Two Felling Methods in Final Cutting of Shelterwood, Single-Grip Harvester Productivity and Damage to the Regeneration

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In order to find an efficient and careful way of final-cutting shelterwoods, two felling methods, in a single-grip harvester system, were compared with respect to productivity and damage caused to the regeneration. The shelterwood (140–165 m^3/ha) consisted of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) and the natural regeneration (9530–11 780 seedlings/ha) mostly of Norway spruce. Treatments were: (i) conventional felling on both sides of the harvester striproad, preferably in blanks of the regeneration; (ii) felling of the trees top-end first into the striproad using a method named "tossing the caber". Both treatments included forwarding after felling. Conventional felling had a non-significantly higher productivity (27.4 m^3/E_{15}–h) and lower cost (25.9 SEK/m^3) than tossing the caber (26.1 m^3/E_{15}–h and 27.2 SEK/m^3). However, tossing the caber was significantly more efficient in the felling and processing of pine trees compared with conventional felling. The mean proportions of the disappeared and damaged seedlings were approximately 40% after both treatments. The logging-related damage to the regeneration decreased with increased distance to the striproad in the tossing the caber treatment but not in conventional felling. The conclusions were that there were no differences between the treatments regarding productivity, cost and total damage to the regeneration in mixed conifer shelterwoods but that tossing the caber could be a more productive method than conventional felling in pine dominated stands. Tossing the caber could also be beneficial at a regeneration height of 2–3 m since at this height the damage to the regeneration seems less than at conventional felling.

Keywords cost, forest operations, felling technique, logging-damage, silviculture, time study
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1 Introduction

The shelterwood system is an old method for regeneration of Norway spruce (*Picea abies* (L.) Karst.) that has been put into use again (Westerberg 1995) on approximately 5% of the annually regenerated area in Sweden (Braf 1998). However, logging-related damage to the regeneration, especially at the final cutting, is a problem in the shelterwood system. Few studies are reported on final cutting of shelterwood with harvester systems, and hence, the knowledge is limited concerning productivity, cost and damage to the regeneration. As the logging methods for the shelterwood system are still under development, comparative studies of machines and methods are needed (Bergstrand 1987, Samseth 1990). Furthermore, Leikola (1982) argued that the development of careful logging methods is one of the most important research tasks within the area of natural regeneration.

Earlier studies of manual- or motor-manual cut-to-length methods show that between 8–38% of the original conifer seedlings were dead or damaged after final cutting of conifer shelterwoods (Hartelius 1944, Skoklefald 1967, Andersson and Fries 1979).

Two Russian methods to minimise damage to advance growth after whole-stem logging with motor-manual felling and a skidder are described in Jeansson and Lestadius (1981). The first is the Kostroma method where the overstory trees are felled in a fan pattern over a lying tree, are delimbed and skidded root-end first to the striproad. This damaged 20% of the conifer advance growth (<1 m) during winter- and 40% during summer logging. The second is the Narrow strip method where the trees are felled with the crowns pointing towards the striproad and are skidded top-end first. This damaged up to 10% of the conifer advance growth between the striproads, compared with up to 85% in a conventional felling and skidding operation. Youngblood (1990) found approximately 29% of the conifer seedlings to be mortally damaged after shelterwood removal by ground-skidding and cable-yarding.

In studies of damage caused to conifer regeneration by cut-to-length harvester systems, Gingras (1990) reported a 30% reduction and Meek and Plamondon (1996) a 27–44% reduction in the stocking, after final cutting of a softwood dominated and a pure softwood stand, respectively. Furthermore, Vorob et al. (1994) found 52–56% of the conifer advance growth to be dead or damaged after removing a broad-leaved overstory. After final cutting of conifer shelterwoods overstoring conifer regeneration, Westerberg and Berg (1994) found 48–54% and Sikström and Glöde (2000) found 38–65% of the original seedlings to be dead or damaged. Moreover, Peltoniemi (1991) and Mäkelä (1990) found that up to a third of the original conifer seedlings were dead, dying or damaged after final cutting of conifer shelterwoods. Mäkelä (1995) concluded that the harvesting costs, in the former two studies, were at their lowest using a single-grip harvester and that the two-grip harvester was the most expensive method. However, Glöde (1999) could not find any significant differences between single- and two-grip harvester systems concerning productivity and cost in final cutting of conifer shelterwoods.

