www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

Damage to Residual Stand Caused by Mechanized Selection Harvest in Uneven-Aged *Picea abies* Dominated Stands

Emil Modig, Bo Magnusson, Erik Valinger, Jonas Cedergren and Lars Lundqvist

Modig, E., Magnusson, B., Valinger, E., Cedergren, J. & Lundqvist, L. 2012. Damage to residual stand caused by mechanized selection harvest in uneven-aged *Picea abies* dominated stands. Silva Fennica 46(2): 267–274.

Permanent field plots were established in two uneven-aged Norway spruce (*Picea abies* (L.) Karst) dominated stands in west-central Sweden. The objective was to quantify level and type of damage caused by harvesting and to quantify the difference between two treatments: T20) only skid road harvest (20 m distance between ca. 4 m wide roads), and T40) skid road harvest (40 m distance between ca. 4 m wide roads) combined with thinning between the roads. In T40, the goal was to harvest approximately the same standing volume as in T20. After harvest, two circular sample plots (radius 18 m, i.e. 1018 m^2) were established at random locations within each treated area. All mechanical damage on the stem caused by harvest was measured and registered, including bark stripping larger than 15 cm^2, stem broken or split, and tearing of branches causing damage on the stem. About 70–90 per cent of the damaged trees were smaller than 15 cm dbh. Very few trees larger than 25 cm dbh were damaged. In T20, more than 50 per cent of the damaged trees were located less than 5 m from the skid road, compared to less than 25 per cent for T40, in which more than 50 per cent of the damaged trees were located 5–10 m from the skid road. Creating only half the number of skid roads caused no more damage, and was probably more profitable because mean stem volume was about 1.5 times larger than in T20.

Keywords selection cutting, logging damage, continuous cover management, residual stand, logging methods
Addresses *Modig*, Statens fastighetsverk, Jokkmokk, Sweden; *Magnusson*, Skogsstyrelsen, Bräcke, Sweden; *Valinger* and *Lundqvist*, Deparment of Forest Ecology and Management, SLU, SE-901 83 Umeå, Sweden; *Cedergren*, Mariehamn, Åland
E-mail lars.lundqvist@slu.se
Received 23 November 2011 **Revised** 13 March 2012 **Accepted** 14 March 2012
Available at http://www.metla.fi/silvafennica/full/sf46/sf462267.pdf

1 Introduction

There is today a growing interest in uneven-aged forestry, which increases the demand for knowledge about how to perform the harvests. In the selection system, trees lost through harvest or mortality should continuously be replaced by ingrowth of new trees from below. The level of ingrowth that is required is thus a direct result of the mean number of trees harvested per year, and the level of mortality.

In Fennoscandia the selection system is usually restricted to Norway spruce (*Picea abies* (L.) Karst) stands. Studies of the stand dynamics of such forests have shown that the annual ingrowth can be expected to be about 5–15 trees ha^{-1} (e.g. Lundqvist 1993, Andreassen 1994, Lundqvist et al. 2007). This level of ingrowth has been shown to be sufficient to maintain tree density, basal area and standing volume at levels necessary for high and sustainable growth and yield (Lundqvist 1994, Lundqvist et al. 2007).

The above results have been attained on experimental plots, where the harvest operations are conducted in ways to ensure a minimum of damage to the residual stand. Granhus and Fjeld (2001) have shown that the level of damage to advance growth in commercially harvested uneven-aged Norway spruce stands is affected primarily by the amount of removal, and distance from the nearest skid row. In a pilot study, Hagström (1994) found that on average 5.1 per cent of trees from 0.5 m height to 6 cm dbh were damaged. Granhus and Fjeld (2001) found substantially more damage: on average 41 per cent of trees with height 0.5–3 m. A difference between the studies was that basal area removal was twice as high in the latter study. Surakka et al. (2011) partly confirmed these earlier studies, but instead of proportion of basal area harvested they found that the absolute level of basal area removal was a better predictor for sapling (0.5–2 m height) damage. Among trees higher than 3 m, Fjeld and Granhus (1998) showed that an average of 13.7 per cent of the trees was damaged, and that mechanized harvesting systems caused more damage than chain-saw systems.

