Swedish University of Agricultural Sciences
Faculty of Forestry
Uppsala, Sweden

Stump heights and sprouting of European aspen, pubescent and silver birches, and damage to Norway spruce and Scots pine following mechanical and brush saw cleaning

TORD JOHANSSON
Department of Forest Yield Research

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Abstract

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Results of precommercial thinning (cleaning) by brush saw and by a machine-mounted device, consisting of a hydraulically-driven heavy disc with two short steel flails mounted in a journal bearing, are presented. Plots were laid out in middle and south Sweden in 1983, some being observed annually until 1989. There were significant differences between the two methods as regards the number of sprouts on European aspen (*Populus tremula* L.) and birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) stumps six years after cleaning. Plots cleaned by machine had a larger number of birch or aspen sprouts, than plots cleaned by brush saw. Mean height of stumps was significantly greater on plots cleaned by machine. Stumps cleaned by machine under snow conditions were 30-70 cm high. There were no significant differences in the number of sprouts or in the height of sprouts, between high and low stumps. Cleaning by machine damaged 7-13 per cent of conifers classified as main stems, as compared to no damage caused by brush saw cleaning. Practical recommendations are given: cleaning by machine under a snow cover is not recommended in most cases.

Key words: Betula pendula, Betula pubescens, Populus tremula, Pinus sylvestris, Picea abies, sprouts, stump height, growth, damage, mechanical cleaning, brush saw.

Tord Johansson, Swedish University of Agricultural Sciences, Department of Forest Yield Research, S-770 73 Garpenberg, Sweden.

Contents

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Introduction

In Sweden, prohibition of the use of herbicides causes difficulties as regards forestry cleaning operations. The cost of release by brush saw is high, and there are too few trained staff to meet the need. The number of broadleaved trees per hectare is great (10,000–100,000 stems/ha) on reforested areas, where young conifers may be damaged by the broadleaves. Pubescent (*Betula pubescens* Ehrh.) and silver birch (*B. pendula* Roth) make up 75 per cent of all broadleaved trees, while ten per cent consists of European aspen (*Populus tremula* L.) (Folkesson & Johansson, 1981).

Broadleaved trees, including the species mentioned above, regenerate vegetatively. Many studies on competition between broadleaves and conifers have dealt with the effects on sprouting and suckering of cutting trees at different seasons. These studies have generally been made with the aim of reducing the need to cut sprouts and suckers some years after cleaning (Stoeckler, 1947; Haveraaen, 1963; Etholén, 1974; LaBonte & Nash, 1978; Johansson, 1986, 1987, 1992*b*, *c*; Kvaalen, 1989). The biomass production of birch has been discussed by Ferm, Kauppi & Rinne (1985), who emphasised the rapid growth of sprouts from the stumps of young birches. Hakkila (1985) discussed the potential for producing forest energy, especially from small birches, as also methods for harvesting such birches (Hakkila, 1978). Lehtonen (1976) and Harstella & Tervo (1978) reported methods for harvesting sapling stands. The conventional chain saw or skidders are the methods most often used.

An efficient and rapid method is needed for carrying out pre-commercial thinning of the neglected sapling stands, which cover ca 400,000 ha, and of conifer plantations containing tall, thin hardwood stems. The first machine for these purposes appeared in 1980, and until 1985, was the only type tested for practical cleaning work (for details, see Wästerlund (1988)). Petré (1984) studied the efficiency of this machine, and reported that it could compete economically with manual brush saw cleaning when there were more than 10 000-15 000 trees per hectare to be cut. The best results were obtained from cleaning carried out after the autumn leaf fall.

The method has now won general acceptance in forestry, and there is an increasing interest in it. Wästerlund (1988) investigated whether the root system of conifers was damaged by the machine's wheels and by soil compaction. He reported a reduction of annual height growth by 25 per cent during the first two years after treatment, as a result of soil compaction. Work with a special machine, during the snow-free season alone, is very expensive. Foresters therefore wish to clean even on snow, with high stumps (50–75 cm) as a result. High birch stumps (40–80 cm) did not produce more sprouts or taller sprouts, than low stumps (0–20 cm; Johansson, 1991). The consequences of leaving high birch stumps, as regards the effects of competition with conifers, have not been studied in Sweden.

The aim of this study was to compare sprouting of European aspen and of pubescent and silver birch following mechanical cleaning, and motor-manual cleaning by brush saw. Damage to conifers caused by the two methods was also studied, both immediately after treatment and 5–6 years later. Sprouting following mechanical cleaning on snow was studied in one trial. At the outset of this study, a question of interest was whether stumps cut by machine are affected by rot more quickly than stumps cut by brush saw. However, field observations alone were made of this.

Material and methods

The base machine used was a conventional, small (17 tonnes) forwarder (Bruunett Mini 578), modified by having a crane mounted to work in front of it. At the tip of the crane was attached a hydraulically-driven heavy disc, with two short, steel flails loosely mounted in journal bearings. When the disc rotated, the flails were activated by centrifugal force. The ground clearance of the machine was 0.56 m. Conifer plants could be at least 1.10–1.20 m tall before they were damaged.

The study is divided into three sections: an experiment in which mechanical and brush saw cleaning were compared, a survey of the effects of mechanical and brush saw cleaning at different localities, and a study of the effects of mechanical cleaning in the presence of a snow cover. The number and growth of

sprouts of European aspen, pubescent and silver birch and the growth of, and damage to, Scots pine and Norway spruce, following mechanical cleaning and motor-manual cleaning by brush saw, were compared.

The development of birch sprouts was studied annually during the years 1983–1989 at the single locality Ljusnarsberg (Lat. 60°10'N, Long. 15°20'E). The forest type was fresh dwarf shrub (Hägglund & Lundmark, 1982). Wästerlund (1988) has described the locality in greater detail. The experimental area consisted of two 10 · 20 m plots cleaned by brush saw and by machine, respectively. Sixty birches per treatment were marked in 1983. On the plot cleaned by machine, 41 stumps were pubescent birches and 19 silver birches. On that cleaned by brush saw, the numbers were 39 and 21, respectively. Sprouts of *Betula* species were classified by their morphology. In addition to the experimental plots mentioned above, the percentage of sprouting stumps one growing season after treatment was recorded for all cut stumps on 10 · 10 m plots cleaned by machine and brush saw. Only 1 per cent of pubescent and silver birch stumps cleaned by machine, and 2.5 per cent of the stumps cleaned by brush saw, did not sprout. The mean stump diameter of both birch species on plots cleaned by machine and brush saw was 50 mm and the stump height was 28–33 cm. The number of sprouts, and their height, were measured annually.

