an increased interest in biodiversity on forest land and the improved quality of timber with this method, a third step is included in which 100–150 stems/ha are left in the second step.

Comments: A modification of the second step is interesting in two ways. Firstly, the stand will not be as dark as if only spruce are left. Secondly, the birch trees left will produce timber with high quality.

MATERIAL AND METHODS

The experiment was started in 1983 and is based on trials established on eight localities in central and southern parts of Sweden (Fig. 4). Two plots (No. 5 and 6) were established at the same locality (Table 3). All treatments were carried out during the period 1983–85. The experimental stands were 20 to 30 years old at the start of the experiment. They were dense, even-aged, self-regenerated birch sheltering young Norway spruce on moist or mesic sites of high site quality.

The experiment included two thinning regimes:

- Thinning of the birch overstorey to create a shelter of 500 stems/ha
- Total removal of the birch trees.

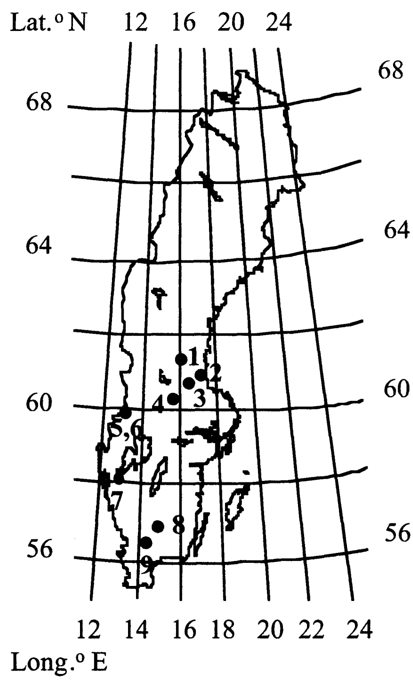

FIG. 4–Map of the geographical localisation of experimental plots

TABLE 3–Location and some main characteristics for the experimental plots

Plot No.	Latitude N	Longitude E	Altitude (m)	Age (years)	Site index (spruce) H_{100} m
1	60° 59′	15° 38′	335	23	25–27
2	60° 31′	16° 14′	185	32	28
3	60° 28′	16° 05′	150	20	31
4	60° 23′	15° 52′	160	24	30
5	60° 03′	13° 23′	170	29	30–31
6	60° 03′	13° 23′	170	21	28–30
7	56° 49′	14° 41′	170	27	30–35
8	56° 39′	14° 15′	150	26	31–34
9	57° 54′	12° 15′	110	22	29–31

Then there were two levels of biomass removal:

- All cut stemwood and branches were removed
- No stemwood and branches were removed.

Each plot had an area of 750 m^2 with a 5-m-wide buffer strip. The total experiment involved 41 plots, i.e., 10 replicates of each of three treatments and 11 replicates of the fourth treatment. Before the initial treatment, the species, health (injuries), diameter at breast height (dbh), and height were recorded (Table 4).The mean diameter at breast height was higher for birch than for spruce (Table 4) and birch stands were 3–4 m higher than spruce stands.

TABLE 4–Stand characteristics before thinning

		Diameter (dbh) (mm)	Stocking (stems/ha)
Shelter plots			
Birch	Mean	52±3	6225±759
	Range (min–max)	38–85	1520–13 187
Norway spruce	Mean	49±3	4154±461
	Range (min–max)	26–84	1667–9573
No-shelter plots			
Birch	Mean	56±5	9330±1193
	Range (min–max)	37–106	2214–20 280
Norway spruce	Mean	45±3	3782±422
	Range (min–max)	25–64	880–8800

After registration, all stems except Norway spruce were removed on plots assigned to the non-sheltered treatment. On shelter plots 500 birch stems/ha were left. Only damaged spruce trees were removed. The mean diameter for shelter birch trees was 108 mm and for spruce growing as an understorey it was 50 mm (Table 5). Spruce without shelter birch had a diameter of 45 mm. The height of birch shelters was 12.6 m and the spruce stands were about 5 m shorter both under birch shelters and growing without shelter. After treatment the mean stocking of spruce was 5077 (1667–12 040) and 4400 (880–8800) stems/ha respectively for shelter and no-shelter plots (Table 5).