In commercial forestry in Fennoscandia today, harvest operations are usually mechanized, using single-grip harvesters. If the selection system is to gain acceptance in Swedish forestry, it must be possible to use mechanized systems for harvesting. Studies of mechanized harvests in even-aged stands show that it is possible to reduce damage substantially by using skilled harvester operators (Sirén 1999). The risk of damage is also affected by the ambient temperature and of snow covering seedlings and saplings (Wästerlund 1986, Eliasson et al. 2003).

In forests not previously subjected to selection harvests, the first treatment will include establishment of skid roads for forwarding. At subsequent harvests, the same skid roads will be used, and the spatial distribution of damage can thus be expected to be different. Only harvesting the skid roads results in a harvest where mean stem volume is considerably smaller than what is expected from the subsequent selection harvests. Because of this the proportion of saw timber will be lower, and the harvest cost per m^3 will be higher (Lageson 1996) at this initial harvest compared to future selection harvests. One way to increase the profitability of the first harvest could be to only establish half the number of the skid roads at the first harvest, and harvest the remaining volume between the roads, as in normal selection harvests. At the second harvest, the second half of the number of skid roads would be established.

In the early 2000s, the Swedish Board of Forestry initiated a general study of continuous cover forestry in Sweden (Cedergren 2008). One of the subjects of interest was the expected level of damage in mechanized selection harvests. For this purpose a pilot study was performed, in which permanent field plots were established and the initial harvest monitored. The objective of this study was to roughly quantify the level and type of damage caused by the harvest, and to quantify the difference between cutting only skid roads, and cutting only half the number of skid roads and harvesting large trees between the skid roads as well.

2 Materials and Methods

The field plots were established in two uneven-aged stands in west-central Sweden, stand one

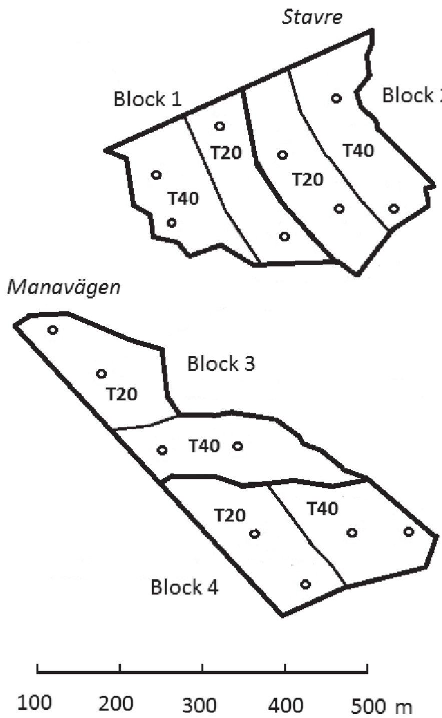

Fig. 1. Layout of the experimental sites with blocks (1–4), treatments (T20, T40) and sample plot positions (small circles).

(Stavre) situated about 10 km north of Bräcke (62°50.0´N, 15°24.0´E, 300 m a.s.l.), and stand two (Manavägen) about 20 km northeast of Bräcke (N62°53.8´N, 15°38.3´E, 325 m a.s.l.). The sites were mesic, soil type moraine, ground vegetation dominated by *Vaccinium myrtillus* L. and mosses. Both stands were dominated by Norway spruce (*Picea abies* (L.) Karst), with a few Scots pines (*Pinus sylvestris* L.), birches (*Betula* spp. L.), and aspen (*Populus tremula* L.). Stand one had not been managed for several decades, whereas stand two had been subjected to a harvest similar to single-tree selection more than 20 years ago.

The experiment had two treatments (T): T20) only skid road harvest (20 m distance, roads ca. 4 m wide), and T40) skid road harvest (40 m distance, roads ca. 4 m wide) combined with thinning between the skid roads. In T40, the goal was to harvest approximately the same standing volume as in T20. Each treatment area was 1.1–1.4 ha in size, and the treatments were replicated twice in each stand, i.e. four blocks in total, with blocks 1 and 2 at Stavre and blocks 3 and 4 at Manavägen (Fig. 1).