Effects of mechanical and manual cleaning were studied at six localities in middle and south Sweden (Table 1). The trials were laid out and cut in spring 1983, and were measured in 1983 and 1987. At each locality, half of the area was cleaned by brush saw and half by machine. There were rough conditions on all plots, and plot No. 6 was, in addition, moist. On each of the cleaned areas, one plot 25 · 50 m was laid out. The plots were placed in such a way that site conditions and canopy density were as comparable as possible. Twenty-five plots, with a radius of 1.7 m (10 m^2), were laid out at a spacing of 10 m in the row and 5 m between rows. All stumps on the plot were counted, and aspen and pubescent birch sprouts were measured. In 1987, the plots were reconstructed as far as possible, to compare results from 1983 and 1987. The same procedure as described above was followed, but in addition, conifers were counted, their height and stem diameter at breast height (1.3 m) was measured and damage was classified.

Mechanical cleaning in winter on pubescent birches was studied in one trial (Hällefors), which was established and cut in spring 1988. The number of sprouts, and their height, were measured in 1988 and 1989. Four types of stump were identified: Normal (10–30 cm high), 50–70 cm high, > 70 cm high and hedge-formed (high stumps with cut twigs). The stumps were tentatively classified into two diameter classes: Thin (diameter < 20 mm) and coarse (diameter > 20 mm). Fifty stumps per treatment were used, in all, 400 stumps.

The study of height and diameter growth and of damage caused by the cleaning of conifer plants was carried out at the six localities presented in Table 1. The examination of damage was concentrated to: Cut conifers, cut leaders and damage to plants by the wheels or frame of the machine. These types of da-

Table 1. *Some characteristics of the series of six localities in south and middle Sweden cleaned by machine and brush saw*

Trial No.	Lat. N. Long. E.	Forest type	Treatment[1]	No. of stumps			
				Aspen	Pubescent birch	Other species	Total
1	60°25'	Fresh/moist	M	175	73	44	292
	15°20'	dwarf shrub	B	84	196	43	323
2	59°58'	Fresh	M	0	123	28	151
	15°20'	dwarf shrub	B	0	117	69	186
3	62°20'	Fresh	M	0	166	5	171
	14°33'	dwarf shrub	B	4	288	4	296
4	57°30'	Fresh	M	22	299	34	355
	15°25'	dwarf shrub	B	11	190	63	264
5	56°49'	Fresh	M	52	20	43	115
	14°20'	dwarf shrub	B	26	80	67	173
6	60°25'	Moist	M	2	56	14	72
	16°53'	dwarf shrub	B	0	62	7	69

[1] M = Machine, B = Brush saw.

mage are manifested 4–5 years later as stems with curves, leaning plants or stumps only remaining after cutting. All these types of damage were denoted "damage by cleaning".

Forest type was classified according to Hägglund & Lundmark (1982). In all experiments, diameter was measured in mm and height in cm.

Data were analysed by variance analysis, chi-square analysis and pairwise comparison of means, using the SAS/STAT system for personal computers. Throughout the report, a significance level of 0.05 has been used.

Results

Comparison of methods

On the trial area there were 23 850 and 26 750 birches per hectare before cleaning by machine and brush saw, respectively. The number of sprouts per living stump decreased during the period 1984–1989, (Fig. 1). In 1989, 2.1 and 2.5 sprouts per living pubescent birch stump and 2.2 and 2.3 sprouts per living silver birch stump, remained after cleaning by machine and brush saw, respectively. The mean height of pubescent birch sprouts in 1989 was 224 and 202 cm, respectively, and 195 and 189 cm for silver birch sprouts (Fig. 2) The differences in number and height of sprouts per species did not differ significantly between the two methods. Pubescent birch sprouts on stumps cleaned by machine were, however, significantly taller than those of silver birch.

Series of six trials

The mean stump diameter of birch within and between localities varied with treatment. Birch stumps were generally taller on plots cleaned by machine than on those cleaned by brush saw. Stumps left by the machine were 1.3–2.1 times taller than those left by the brush saw (Table 2). The differences in stump height were significant. Stump diameter of aspen within a locality did not differ between treatments, but there was variation between localities (Table 3). On comparable plots, aspen stump height was greater in two cases after cleaning by machine and in one case after cleaning by brush saw (Table 3). On plot No. 5, the differences were significant. The number of birch and aspen sprouts per living stump in 1983 was the same on all plots, irrespective of treatment, viz. 7–8 sprouts per living stump. After one growing season, 90–95 per cent of treated stumps were still alive. The mean height of birch and aspen sprouts after one growing season was 15–20 cm.

In 1987, the number of pubescent birch sprouts

Table 2. *Height (cm) and diameter (mm) of pubescent birch* (Betula pubescens *Ehrh.) stumps cleaned by machine and brush saw in the series of six trials in south and middle Sweden. t-test (LSD) for height (cm) and diameter (mm)*

Trial-No.	Treatment*	Stump diameter, mm		Stump height, cm	
		Mean ± 1 SD	Min.–Max.	Mean ± 1 SD	Min.–Max.
Birch					
1	M	22 ± 17	3–96	25.8 ± 9.9	6–54
	B	18 ± 13 ns	3–83	19.8 ± 6.9*	2–46
2	M	12 ± 8	1–50	22.9 ± 7.7	8–47
	B	9 ± 6 ns	1–42	18.5 ± 7.0*	4–48
3	M	39 ± 25	6–99	40.5 ± 15.1	12–95
	B	20 ± 16 ns	2–96	19.1 ± 7.9*	3–61
4	M	10 ± 6	2–44	35.9 ± 15.7	7–92
	B	23 ± 17 ns	4–89	26.4 ± 11.0*	6–60
5	M	24 ± 12	3–47	42.4 ± 22.1	14–97
	B	23 ± 15 ns	3–87	23.5 ± 8.4*	10–69
6	M	17 ± 15	4–92	25.2 ± 9.0	5–50
	B	13 ± 7 ns	4–47	19.7 ± 6.6*	10–38

[1] M = Machine, B = Brush saw.
* = Significant at 0.05 level.
ns = Not significant.