Travelling and slash from the delimbed trees causes most of the damage to the regeneration at final cutting of shelterwood (Skoklefald 1967, Sikström and Glöde 2000). However, Skoklefald (1967) argued that the damage from slash could be reduced if it was evenly spread and Hagner (1962) suggested that felling the shelter trees in different directions would spread the slash. On the contrary, Meek and Plamondon (1996) studied a single-grip harvester system in a softwood stand and found that concentrating log and slash piles reduced the damage to the advance conifer regeneration compared with dispersal of slash and a conventional cut-to-length method.

In order to find an efficient and careful way of final-cutting shelterwoods an alternative felling method named "Tossing the caber" was developed, in which the trees are felled top-end first into the striproad where they are processed. A comparative study between tossing the caber and conventional felling was carried out to examine productivity, cost and how logging-related damage to the regeneration was affected by the concentration of the felling and processing when tossing the caber. The hypothesis was that there would be no difference in productivity and cost between the two felling methods and that the proportion of damaged seedlings would increase in the striproad, decrease between the striproads and, on average, be lower when using the tossing the caber method compared with conventional felling.

2 Materials and Methods

2.1 Experimental Stand and Treatments

The experimental stand was situated in the south-east part of Sweden at 58°33´N on a level site with an even ground surface. It consisted of a Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) shelterwood overstoring natural Norway spruce dominated regeneration (Table 1). The stand was divided into two blocks based on mean regeneration height (h) and soil type. One block was located on mineral soil (h = 1.3 m) and the other on peat-soil (peat depth > 0.3 m, h = 1.8 m). Each block was divided in two halves, where the treatments were randomised (i.e. a randomised block design was used).

Treatments included forwarding and consisted of final cutting of shelterwood with two felling methods: (i) conventional felling on both sides of the harvester striproad, preferably in blanks of the regeneration. The operator was instructed that the trees should be processed on the same side of the harvester as they were felled, in order to minimise dragging of trees within the regeneration. Conventional felling was applied on 89 and 157 trees in blocks 1 and 2, respectively, in areas of 0.27 and 0.25 ha; (ii) felling of the trees top-end first into the striproad using the tossing the caber method. The operator instruction was that when a tree was cut and began to fall, the boom should be used to lift and steer the tree towards the striproad in order to land it with the top-end first. The grip of the root-end should be retained to avoid damage to the regeneration and, if necessary, the moment of falling should be used to push the tree towards the striproad. When the top-end had landed in the striproad, the back-end should be lifted over the regeneration and into the striproad, where the tree should be processed parallel to the direction of the striproad (Fig. 1). Tossing the caber was applied on 90 and 93 trees in blocks 1 and 2, respectively, in areas of 0.28 and 0.23 ha. The same operator, who was trained and skilled in both methods, was used throughout the study.

Harvesting was done with a Rottne Rapid 890/600 single-grip harvester. The general instruction was to work at the normal sustainable pace and to keep damage low in the regeneration stand. Furthermore, to drive and fell in blank spots of

Table 1. Pre-harvest data for the regeneration and data for the harvested shelterwood in the two treatments given as means averaged over both blocks, with 95% confidence intervals [ ] or with minimum and maximum values of individual shelter trees ( ).

	Conventional felling	Tossing the caber
Regeneration		
Seedlings ha^{-1}	9530 [±5670]	11 780 [±4980]
Mean height (m)	1.3 [±0.2]	1.2 [±0.2]
Spruce / Birch (% by no.)	94 / 6 [±11/11]	93 / 7 [±9/7]
Blanks (%)	3 [0–10]	2 [0–4]
Shelterwood		
DBH – in total (cm)	23.3 (8–44)	24.6 (8–45)
– pine (cm)	25.7 (10–39)	26.8 (14–40)
– spruce (cm)	22.4 (8–44)	23.6 (8–45)
Mean height (m)	18.2 (13.6–21.2)	18.4 (13.5–21.3)
Mean stem volume (m^3)	0.36 (0.03–1.10)	0.39 (0.03–1.16)
Volume (m^3 ha^{-1})	165	140
Pine / Spruce (% by vol.)	34 / 66	36 / 64