The cut to length system applied in this study included a Valmet 901.3 single grip harvester with a Valmet 350 felling head, and a Valmet 840.3 forwarder. The operators chosen had long experience of thinning in even-aged stands and a record of low levels of damage. Both treatments within a block were driven by the same driver. Harvest was done during winter, on frozen ground.

After harvest, two circular sample plots (radius 18 m, i.e. 1017 m^2) were established at random locations within each treated area, with position set by using a random function in ArcMap 9.2 and a GPS locator, i.e. 16 circular plots in all. Within each circular plot species was noted, and diameter at breast height (dbh, 1.3 m) was callipered to the nearest mm for all trees higher than 1.3 m. Tree height was measured on sample trees chosen by the digital caliper (Haglöfs Mantax Computer with software SCAMan 1.6), sampling 10 trees per 25 m^2 basal area measured, resulting in about five sample trees per circular plot. All stumps originating from the harvest were also callipered, at about 0.3 m above ground.

All mechanical damage caused by the harvest was measured and registered, including bark stripping larger than 15 cm^2, stem broken or split, and tearing of branch causing damage on the stem. Number of injuries, damage type and height of each damage, and distance to skid road, were registered for each damaged tree. An attempt was also made to identify the cause of damage: machine movement (driving), crane work (crane), tree felling (felling), de-branching and partitioning of felled trees (handling), and unknown cause (other).

Skid road area was measured on each circular plot, using a slightly modified version of the system defined by SkogForsk (2011). Skid road centre was visually defined, and the length of the road crossing the circular plot defined as the distance between the points where the skid road centre crossed the plot circumference. Width of the skid road was estimated by identifying the trees closest to the skid road centre on either side of the skid road, and adding the distances from these trees to the skid road centre.

A height-diameter relation was estimated for

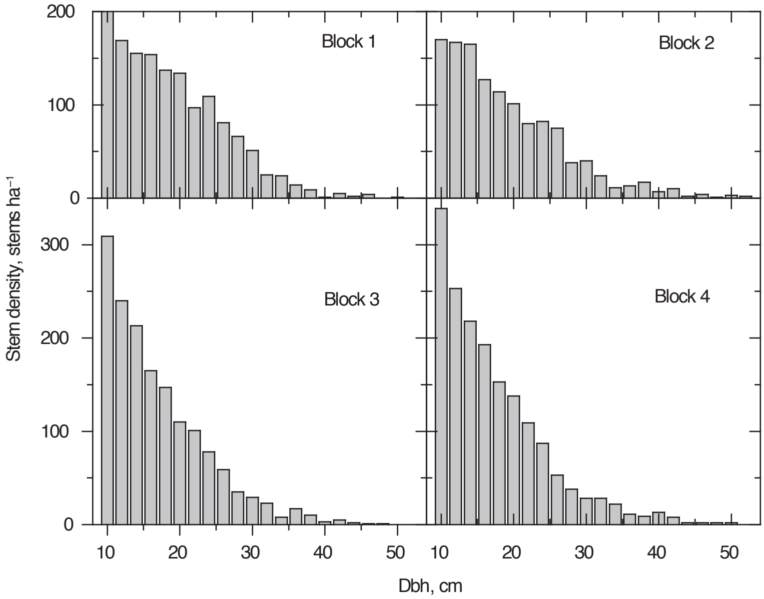

Fig. 2. Diameter distributions before treatment for each block with 2-cm dbh classes.

Table 1. Stand characteristics before treatment.

Site	Block	Treatment	Standing volume, $m^3 ha^{-1}$	Stem density, st ha^{-1} Total	Stem density, st ha^{-1} dbh > 8 cm
Stavre	1	T20[a)]	350	2211	1174
	1	T40[b)]	396	2226	1183
	2	T20	379	2575	1405
	2	T40	372	2757	1402
Manavägen	3	T20	229	3440	1366
	3	T40	266	2791	1134
	4	T20	206	2708	1214
	4	T40	264	2737	1046

[a)] 20 m between skid roads
[b)] 40 m between skid roads

Table 2. Result of the thinnings.