Table 3. *Height (cm) and diameter (mm) of European aspen* (Populus tremula *L.) stumps cleaned by machine and brush saw in the series of six trials in south and middle Sweden. t-test (LSD) for height (cm) and diameter (mm)*

Trial No.	Treatment[1]	Stump diameter, mm		Stump diameter, mm	
		Mean ± 1 SD	Min.–Max.	Mean ± 1 SD	Min.–Max.
Aspen					
1	M	18 ± 10	3–59	28.7 ± 10.5	4–58
	B	19 ± 8 ns	3–43	29.3 ± 14.0 ns	10–73
4	M	8 ± 6	3–28	33.3 ± 12.6	12–56
	B	7 ± 3 ns	4–13	24.3 ± 11.5 ns	12–52
5	M	16 ± 7	7–40	42.4 ± 22.1	14–99
	B	14 ± 7 ns	3–32	23.5 ± 8.4*	10–69

[1] M = Machine, B = Brush saw.
* = Significant at 0.05 level.
ns = Not significant.

was greater after cleaning by machine than after cleaning by brush saw, on four of six plots; on one plot only (No. 4) was it lower (Fig. 3). The differences were significant on plots Nos. 1, 3 and 4. On two of three comparable aspen plots, Nos. 1 (significant differences) and 5, the number of sprouts was greater after cleaning by machine than after cleaning by brush saw (Fig. 4). The mean height of pubescent birch sprouts ranged between 90 and 255 cm after cleaning by machine, and between 70 and 195 cm after cleaning by brush saw (Fig. 5). The mean height of birch sprouts on four of six comparable plots (Nos. 2, 3, 4 and 5), was greater after cleaning by machine than after cleaning by brush saw. Significant differences were found at plots Nos. 1, 3, 4 and 5. The mean height of aspen sprouts ranged between 100 and 161 cm after cleaning by machine, and between 90 and 146 cm after cleaning by brush saw. On one of three aspen plots (No. 4), the mean height of aspen stump sprouts was greater after cleaning by machine (Fig. 6) than after cleaning by brush saw. There were significant differences on two plots (Nos. 1 and 4).

Trial under snow conditions

On comparable plots, the mean height of pubescent birch stumps was the same within a treatment (Table 4). The mean diameter of thin stumps varied (range 11–19 mm) between the treatments, especially on hedge-formed stumps (Table 4). On coarse stumps, the range of variation was great, 24–80 mm. The number of sprouts was greater on coarse than on thin stumps (Fig. 7). The number of sprouts was greater in 1989 than in 1988, with the exception of hedge-formed and "normal" stumps, where it was the same or lower in 1989 than in 1988 (thin, normal stumps). The difference in number of sprouts (1989) between thin and coarse stumps was significant for hedge-formed stumps of height 50–70 cm and for stumps > 70 cm tall. The height of sprouts in 1989 on hedge-formed stumps was significantly lower on thin stumps than on coarse stumps (Fig. 8). Branches and sprouts above half the stump height occurred on ten per cent of stumps with normal stump height, on 38 per cent of stumps 50–70 cm high, on 28 per cent of stumps > 70 cm high and on 67 per cent of hedge-formed stumps. The mixture of branches and sprouts causes the stand to resemble a hedge with small conifers within.

Growth of and damage to conifers

Damage caused by cleaning was generally detected on conifers which had been released by machine. There were differences between the damage caused by machine and that caused by brush saw (Table 5). On plots cleaned by machine, 7–13 per cent of all main stems were damaged. In 1983, the height after cleaning for conifer main stems, varied between 65 and 165 cm for Scots pine and between 40 and 176 cm for Norway spruce. This indicates that the main parts of the stems were lower than the height at which damage was done to the conifers. The differences in mean height in 1987, between plots cleaned by machine and those cleaned by brush saw, were significant on plots Nos. 4 and 6 for Norway spruce. No significant differences between the methods, with regard to diameter at breast height, were observed.