TABLE 5–Stand characteristics after first treatment

		Diameter (dbh) (mm)	Height (m)	Stocking (stems/ha)
Shelter plots				
Birch	Mean	108±6	12.6±0.7	495±4
	Range (min–max)	63–136	7.1–18.0	427–507
Norway spruce	Mean	50±3	7.9±0.4	5077
	Range (min–max)	30–85	5.2–12.3	1667–12 040
No-shelter plots				
Norway spruce	Mean	45±3	7.5±0.5	4075
	Range (min–max)	25–63	4.5–12.7	880–8800

After five growing seasons the plots were examined. The measurements made at the time of establishment were repeated. On some plots some birch stems were felled and the spruce stands were thinned. A second examination was made six to eight growing seasons later on. On shelter plots all birch trees were felled, but on one plot per locality about 100 birch stems/ha were left.

RESULTS

When the experiment started the biomass removal on shelter plots was 40.6 tonnes d.w. birch/ha and 0.7 tonnes d.w. Norway spruce/ha (Fig. 5). All birch trees were removed on no-shelter plots where 70.0 tonnes d.w. birch biomass/ha were harvested. Few stems of Norway spruce were cut.

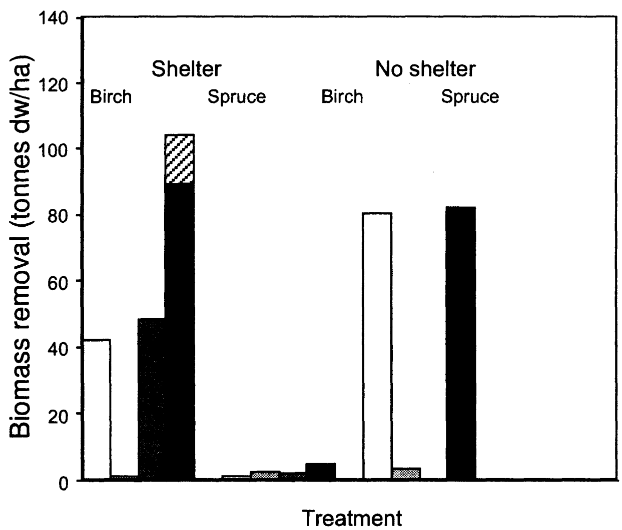

FIG. 5–Biomass removed (tonnes dw/ha) at the start of the treatment (□), at first examination (▩), at second examination (■), and total biomass removed (■) for mixed stands of Norway spruce (*Picea abies*) and birch (*Betula pendula* and *Betula pubescens*). On one shelter parcel per locality about 100 birch/ha were left and biomass production is indicated (▨).

After five growing seasons the mean diameter for shelter birch was 133 mm. Spruce growing with shelter had a mean diameter of 76 mm compared with 70 mm for spruce without shelter. The height of shelter birch was 14.2 m and the spruce heights were 9.7 and 8.5 m respectively for sheltered and non-sheltered stands. The number of spruce per hectare after thinning was 2811 and 2517 respectively on shelter and no-shelter plots (Table 6). Only small amounts of birch biomass were removed from shelter plots, 0.6 tonnes d.w./ha. However 2.4 tonnes d.w. Norway spruce biomass/ha were harvested (Fig. 5).

TABLE 6–Stand characteristics of remaining trees after first (5 growing seasons) and second (6 to 8 years later) examinations.

	First examination			Second examination		
	Diameter (dbh) (mm)	Height (m)	Stocking (stems/ha)	Diameter (dbh) (mm)	Height (m)	Stocking (stems/ha)
Shelter plots						
Birch				Shelter birch		
Mean	133±4	14.2±0.5	499±5	193±1	17.3±1.0	104±5
Range (min–max)	81–199	8.2–20.0	480–574	126–249	10.5–21.6	80–120
Norway spruce						
Mean	76±3	9.7±0.5	2811±110	94±3	12.0±0.5	2665±99
Range (min–max)	46–99	5.3–13.5	1693–3373	68–115	8.1–15.0	1547–3360
No-shelter plots						
Norway spruce						
Mean	70±0	8.5±1	2517±154	90±1	10.6±0.7	2435±142
Range (min–max)	33–92	4.2–11.2	1293–3453	46–117	5.4–14.3	1240–3373