Site	Block	Treatment	Skid road area, %	Proportion removed, % Volume	Proportion removed, % Stems[a)]	Mean stem harvested, m^3 stem^{-1}
Stavre	1	T20	17.8	7.5	11.7	0.19
	1	T40	10.1	14.2	10.7	0.44
	2	T20	26.1	21.1	15.4	0.37
	2	T40	24.7	23.3	15.4	0.26
Manavägen	3	T20	21.4	12.8	19.8	0.11
	3	T40	12.1	19.0	11.6	0.38
	4	T20	18.7	17.8	5.3	0.57
	4	T40	11.6	17.4	7.5	0.59

[a)] Only stems with dbh > 8 cm

each stand and tree species from sample tree data. Stand volume of pine, spruce and birch was then calculated for each 2 cm dbh class using class midpoint and its corresponding height, and using Brandel's (1990) equations using dbh, height, latitude (only pine and spruce) and altitude (only spruce). For aspen Eriksson's (1973) equations were used.

A treatment mean was calculated for all blocks and treatments from the two circular plots inventoried in each treatment area.

All four blocks had inversely J-shaped diameter distributions before treatment (Fig. 2). Preharvest volumes were 350–396 m^3 ha^{-1} in blocks 1 and 2, and 206–266 m^3 ha^{-1} in blocks 3 and 4 (Table 1). Mean stem volume per harvested tree was 0.25 and 0.38 m^3 $tree^{-1}$ in T20 and T40, respectively. Relative skid road area differed both between and within treatments, but was generally lower for T40 (Table 2), and in three of the blocks a larger proportion of the standing volume was removed in T40. The removed percentage of standing volume varied between 7.5 per cent and 23.3 per cent.

T-tests were used to test for statistically significant differences between treatments, using a significance level of $p<0.05$ for all statistical analyses, using PASW 18 (SPSS Inc. 2010).

3 Results

A total of 278 injuries were registered, distributed on 193 trees. Overall level of damage was low, about 4.5 per cent of the trees, and there were no significant differences between treatments (Table 3). Eighty per cent or more of the damaged trees were smaller than 15 cm dbh, a proportion significantly larger than the total proportion of small trees (Fig. 3). Very few trees larger than 25 cm dbh were damaged.

Most damage was caused by felling of trees, and although there were some differences in occurrence of damage between the other causes, there were no significant differences between treatments (Table 4). The most common injury was bark stripping, which constituted two thirds of the damage, followed by stem breakage which constituted almost all other damage.

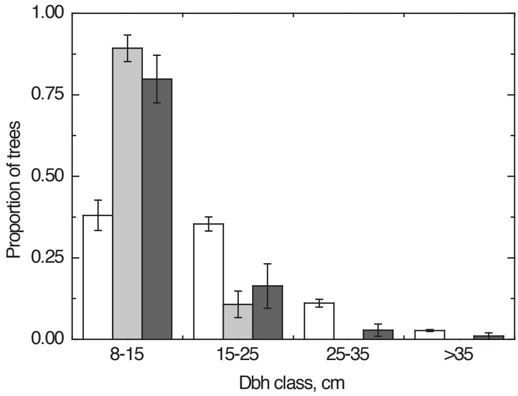

Fig. 3. Diameter distribution of all trees (white) and of damaged trees in T20 (grey) and T40 (black) per diameter class. Vertical bars denote standard error to the mean.

Table 3. Mean level of damage[a].

Treatment	No. of trees	No. of registered injuries	No. of damaged trees
T20	521.5	31	21.5 (4.24%)
T40	507.5	38.5	26.8 (4.73%)

[a] Only stems with $dbh>8$ cm

Table 4. Relative distribution of registered injuries between different causing operations[b].

	Proportion of injuries[a] caused by different operations[b], %				
Treatment	Handling	Driving	Crane	Felling	Other
T20	14.0	26.5	17.4	34.8	8.1
T40	24.5	8.4	9.6	48.4	8.5

[a] Only on stems with $dbh>8$ cm
[b] Handling = de-branching and partitioning of felled trees, Driving = machine movement, Crane = crane work, Felling = felled trees hitting standing trees, Other = unknown cause

In T40, significantly more trees were damaged 5–10 m from the skid road, compared to T20 (Table 5). The rather large proportion of trees damaged more 10 m from the skid road for T20, indicate that there was some deviation from the target skid road distance.