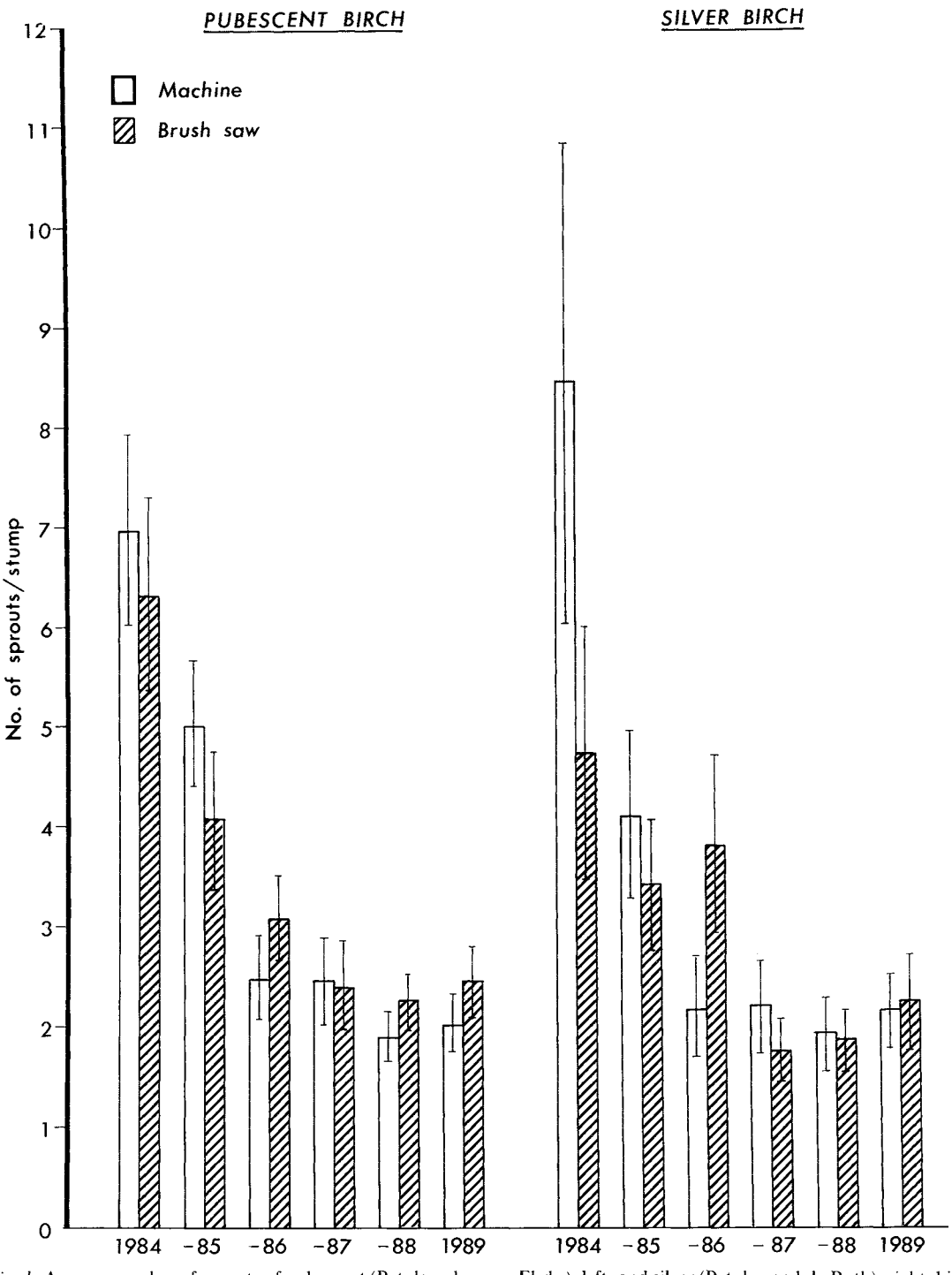

Fig. 1. Average number of sprouts of pubescent (Betula pubescens Ehrh.), left, and silver (Betula pendula Roth), right, birch stumps cleaned by machine and brush saw. (Comparison of methods.) Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

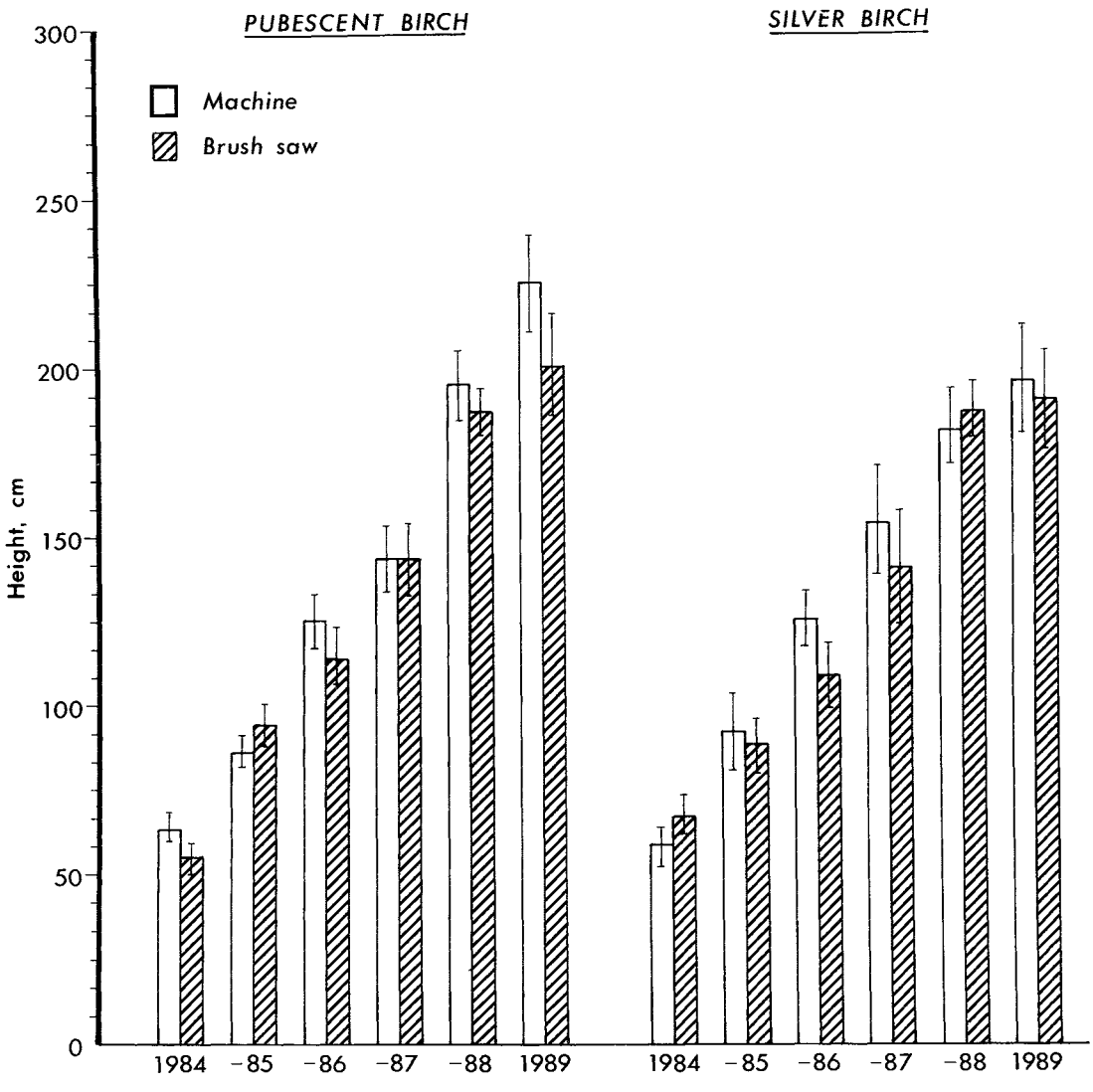

Fig. 2. Mean height of pubescent (Betula pubescens Ehrh.), left, and silver (Betula pendula Roth), right, birch sprouts after cleaning by machine and brush saw. (Comparison of methods.) Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