When the plots were examined for the second time 13–15 years after the experiment started, all birch trees were removed from shelter plots. However, on one shelter plot per locality 100 birch/ha were left. These remaining birch were 17.3 m high and the height for sheltered and non-sheltered spruce was 12.0 m and 10.6 m respectively. Mean diameter of the remaining birch trees was 193 mm and the spruce diameter was 94 and 90 mm respectively. The number of spruce had been reduced by 100 stems/ha (killed and damaged). The amount of birch biomass harvested was 45.3 tonnes dw/ha and of Norway spruce 2.0 tonnes dw/ha (Fig. 5). The total birch biomass removed from shelter plots was 85.9 (40.9–145.3) tonnes dw/ha, and 72.7 (34.9–142.7) tonnes dw/ha on no-shelter plots. If the biomass yield of the birch shelter of 100 stems/ha is included, 14.9 tonnes dw/ha should be added to the biomass figures for shelter plots (Fig. 5).

After 13–15 years from the beginning of the experiment, the biomass of Norway spruce remaining on shelter plots was 32.9 (10.9–48.6) tonnes dw/ha and 14.9 (7.7–21.0) tonnes dw birch/ha, and on no-shelter plots 37.9 (5.0–63.4) tonnes dw Norway spruce/ha (Fig. 6).

DISCUSSION

A high proportion of birch stems were removed on shelter plots. However, it is not possible to have more than 500 birch stems/ha for shelter without causing decreased growth

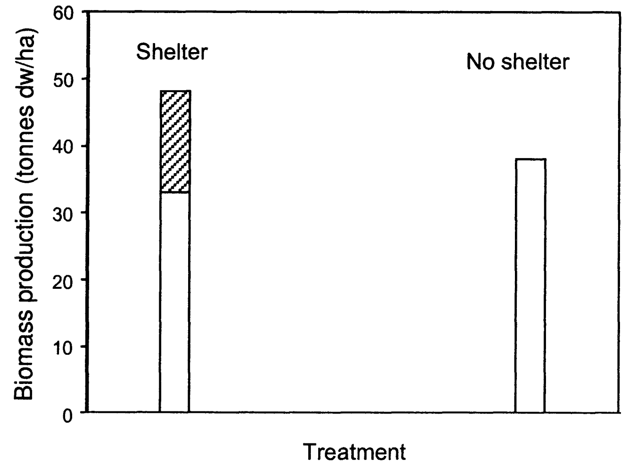

FIG. 6—Standing biomass (tonnes dw/ha) of Norway spruce in mixed stands of spruce and birch after removal of the birch shelter (□). On one shelter parcel per locality about 100 birch/ha were left and biomass production is indicated (▨).

on Norway spruce stands. According to Braathe (1988) the stocking must be low otherwise height growth will be decreased.

The amount of biomass removal after first treatment on no-shelter plots was high, but the mean diameter of the stems was only 52–58 mm (Table 7). Furthermore, the number of stems removed was high. When harvesting thin stems the cost will be higher than if the stems are thicker because harvesting costs are negatively related to mean tree diameter (Fig. 7).

As shown in Fig. 5, the total amount of biomass removed during the study period (14 years) was higher on shelter plots than on no-shelter plots. Initially, the number of birch trees on shelter plots was lower than on no-shelter plots (Table 4). On some of the no-shelter plots

TABLE 7—Characteristics for removed birches at first treatment and after first and second examination

Period		Diameter	Stocking (stems/ha)
Shelter plots			
First treatment	Mean	52±3	6225±759
	Range (min–max)	35–73	1520–13 187
First examination	Mean		
	Range (min–max)		
Second examination	Mean	157±7	456±13
	Range (min–max)	103–215	373–507
No-shelter plots			
First treatment	Mean	56±5	9330±1 193
	Range (min–max)	33–96	2214–20 280
First examination	Mean		
	Range (min–max)		
Second examination	Mean		
	Range (min–max)		

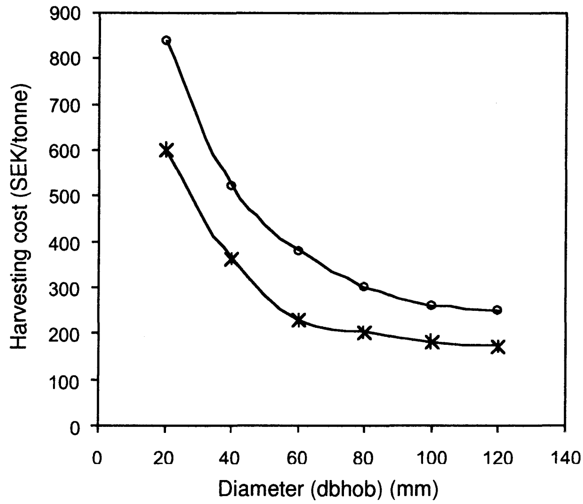

FIG. 7–Relationship between mean diameter of harvested trees (mm) and harvesting costs (SEK) per tonne for chips (o) and trees (*).