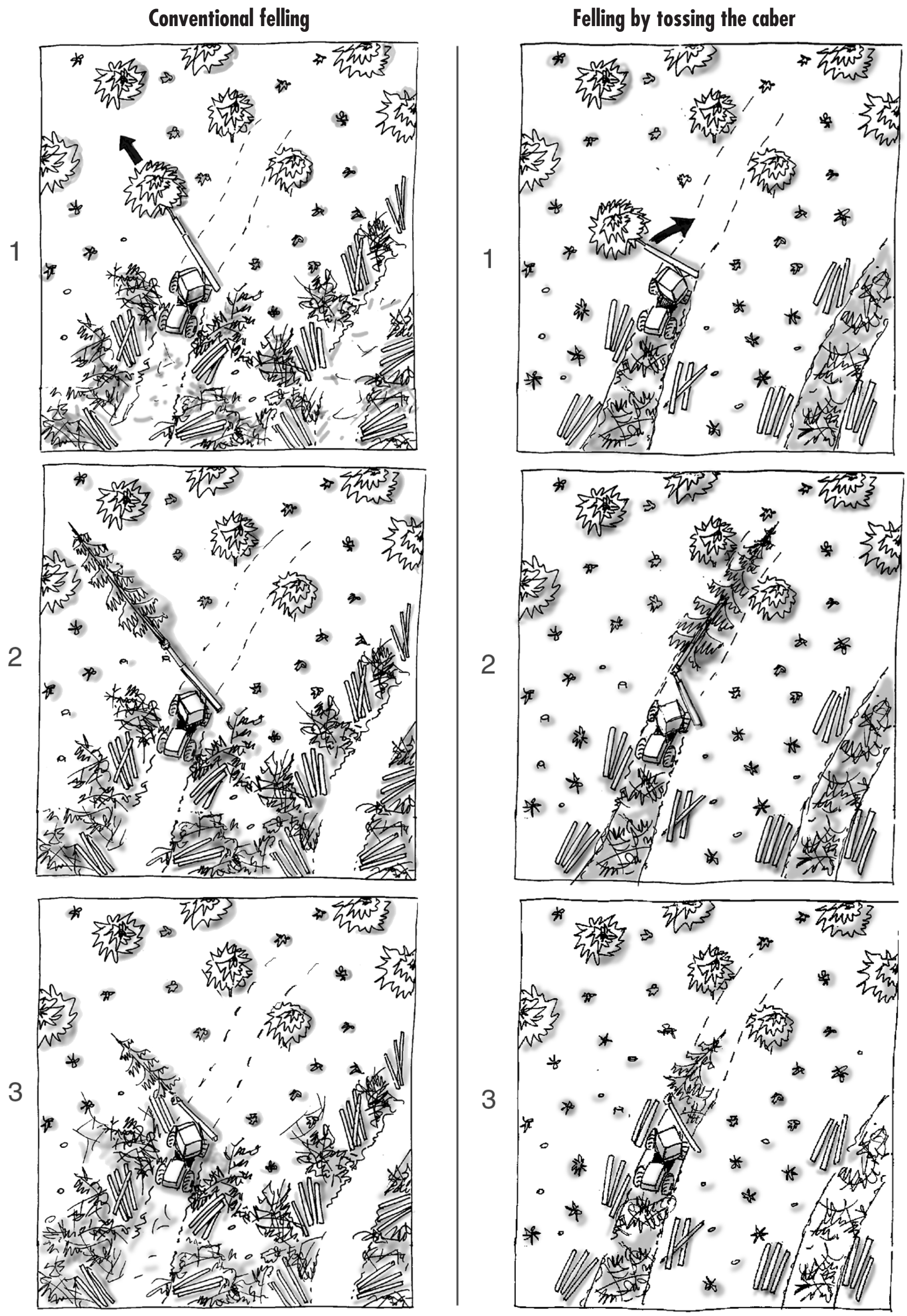

Fig. 1. Conventional felling and felling by "Tossing the caber" method. 1. Direction of the felling (see arrow); 2. Location of the felled trees in relation to the striproad planned ahead of the machine; 3. Location of the tree when it is processed and the resulting distribution of timber and slash.

Table 2. Definitions of the work cycle elements for the single-grip harvester.

Boom-out: Begins when the boom is moving towards the tree and ends when the harvester head is 1 m from the stem.
Felling: Begins when the harvester head is 1 m from the stem and ends when the feed rolls start to turn.
Processing: Begins when the feed rolls start to turn and ends when the last piece of the tree drops from the harvester head. Has higher priority than other elements.
Start/wait: Begins when the last piece of the tree drops from the harvester head and ends when boom-out or travelling starts.
Travelling: Begins when the wheels start to turn and ends when the wheels are still. Has lower priority than the boom-work elements.
Halt: Begins after travelling has ended and ends when boom-out starts.
Miscellaneous: Other activity related to productive work, e.g. sorting of logs, retake when felling, relocation of the harvester during processing or boom-in, sight clearing, etc.
Disturbance: Begins when disturbance occurs in time elements above and ends when disturbance is over, e.g. backing for difficult branches when processing, tree is stuck when felling, minor travelling problems etc.
Interruption: Time not related to productive work such as breaks, repairing or maintenance of machine, major travelling problems, etc.

the regeneration, except if the operator observed single seedlings in otherwise blank spots, then he should drive and fell in the densest parts of the regeneration. Forwarding was done with a Bruunett Mini 678F. The operator of the forwarder was instructed to drive strictly in the harvester striproads, to be careful with the regeneration and to forward the treatments separately.