Table 5. Mean distribution of damaged trees[a)] on different distances from skid road edge.

Treatment	Proportion of damaged trees, %			
	Dist.[b)] < 5 m	Dist. 5–10 m	Dist. 10–15 m	Dist. > 15 m
T20	57 (7.3)[c)]	27 (7.4) a[d)]	14 (3.5)	-
T40	28 (5.6)	54 (3.2) b	3 (1.9)	16 (3.7)

a) Only stems with dbh > 8 cm
b) Dist = distance from skid road edge
c) Standard error to the mean within parenthesis
d) Different letters indicate statistical difference between treatments at the 5 per cent level

4 Discussion

Mean stem volume in T40 being 1.5 times the stem volume in T20, meant that overall harvest cost in T40 was probably lower. Lack of clear differences between treatments in level and type of damage, means that harvests could be designed to minimize harvest costs.

The general level of damage was low in this study compared to previous studies by e.g. Hagström (1994), Fjeld and Granhus (1998), Granhus and Fjeld (2001), and Surakka et al. (2011). There could be several explanations for this. Of the earlier studies, only Fjeld and Granhus (1998) studied damage on trees, whereas the others studied advance growth, seedlings and (or) saplings. Thinning intensity was much lower in this study, and the earlier studies all suggested that the amount of harvest, whether expressed as absolute or relative level, is one of the strongest determinants for level of damage. Another reason could be that Fjeld and Granhus (1998) had a wider concept of damage. Trees with broken branches or reduction of the crown were classified as damaged, whereas only stem injuries were registered in this study. Another difference is that in the study by Fjeld and Granhus (1998) trees to be harvested were marked in advance, which meant that the harvester drivers could not adapt their mode of work to the current conditions to avoid unnecessary damage. In this study the choice of trees to harvest was done by the driver, and Sirén (1999) has shown that skilled operation of harvester and forwarder can reduce the level of damage.

The concentration of injuries to small trees meant that damage caused by the harvest would not affect stand development or future harvests for the next few decades. Based on earlier studies in similar stands (e.g. Lundqvist 1993) one can expect trees smaller than 15 cm dbh to have a dbh increment of about 2–3 mm per year. This means that most of the injured trees would not reach harvestable size for another 40–50 years, by which time a substantial part of them would have died from natural causes.

In Swedish forestry, the Swedish Forest Agency recommends less than 5 per cent damage in ordinary thinnings. That level was surpassed in only one treatment area. The recommendation is focused on thinnings in even-aged stands, where the objective is to create a valuable stand for the final harvest. With 2–3 thinnings, some 5–10 per cent of the trees in the final stand may be damaged. In uneven-aged forestry it is primarily the mature trees that are thinned, and there is normally no tending of really small trees (cf. Schütz 2001). According to observations on Swedish permanent plots in uneven-aged Norway spruce stands, less than 0.5 per cent of trees with dbh > 8.5 cm die through self thinning per year (Lundqvist 1993). Seen over a 50 year period, this means that about 25 per cent of the injured trees would probably die anyhow before they reach mature size. Assuming that harvests are repeated every 15–20 years, about 10 per cent of the larger, harvestable trees will have old injuries, which might affect both growth and log quality.

Bark stripping is a dangerous injury, which might cause infection by fungi, and the risk increases with the size of the injury (e.g. Isomäki and Kallio 1974, Mäkinen et al. 2007). Trees are least prone to receive bark stripping during the winter (Wästerlund 1986). Really small trees and saplings are, however, more prone to stem breakage when the temperature is below –15 °C. To minimize damage, harvests could preferably be done in March-April when trees are still dormant, temperatures are seldom below –10 °C, and seedlings and saplings are usually protected from damage to some extent by a snow cover (Eliasson et al 2003).

In conclusion, overall level of damage was low, and the injuries were primarily found on small trees, i.e. trees that will not reach harvestable size for at least 40–50 years. Creating only half the number of the skid roads at the initial harvest resulted in the same level of damage as only harvesting skid roads, but can be assumed to be more profitable because of the larger mean size of trees harvested. This mode of operation deserves further study.