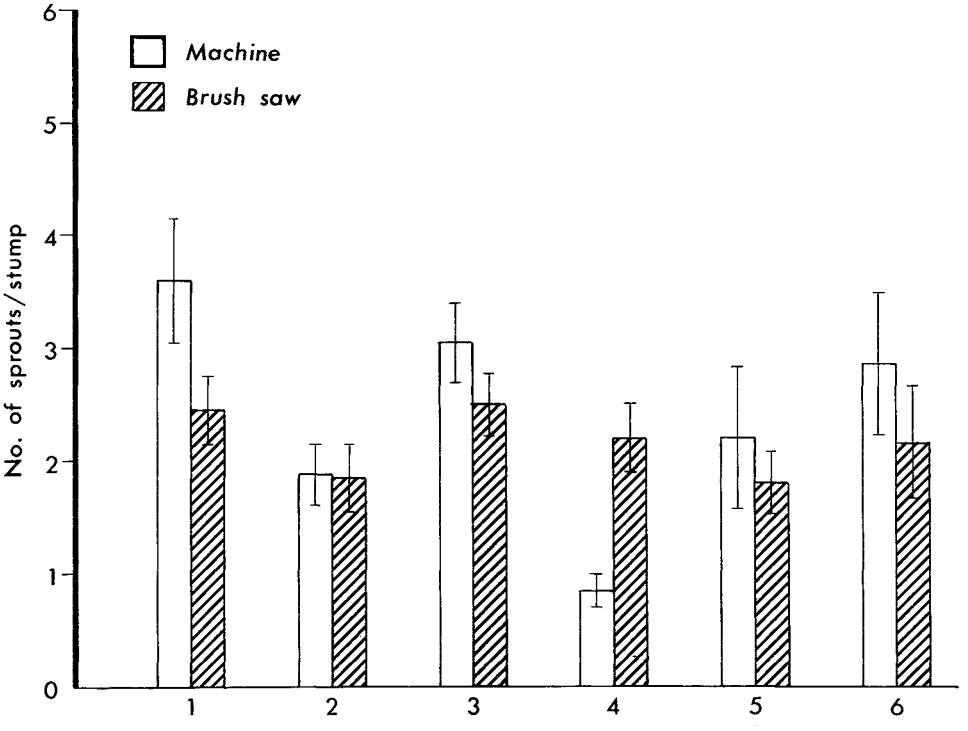

Fig. 3. Number of sprouts of pubescent birch (Betula pubescens Ehrh.) stumps four years after cleaning by machine and brush saw in the series of six trials. Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

Table 4. *Height (cm) and diameter (mm) of pubescent birch* (Betula pubescens *Ehrh.) stumps cleaned by machine under snow conditions in Hällefors. 30 stumps per treatment*

	Stump height, cm		Stump diameter, mm	
Treatment	Mean ± 1 SD	Min.–Max.	Mean ± 1 SD	Min.–Max.
Hedgeform				
Thin	67.8 ± 10.5	42–90	11 ± 4	6– 27
Coarse	65.4 ± 11.8	42–88	24 ± 7	15– 46
Normal				
Thin	24.5 ± 5.0	14–37	19 ± 7	11– 38
Coarse	27.0 ± 5.2	19–38	80 ± 16	44–118
50–70 cm				
Thin	55.8 ± 5.9	45–70	16 ± 5	9– 25
Coarse	55.2 ± 5.0	45–65	57 ± 17	30–104
>70 cm				
Thin	71.6 ± 6.5	62–92	16 ± 4	9– 26
Coarse	72.8 ± 10.2	54–97	44 ± 9	29– 63