2.2 Productivity Measurements and Analyses

Sight and weather conditions were considered equal during the study, which was carried out in late February 1994. The temperature varied from –8° to –3°C, the ground was frozen and the snow depth was 0.3–0.4 m, including a 5 cm top layer of crust snow.

Tree diameter at breast-height (DBH) was marked on all shelter-trees (DBH > 10 cm). Continuous time studies (cmin) were made using SIWORK3 software (Rolev 1988) and the work cycle elements defined in Table 2. All element times were measured as effective times (E_0) (Forest work study… 1978). For each processed tree, the DBH and tree species were registered (Table 1). The tree heights were derived from a height curve constructed from 20 randomly chosen height measured shelter-trees. All tree volumes were calculated according to Näslund (1947) and are presented as solid volume under bark (m^3) (Table 1). The element disturbance was included in productive time (added to miscellaneous) in the analysis because it might reveal differences in operational methodology between the treatments.

The travelling distance for each machine movement was registered with a measuring line. The working width was measured at every 20 m along the striproads as the distance between marked stumps on one side of the striproad perpendicular to the other side. Means for travel distance and speed, working width and felled trees per set-up place were calculated per block and treatment and averaged over both blocks.

Hence, the study includes both measurements for which the tree is the experimental unit (the work cycle elements) and measurements for which the block and treatment, i.e. the block half, is the experimental unit (travel distance, working width, travel speed, felled trees/set-up place). Analysis of each type of measurement has incorporated the appropriate error term.

The effects of treatment on the time study elements boom-out, start/wait, travelling and miscellaneous were investigated by analysis of variance using SAS/STAT (1987) software and a generalised linear model (1) to account for the block and unequal replication of trees. For the elements felling and processing, where tree species, volume and height were considered to have a potential effect, additional terms to allow for these were included in the model (2). Interactions between included terms, in both models, were examined and added to the models if significant effects ($p < 0.05$) were found. The residuals in the two models were tested for normality with the W-test (Shapiro and Wilk 1965) using SAS/STAT (1987) software procedure UNIVARIATE. In both models the difference between treatments was considered significant if $p < 0.05$.

$$y_{ijk} = \mu + u_i + t_j + e_{ijk} \quad (1)$$

$$y_{ijlm} = \mu + u_i + t_j + s_l + (ts)_{jl} + \beta_1 d_{ijlm} + \beta_2 h_{ijlm} + e_{ijlm} \quad (2)$$

where:

y_{ijk} = the measurement on the k'th tree in the j'th treatment and i'th block
y_{ijlm} = the measurement on the m'th tree of the l'th species in the j'th treatment and i'th block
μ = total mean
u_i = effect of block i (i = 1, 2)
t_j = effect of treatment j (j = 1, 2)
s_l = effect of tree species l (l = 1, 2)
$\beta_{1,2}$ = regression coefficients
d_{ijlm} = value of DBH for the tree $ijlm$ (m = 1, n_{ijlm} where n_{ijlm} is the no. of trees per block, treatment and species i.e. 27, 62, 24, 66, 41, 116, 30 and 63)
h_{ijlm} = value of tree height $ijlm$ (m = 1, n_{ijlm})
$e_{ijk,\,ijlm}$ = residual effect comprising between tree variation and block interaction.

The factor of 0.71 was used as the relation between productivity per effective time (m^3/E_0–h) compared with per gross effective time (m^3/E_{15}–h) (Glöde 1999).

The machine cost was chosen as prevailing reimbursement (Holmen Skog AB) to contractors with the studied harvester type and was set to 710 SEK/E_{15}–h.

2.3 Regeneration Measurements and Analyses

Before final cutting, 12 circular plot centres in each treatment in block one and 9 circular plot centres in each treatment in block two were marked with aluminium rods, in a grid system of 15 × 15 m. The heights of all conifer seedlings > 0.4 m and < 10 m were registered on the circular plots (r = 2.52 m) before and one week after final cutting. Potential birch (*Betula* sp.) crop-tree seedlings were measured if no conifers were found. In conventional felling 232 and 169 seedlings were registered in blocks 1 and 2, respectively, and in tossing the caber 291 and 206 seedlings were registered in blocks 1 and 2, respectively. The circular plots were divided into quarters and if both conifer- and birch seedlings were missing on a quarter it was registered as a blank. After final cutting, logging-related damage to the seedlings was registered according to Sikström and Glöde (2000) concerning type and severity (Table 3). Furthermore, the distances from the circular plot centres to the centre of the nearest striproad were measured and slash coverage in percent of the circular plot area was estimated.