Acknowledgements

We thank Johan Bjenndal at SCA for help with field inventory. Swedish Forest Agency financed part of the study within their project "Hyggesfritt skogsbruk och kontinuitetsskogar".

References

Andreassen, K. 1994. Development and yield in selection forest. Meddelanden fra Norsk Institutt for Skogforskning 47(5): 1–37.

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

Cedergren, J. 2008. Kontinuitetsskogar och hyggesfritt skogsbruk. Skogsstyrelsen, Jönköping, Meddelande 1/2008.

Eliasson, L., Lageson, H. & Valinger, E. 2003. Influence of sapling height and temperature on damage to advance regeneration. Forest Ecology and Management 175: 217–222.

Eriksson, H. 1973. Tree volume functions for ash, aspen, alder and lodgepole pine in Sweden (Fraxinus excelsior L., Populus tremula L., Alnus glutinosa (L.) Gartn., Pinus contorta Dougl. var. latifolia Engelm.). Department of Forest Yield Research, Royal College of Forestry, Research Notes 26. (In Swedish.)

Fjeld, D. & Granhus, A. 1998. Injuries after selection harvesting in multi-storied spruce stands – the influence of operating system and harvest intensity. Journal of Forest Engineering 9: 33-40.

Granhus, A. & Fjeld, D. 2001. Spatial distribution of injuries to Norway spruce advance growth after selection harvesting. Canadian Journal of Forest Research 31: 1903–1913.

Hagström, S. 1994. En studie av avverkningsskador på inväxningsbeståndet vid blädning. Examensarbete. Sveriges Lantbruksuniversitet, Skogsvetenskapliga fakulteten, Studentuppsater 2, 1994. (In Swedish.)

Isomäki, A. & Kallio, T. 1974. Consequences of injury caused by timber harvesting machines on the growth and decay of spruce. Acta Forestalia Fennica 137. 24 p.

Lageson, H. 1996. Thinning from below or above? Implications on operational efficiency and residual stand. Swedish University of Agricultural Sciences, Acta Universitatis Agriculturae Sueciae, Silvestria 14.

Lundqvist, L. 1993. Changes in the stand structure on permanent plots managed with single-tree selection. Scandinavian Journal of Forest Research 8: 510–517.

— 1994. Growth and competition in partially cut subalpine Norway spruce forests in northern Sweden. Forest Ecology and Management 65: 115–122.

— , Chrimes, D., Elfving, B., Mörling, T. & Valinger, E. 2007. Stand development after different thinnings in two uneven-aged Picea abies forests in Sweden. Forest Ecology and Management 238: 141–146.

Mäkinen, H., Hallaksela, A. & Isomäki, A. 2007. Increment and decay in Norway spruce and Scots pine after artificial logging damage. Canadian Journal of Forest Research 37(11): 2130–2141.

Schütz, J-P. 2001. Der Plenterwald und weitere Formen strukturierter und gemischter Wälder. Parey Buchverlag, Berlin.

Sirén, M. 1999. One-grip harvester operations, silvicultural results and possibilities to predict tree damage. In: Keane, M.G. & Kofman, P.D. (eds.).

The thinning wood chain. Proceedings, IUFRO (Research Unit 3.09.00) Conference on Harvesting and Economics of Thinnings, Ennis, Ireland, 4–7th May 1999. p. 152–167.

SkogForsk. 2011. Provytor för att beräkna gallringsuttaget. [Sample plots to estimate thinning strength]. Available at: http://www.skogforsk.se/sv/KunskapDirekt/Gallra/Uppfoljning-1/Provytor/. [Cited 25 Jan 2012].

Surakka, H., Sirén, M., Heikkinen, J. & Valkonen, S. 2011. Damage to saplings in mechanized selection cutting in uneven-aged Norway spruce stands. Scandinavian Journal of Forest Research 26: 232–244.

Wästerlund, I. 1986. The strength of bark on Scots pine and Norway spruce trees. Sveriges Lantbruksuniversitet, Institutionen för skogsteknik, Garpenberg, Rapport 167.

Total of 19 references