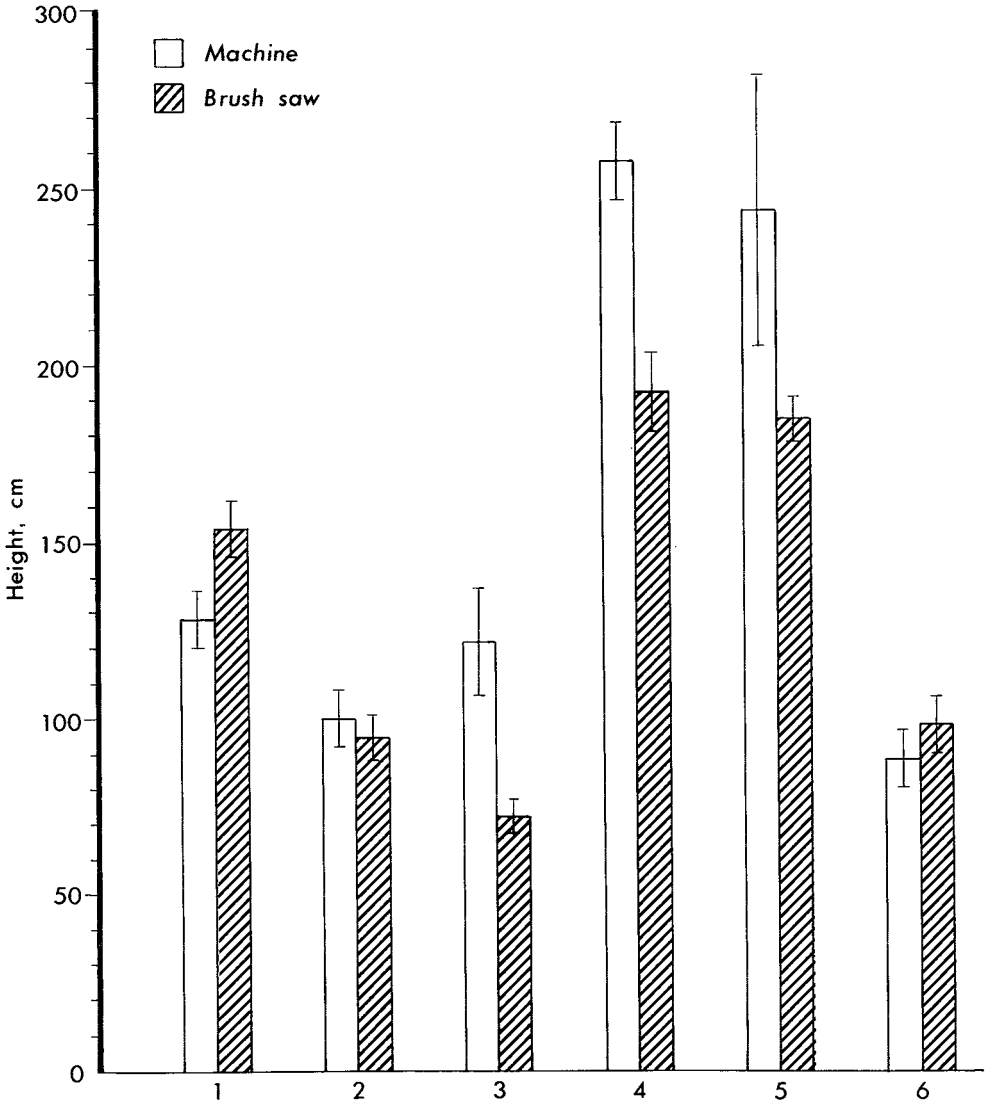

Fig. 4. Average number of sprouts of European aspen (Populus tremula L.) stumps four years after cleaning by machine and brush saw in the series of six trials. Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

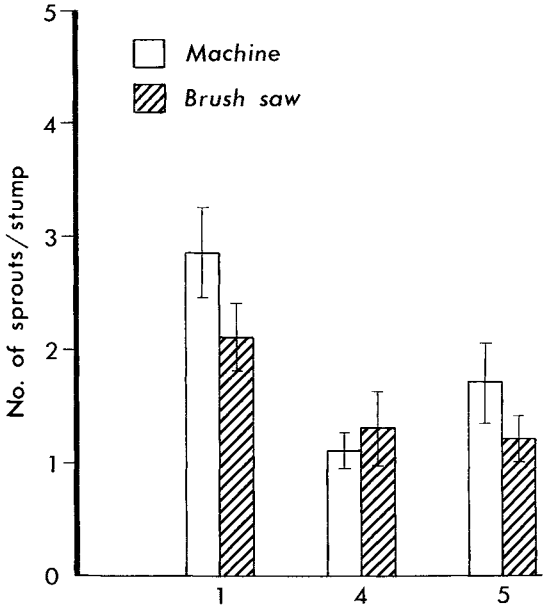

Fig. 5. Mean height of pubescent birch (Betula pubescens Ehrh.) sprouts four years after cleaning by machine and brush saw in the series of six trials. Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

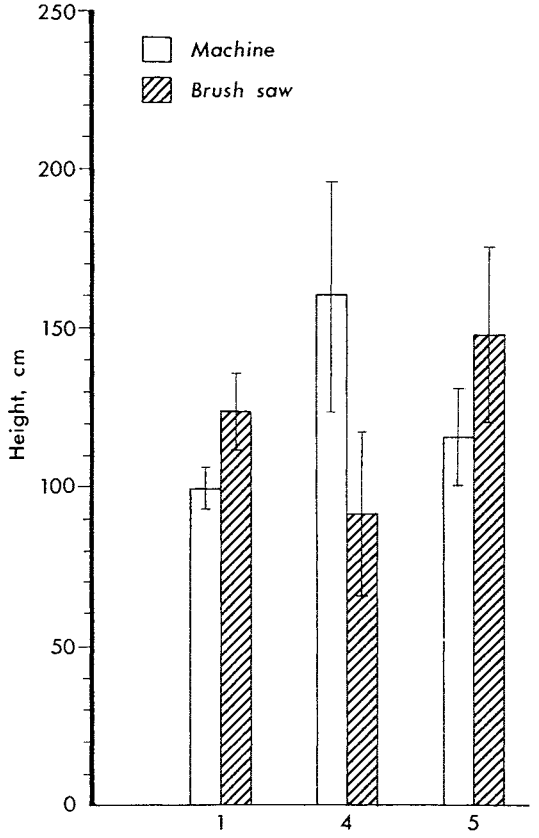

Fig. 6. Mean height of European aspen (Populus tremula L.) sprouts four years after cleaning by machine and brush saw in the series of six trials. Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

Table 5. *Number and height (cm) of main stems of conifers and frequency of damage (per cent) caused by cleaning by machine and brush saw in the series of six trials in south and middle Sweden*

Trial No.	Treatment[1]	Number			Height, cm				Diameter, mm (DBH)		Damage by cleaning, %		
		Total n	Pine %	Spruce %	Pine 1983	1987	Spruce 1983	1987	Pine	Spruce	Pine	Spruce	Total
1	M	87	2	98	69	105	77	150	23	18	0	13	13
	B	41	2	98	65	120 ns	73 ns	181 ns	29 ns	20 ns	0	0	0
2	M	83	77	23	86	242	99	187	28	22	9	0	9
	B	78	73	27	87	220 ns	97 ns	190 ns	24 ns	20 ns	0	0	0
3	M	59	0	100	–	–	173	346	–	44	–	8	8
	B	44	45	55	165	450	176 ns	418 ns	72	54 ns	0	0	0
4	M	61	0	100	–	–	116	343	–	34	–	7	7
	B	83	6	94	91	282	103 ns	287*	32	29 ns	0	0	0
5	M	48	0	100	–	–	145	398	–	44	–	13	13
	B	55	0	100	–	–	165 ns	466 ns	–	58 ns	–	0	0
6	M	56	75	25	68	240	48	112	32	16	0	12	12
	B	71	52	48	59	176 ns	40 ns	131*	23 ns	20 ns	0	0	0

[1] M = Machine, B = Brush saw.
* = Significant at 0.05 level.
ns = Not significant.