Mean values per block and treatment were calculated and averaged over the blocks (treatment means) for: seedlings per ha based on the number of seedlings per circular plot; seedling height based on the arithmetic mean of the seedling heights per circular plot; proportion of undamaged, damaged and disappeared seedlings per circular plot in relation to the original number of seedlings; proportion of seedlings in different classes of damage type and severity per circular plot in relation to the total number of damaged seedlings; proportion of blanks based on the number of blank circular plot quarters per block and treatment (quarters with all seedlings severely damaged were regarded as blanks); distance from the circular plot centre to the striproad centre as arithmetic mean; slash coverage as arithmetic mean of the estimated proportion of slash per circular plot. A 95% confidence interval was calculated for each treatment mean based on the pooled standard deviation in order to account for the different number of circular plots in the two blocks, and on Student's *t* distribution. All 95% confidence intervals for variables measured as proportions were calculated with arcsine square-root transformed standard deviation to account for unsymmetrical confidence intervals.

All re-found seedlings were sorted in 0.5 m wide height-classes, starting at 0.5–0.9 m and ending at > 2.9 m, and were compared per treatment regarding damage severity.

The relation between the proportion of damaged seedlings per circular plot and the distance

Table 3. Classification of logging-related damage by type and severity and estimated implication on seedling growth and quality (Sikström and Glöde 2000).

Type of damage (1–5)	Damage severity (1–3)[a]
1. Top or stem broken	1. Leading shoot broken, top branches undamaged 2. Stem broken, can grow a new leading shoot 3. Stem broken, cannot grow a new leading shoot
2. Branches damaged or broken	1. Single branches damaged or broken 2. > single < 50% of branches damaged or broken 3. > 50% of branches damaged or broken
3. Stem damage, bark losses	1. < 25% of stem circumference damaged 2. > 25 < 50% of stem circumference damaged 3. > 50% of stem circumference damaged
4. Seedling partly or fully pulled up or bent down	1. Seedling partly pulled up or leaning < 10° 2. Seedling partly pulled up or leaning > 10° < 45° 3. Seedling fully pulled up or leaning > 45°
5. Seedling covered by slash	1. Lower parts of the seedling covered 2. Most of the seedling covered but not the leading shoot 3. Seedling fully covered by slash

[a] Estimated implication on seedling growth and quality for damage severity 1–3.
1 = mildly damaged, i.e. some loss in seedling growth is expected.
2 = moderately damaged, i.e. loss in seedling growth and/or quality is expected.
3 = seriously damaged, i.e. severe loss in seedling growth and quality or mortality.

to the nearest striproad was analysed with linear regression by treatment using SAS/STAT (1987) procedure REG.

3 Results

The travel distance per hectare was shorter, the travel speed slower, more trees per set-up place were felled, and the working width was larger in conventional felling than in tossing the caber (Table 4).

The time for boom-out, start/wait + halt was not significantly different between the treatments, while tossing the caber had a significantly longer time than conventional felling for elements travelling and miscellaneous (Table 5). Felling + processing of pine trees took significantly shorter time in tossing the caber than in conventional felling, whereas spruce trees took a non-significantly longer time to fell+process in tossing the caber than in conventional felling. In total, there was no significant difference between the treatments in harvesting time.

Table 4. Working pattern during the time study. Means per treatment are given with standard deviation ( ).

	Conventional felling	Tossing the caber
Travel distance (m ha^{-1})	590 (99.7)	790 (2.1)
Working width (m)	15.5 (0.4)	14.8 (0.2)
Travel speed (m min^{-1})	27.2 (6.5)	31.8 (4.4)
Felled trees / set-up place (no.)	2.8 (0.1)	2.2 (0.3)

Conventional felling had a non-significantly higher productivity (27.4 m^3/E_{15}–h) and lower harvesting cost (25.9 SEK/m^3) than tossing the caber (26.1 m^3/E_{15}–h and 27.2 SEK/m^3).