many birch were killed, mostly by self-thinning. The final birch biomass removal on shelter plots was 45 tonnes/ha (Fig. 5) and the mean number of birch removed was 456 stems/ha (Table 7). The harvested biomass of shelter birch trees was more than the removal of 6225 stems/ha on shelter plots 13 years earlier (Fig. 5).

The remaining birch trees should be left until they are 50–60 years old. During this period the wood quality of the birches will be good and both veneer and special timber quality could be obtained. They were 17.3 m high (10.5–21.6 m) at the age of 33–50 years with a mean diameter of 193 mm (126–249 mm). The dimensions of these stems will increase and at 60 years of age they could be 25–30 m high with a diameter of 250–350 mm. As the birch stems have thin branches, the harvesting of shelter will not seriously damaged the remaining spruce.

The biomass of Norway spruce remaining in shelter stands was 32.9 tonnes dw/ha compared with 37.9 tonnes dw/ha for no-shelter stands (Fig. 6). This indicates that there is a loss in biomass production for Norway spruce sheltered by birch. But as the total biomass production in shelter stands was 133.7 (100.8 + 32.9) tonnes dw/ha compared with 110.6 (72.7 + 37.9) tonnes dw/ha for no-shelter stands, the shelter stands supplied a total of 23.1 tonnes dw/ha.

Mård (1996) studied the influence of the birch shelter on the yield production of Norway spruce and presented results 5 years after this experiment was started. He concluded that there was significant loss in Norway spruce yield due to the shelter, but the yield of birch volume was almost three times the loss in spruce yield. The results also indicated that shelter would, owing to increased one-sided competition, enhance the variation in height of the spruce.

Klang & Ekö (1999) studied six Norway spruce stands in two treatments: no-shelter (planted Norway spruce only) and shelter (four stands of planted Norway spruce + naturally regenerated pendula and pubescent birch, and two stands of planted Norway spruce + thinned Scots pine). The shelter reduced the height and the diameter at breast height of Norway spruce. They also reported a 36% decrease of MAI for Norway spruce growing in shelter compared with those growing without shelter. However, the combined MAI for shelter trees and Norway spruce was 24% higher than for pure Norway spruce stands.

The costs of harvesting and transfer of the harvested material to a pick-up site are less for whole trees than for chips. The harvest operation is preferably carried out during the period when the hardwoods are leafless as the leaves should be left in the stand for maintaining the site nutritional status and also because "green" parts in chips do not indicate good quality. Regardless of species to be harvested, most of the stands will still be cut by power saw and the whole trees transferred to a pick-up site. Trees less than 60 mm dbh become more expensive to harvest the thinner they are (Fig. 7) (Johansson 1992).

The harvesting cost mentioned above is not up-to-date but the cost when using a conventional power saw for felling is the same as in 1992. Logging and chipping costs have been cheaper than 1992. Last year there have been presented some interesting technical innovations such as an energy harvester "EnHar". This system is based on a vehicle which cuts one stem or 5–10 stems in one operation. The felling aggregate can fell stems <25 cm at stump height. Then the trees are chipped at once and the chips are loaded in a wagon behind the vehicle for transport later on. The felling capacity is >250 stems/hour with a saw mounted in the felling aggregate and >350 stems/hour with a hydraulic cutter.

CONCLUSIONS

Mixed stands of Norway spruce/birch are a potential source for harvest of biofuels.

Skilful management of mixed stands of Norway spruce and birch could produce 41 to 145 tonnes dw/ha during a rotation period of 30 to 35 years for the shelter species.

Costs for harvesting trees and transferring the harvested material to the pick-up site are less for whole trees than for chips. Trees thinner than 60 mm dbh are more expensive to harvest the thinner they are.

When harvesting the birch shelter in Norway spruce stands, about 100 birch stems/ha could be left for creating high-quality birch timber 15–20 years later.

However, management of mixed stands, for example birch/Norway spruce, is part of the effort to increase the biodiversity on forest land. For a sustainable forest, it is important to present alternatives to conventional forest management.

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