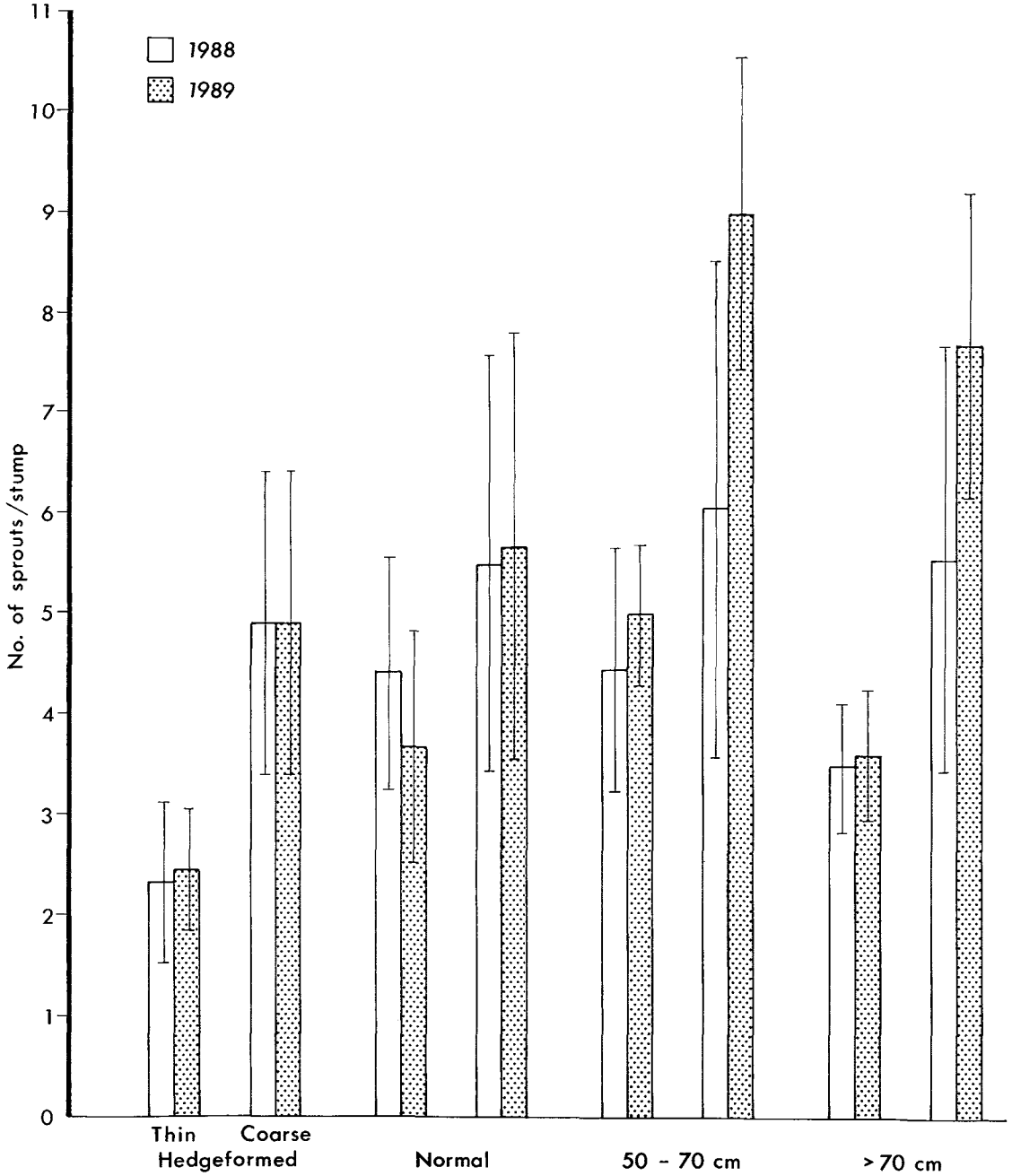

Fig. 7. Average number of sprouts of pubescent birch (Betula pubescens Ehrh.) stumps cleaned by machine under snow conditions. Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

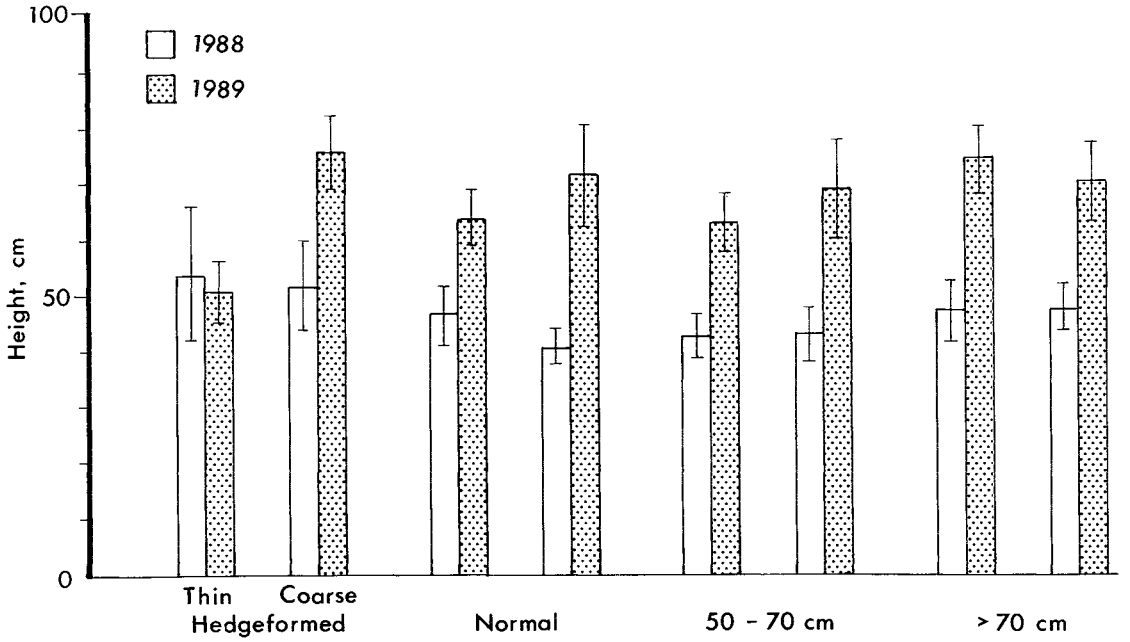

Fig. 8. Mean height of pubescent birch (Betula pubescens Ehrh.) sprouts cleaned by machine under snow conditions. Bars with confidence limit at $p \leq 0.05$ ($\pm$ 1.96 · SE).