All, except two, of the 95% confidence intervals overlapped when comparing treatment means of the regeneration properties after final cutting (Table 6). Exceptions were damage type 5, where tossing the caber had 12 percentage units (p.u.) larger proportion of seedlings covered by slash

Table 5. Time consumption (cmin tree^{-1}) as LS means for the work cycle elements in the treatments conventional felling and tossing the caber. Within a row for the same variable: means with different letter are significantly different at $p < 0.05$; means with a letter in common are not significantly different.

Work cycle element	Tree species	Conventional felling	Tossing the caber
Boom-out	Overall	6.0 a	6.1 a
Start/wait+Halt	Overall	1.4 a	1.6 a
Travelling	Overall	4.7 a	6.9 b
Miscellaneous	Overall	1.4 a	2.6 b
Felling [a]	Pine	17.3 a	15.3 b
	Spruce	16.2 a	17.4 b
Felling + Processing [a]	Pine	47.5 a	42.0 b
	Spruce	40.4 a	42.2 a
Harvesting time, E_0	Overall	56.5 a	59.4 a

[a] A significant interaction ($p < 0.003$) was found between species and treatment; treatment comparison occurs within each species

Table 6. Effects of the final cutting on the circular plot regeneration. Means per treatment averaged over both blocks with 95% confidence intervals [ ].

	Conventional felling	Tossing the caber
Regeneration after final cutting		
Undamaged seedlings ha^{-1}	7260 [±4720]	7600 [±3070]
Mean height (m)	1.1 [±0.3]	1.1 [±0.3]
Spruce / birch (%) [a]	99/1 [±5/5]	99/1 [±3/3]
Blanks (%) [b]	11 [2–23]	16 [3–35]
Proportion of seedlings		
Undamaged seedlings (%)	60 [34–84]	57 [31–82]
Damaged seedlings (%)	19 [8–32]	19 [6–37]
Disappeared seedlings (%)	21 [5–42]	24 [7–46]
Damage type [c]		
1. Top or stem broken (%)	21 [10–35]	16 [7–26]
2. Branches damaged or broken (%)	44 [21–70]	32 [15–52]
3. Stem damage, bark losses (%)	3 [1–4]	5 [2–9]
4. Seedling pulled up or bent down (%)	18 [5–34]	13 [6–20]
5. Seedling covered by slash (%)	11 [2–11]	23 [12–35]
6. Seedling cut-off by harvester head (%)	3 [1–3]	11 [4–12]
Damage severity [c]		
1. Mildly damaged (%)	33 [14–53]	24 [12–39]
2. Moderately damaged (%)	35 [17–57]	44 [20–68]
3. Seriously damaged (%)	32 [10–59]	32 [15–53]
Mean distance from circular plot centres to striproad centre (m)	3.5 [±0.9]	2.9 [±1.0]
Mean slash coverage (%)	42 [18–69]	50 [26–74]

[a] Calculated as percent by number
[b] Proportion of blank circular plot quarters (5 m^2)
[c] See Table 3 for full classifications and definitions

than conventional felling, and damage type 6, where tossing the caber had 8 p.u. more seedlings cut off by the harvester head than conventional felling.

The number of undamaged seedlings decreased by 2270 and 4180 seedlings per hectare after final cutting with conventional felling and tossing the caber, respectively, and the proportion of blanks increased by 8 and 14 p.u. (Tables 1 and 6). The proportion of conifers increased by 5–6 p.u. while the mean height of the seedlings decreased by 0.1–0.2 m in the two treatments.

The mean proportion of disappeared and damaged seedlings after final cutting was 3 p.u. higher after tossing the caber than after conventional felling (Table 6). The proportion of seedlings with damaged branches (damage type 2) was 12 p.u. larger in conventional felling than in tossing the caber. Tossing the caber had a larger proportion of moderately and a smaller proportion of mildly damaged seedlings than conventional felling.

The mean distance from the circular plot centres to the nearest striproad centre was 0.6 m shorter in tossing the caber than in conventional felling (Table 6). The proportion of circular plots within 2 m from the nearest striproad was 19% in conventional felling compared with 43% in tossing the caber, and the proportions of circular plots within 4 m from the striproad were 62% in conventional felling and 81% in tossing the caber. The mean slash coverage was 8 p.u. larger in tossing the caber than in conventional felling.

There was a tendency for the proportion of damaged seedlings to increase with increased seedling height in conventional felling (Fig. 2). The proportion of damaged seedlings was 10% in the lowest and 40% in the highest height class. This was not the case in tossing the caber, where the proportion of damaged seedlings was 20–25% in almost all height classes.

In tossing the caber, the proportion of damaged seedlings per circular plot decreased significantly with increasing distance to the nearest striproad centre, which was not the case in conventional felling (Fig. 3).

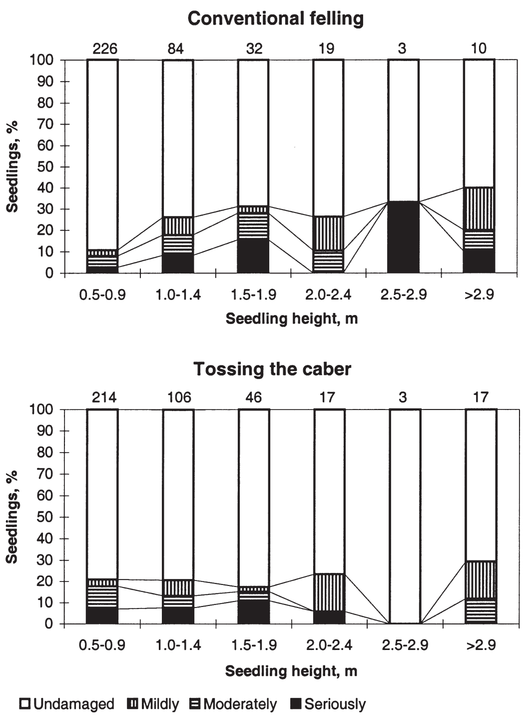

Fig. 2. Proportion of seedlings in different classes of damage severity and seedling height for the treatments conventional felling and tossing the caber. Number of seedlings per height class on top of the bars (see Table 3 for damage severity classes).

4 Discussion

4.1 Productivity and Working Pattern

The hypothesis that there would be no difference in productivity and cost between the two felling methods can not be rejected since the 5% difference in harvesting time was not statistically significant. However, the results indicate that tossing the caber is a more efficient method of harvesting pine trees. Hence, tossing the caber can be an interesting alternative when harvesting pine dominated shelterwoods and seed tree stands. This could be explained by the fact that pine trees usually have larger and thicker branches and therefore are more difficult and time consuming to drag root-end first towards the striproad, as compared with spruce trees. Furthermore, when using tossing the caber, a lot of processing time is probably saved due to the quick drive of the harvester head over the first, usually, branch-free part of the felled pine tree.

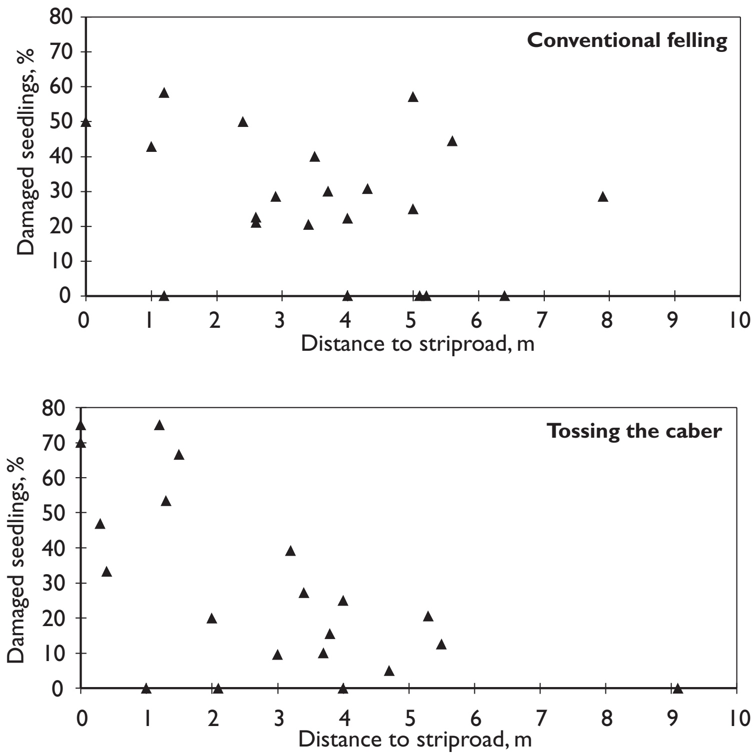

Fig. 3. Distance from circular plot centres to the nearest striproad centre (x) in relation to the proportion of damaged seedlings on the circular plots (y). Linear regressions for:
Conventional felling: $y = 39.0 - 3.21 * x$ ($r^2 = 0.10$; $p = 0.1546$; $n = 21$)
Tossing the caber: $y = 49.7 - 7.38 * x$ ($r^2 = 0.40$; $p = 0.0021$; $n = 21$), where r^2 = degree of explanation; p = level of significance on curve inclination; n = no. circular plots.