Discussion

As there is a large number of sprouts per living stump during the early years after cleaning (cf. Figs. 1 and 7), it is important in what way and at what time cleaning is carried out. The cutting of high stumps, on which living branches remain, on a regeneration area containing young, small conifer plants (especially pines), may cause more serious competition than if cleaning were delayed for some years.

In the series of six trials, stumps of pubescent birch were taller on plots cleaned by machine than on those cleaned by brush saw (Table 2). Especially on plots Nos. 3, 5 and 6, there were large differences in stump height between the two methods, which probably depended on differences in the terrain. There were difficulties when the machine was used for cleaning close to the ground, if there were surface boulders, uneven or sloping ground. By contrast, if the surface is without stones (mainly on moist sites), the worker with a brush saw will cut lower stumps than is possible on fresh sites with more surface stones. In both cases, the machine will cut higher stumps than the brush saw, in avoiding damage to equipment or conifers. Work with a brush saw is more easily adapted to different situations than is that with the machine. The differences in stump height at the three sites mentioned above had little effect on the development of sprouts or on the number of sprouts. However, the height of sprouts was greater after cleaning by machine than after cleaning by brush saw, at two of the three sites (3 and 5), cf. Fig. 5.

In general, most of the sprouts developed close to ground level, so that the stump was, for the most part, free from sprouts 10 cm above ground on stumps higher than 30 cm. Kauppi, Rinne & Ferm (1988) reported that 90 per cent of the buds on stumps of pubescent birch were below ground level, and that one-third of the sprouts originated above ground. Johansson (1992*a*) found that 6–24 per cent of the buds on stumps of pubescent birch were above ground. On high stumps, there were some twigs or sprouts near the cut surface of the stump. Examination of the number of aspen sprouts was based only on stump sprouts. The number of sprouts per living aspen stump was the same as the number of birch sprouts. But in the year of inventory (1987), the height of aspen sprouts was low, as compared with that of pubescent birch sprouts. Sprouts of aspen are, in general, shorter than those of birch. Stump sprouts of aspen did not compete with conifers in the present study, whereas root suckers did so. Root suckers were not counted in the present study. The number of root suckers of cut aspen is, in many cases, very great.

Børset & Haugberg (1960) reported the occurrence of 17,000–70,000 root suckers per hectare and on some areas, 200,000 shoots per hectare have been observed (Blumenthal, 1942). The most usual means of vegetative regeneration of aspen is by root suckers, which grow faster than stump sprouts.

Parts of the stumps cut by machine were more damaged than those cleaned by brush saw. Bark and pieces of wood were removed from the stump, and in theory, such wounds might be infected by fungal spores. In practice, this was not observed. However, on aspen stumps there were traces of damage caused by fungi. The stump was still alive, the sprouts may have been infected and the rot was established in the stem. Root suckers of aspen were not infected by rot.

A practical implication of the study under snow conditions, is that on high stumps, 25–35 cm is added to the height of the sprouts. Branches on hedge-formed stumps will grow up, and the wide canopy of sprouts and branches thus created competes with conifers more seriously than do stump sprouts alone. Another practical implication is that stands of birches with branches close to the ground are to be avoided, if the only way to clean the stand by machine is to leave high stumps. Such stands are often very young, and large numbers of sprouts will develop, even if the stumps are low (Johansson, 1991). In such cases, it may be necessary to wait 1–3 years before releasing the stand, especially if the conifers are mainly spruces, which compete very well with birches, even in dense stands.

Most of the injuries caused by the machine were classified as a bent stem, accompanied by clusters of branches. The injuries resemble damage to Scots pine caused by *Melampsora pinitorqua* (L.). The frequency of injury to conifers by the machine was within the range given by Mellström & Thorsén (1982) and Wästerlund (1988). On the two plots situated on moist sites, the highest level of injury occurred. One explanation of this might be that the wheel of the machine sank into the ground, causing the limit for damaging the conifers to be reached.

A special consequence of leaving high stumps ensues when hardwoods in harrow furrows are cleaned. In middle and south Sweden, on moist and fertile sites, the number and height of hardwoods (mainly birches) in harrow furrows is great. A practical way of solving this type of problem, is to clean between the plants by machine, then to release the conifers with a brush saw. The stumps will then be low, and the conifers may be able to grow and compete with the sprouts. Another method is to cut the birches at the height of the conifers, but for two reasons, this is not a good solution: (1) The stumps remaining are high, and sprouts emerge quickly and compete with the conifers at once; and (2) there is a serious risk for damage to conifer leaders, the result being a reduction in growth and in the development of double leaders, or a bend in the stem at a later stage.

Equipment for stand cleaning has been developed further since this study was made. In 1991, three types of machine are available to forestry. One of them is useable for cleaning alone. The machines have a ground clearance of 0.8–1.2 m, and are lighter than the older models, to reduce soil compaction. The tyre diameter has been increased, to reduce the ground pressure. A practical rule is that the height of conifer stems may be up to twice the ground clearance, before damage to leaders occurs. Today, machine cleaning of dense broadleaf stands mixed with conifers may be carried out in three ways:

1. Cleaning by machine alone,
2. Removal by brush saw of broadleaves growing close to the conifers, and the other parts by machine,
3. Simplified cleaning by machine, whereby broadleaves growing close to the conifers are left, and are cleaned by brush saw later.

Damage to conifers by the machine is reduced if cleaning is carried out when the broadleaves are leafless. Damage to conifers is also reduced if method (2) above, is used, as compared to method (1). In economic terms, cleaning by methods (2) or (3) is cheaper than cleaning by brush saw alone, and cleaning by machine is as expensive as cleaning by brush saw. However, the machine is very useful in dense stands (> 15,000 stems/ha) and where the area to be cleaned is large, especially in today's circumstances, in which the number of trained staff in the forest is decreasing. In some forestry companies, 30–50 per cent of the total annual cleaning area is to be cleaned by machine.

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