The fact that travelling and miscellaneous elements took a longer time in tossing the caber than in conventional felling indicates a difference between the methods due to operational methodology. However, the fewer trees per hectare in tossing the caber might have caused the longer time in the travelling and miscellaneous elements, as well as the smaller working width and the fewer processed trees per set-up place compared with conventional felling. Another explanation could be that the operator, even though he had practised tossing the caber before the study, was not as used to the method as he was to conventional felling, which resulted in the longer time in elements travelling and miscellaneous when tossing the caber.

The lifting and pushing of the trees when ”tossing” them into the striproad requires a larger lifting capacity of the boom than when simply felling the trees. Thus, it is likely that the lifting capacity of the boom limits the working width more when tossing the caber than in conventional felling, at least when the trees are large. This was indicated by the narrower (0.7 m) working width in tossing the caber compared with conventional felling. However, it is difficult to conclude if the difference is consistent since the layout of the striproads varied between the treatments.

4.2 Logging-related Damage Caused to the Regeneration

In accordance with the hypothesis, the proportion of damaged seedlings increased in the striproad and decreased between the striproads when tossing the caber, as compared with conventional felling. However, the total proportion of disappeared and damaged seedlings was not lower in tossing the caber than in conventional felling, which was in conflict with the hypothesis. The assumptions behind the hypothesis was that at a travel distance of 700 m/ha (Glöde 1999) and at a striproad width of 3 m, approximately 2100 m^2/ha of the logged area would be affected by a concentration of the felling and processing into the striproad. Assuming a shelterwood of 200 trees/ha, where the trees have a green crown length of 15 m and a width of 4 m between the shoots on the lowest branches, the tree-crown area that would affect the regeneration would be 30 m^2 per felled tree, i.e. 6000 m^2/ha. Hence, theoretically it would be possible to decrease the area affected by felling by 40 percentage units. Still, our results indicate no difference in the proportion of damaged seedlings between the more dispersed conventional felling and felling concentrated to the striproads according to the tossing the caber method.

However, the representativity of the circular plots could be questioned since 80% of the plots in the tossing the caber treatment were within 4 m from the striproad centre compared with 60% in conventional felling. This difference is too large to be explained by the 0.7 m difference in working width. To increase the comparability between treatments, the regression functions in Figure 3 can be used to plot the proportion of damage at the same mean distance from the circular plots to the nearest striproad. At a mean distance of 3.5 m, the proportion of damaged seedlings is 24% according to the tossing the caber function and 28% according to the conventional felling function. Hence, the difference between the methods is still fairly small concerning the proportion of damaged seedlings. The functions indicate that tossing the caber could result in a decreased proportion of damaged seedlings with increased distance between striproads, which does not seem to be the case in conventional felling. However, limitations in the lifting capacity of the boom might restrict an increased distance between the striproads when tossing the caber.

The proportion of logging-related damage is known to increase with increased seedling height in conventional felling (Skoklefald 1967, Hagström 1994, Sikström and Glöde 2000). Based on our results, felling by tossing the caber could instead be expected to damage seedlings to the same extent in all height classes. Thus, it may be suggested that the tossing the caber method can be used if the regeneration is 2–3 m in the final cutting of shelterwoods.

The proportion of blanks increased in both treatments after final cutting, but this probably has little impact on future volume production since the blanks were small and well scattered, and because the regeneration still was dense.

The fact that slash covered a larger proportion of the seedlings in tossing the caber than in conventional felling might depend on tossing the caber having a larger part of the circular plots in, or close to, the striproad. The latter might also explain the larger mean slash coverage in tossing the caber compared with conventional felling. However, when using the tossing the caber method, a felled volume of 140 m^3 per hectare did not damage or cover all seedlings in the striproad, which is interesting, since a more or less ”blank” striproad was expected.

5 Conclusions

There were no differences between the treatments regarding productivity, cost and total damage to the regeneration in final cutting of the mixed conifer shelterwood. However, felling by the tossing the caber method can be an interesting and more productive alternative than conventional felling in final cutting of pine-dominated shelterwoods or seed tree stands. Tossing the caber can also be beneficial at a regeneration height of 2–3 m since at this height the damage to the regeneration seems less than at conventional felling.

Further studies are needed to: (i) compare productivity and working width at varying species composition, mean stem volume and stems per hectare in the shelterwood; (ii) compare the amount of damage caused to the regeneration at varying striproad distances and at varying densities and mean heights of the regeneration.

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