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

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 m²) 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 cm², 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, Department of Forest Ecology and Management, SLU, SE-901 83 Umeå, Sweden; Cedergren, Mariehamn, Åland

**E-mail** lars.lundqvist@slu.se

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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
(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 m²) 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 m² 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 cm², 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.

<table>
<thead>
<tr>
<th>Site</th>
<th>Block</th>
<th>Treatment</th>
<th>Standing volume, m³ ha⁻¹</th>
<th>Stem density, st ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total dbh &gt; 8 cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>dbh &gt; 8 cm</td>
<td></td>
</tr>
<tr>
<td>Stavre</td>
<td>1</td>
<td>T20 a)</td>
<td>350</td>
<td>2211</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>T40 b)</td>
<td>396</td>
<td>2226</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>T20</td>
<td>379</td>
<td>2575</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>T40</td>
<td>372</td>
<td>2757</td>
</tr>
<tr>
<td>Manavägen</td>
<td>3</td>
<td>T20</td>
<td>229</td>
<td>3440</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>T40</td>
<td>266</td>
<td>2791</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>T20</td>
<td>206</td>
<td>2708</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>T40</td>
<td>264</td>
<td>2737</td>
</tr>
</tbody>
</table>

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

Table 2. Result of the thinnings.

<table>
<thead>
<tr>
<th>Site</th>
<th>Block</th>
<th>Treatment</th>
<th>Skid road area, %</th>
<th>Proportion removed, %</th>
<th>Mean stem harvested, m³ stem⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stavre</td>
<td>1</td>
<td>T20</td>
<td>17.8</td>
<td>7.5</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>T40</td>
<td>10.1</td>
<td>14.2</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>T20</td>
<td>26.1</td>
<td>21.1</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>T40</td>
<td>24.7</td>
<td>23.3</td>
<td>0.26</td>
</tr>
<tr>
<td>Manavägen</td>
<td>3</td>
<td>T20</td>
<td>21.4</td>
<td>12.8</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>T40</td>
<td>12.1</td>
<td>19.0</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>T20</td>
<td>18.7</td>
<td>17.8</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>T40</td>
<td>11.6</td>
<td>17.4</td>
<td>0.59</td>
</tr>
</tbody>
</table>

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). Pre-harvest 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.

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.
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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Proportion of damaged trees, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dist. 0–5 m</td>
</tr>
<tr>
<td>T20</td>
<td>57 (7.3)</td>
</tr>
<tr>
<td>T40</td>
<td>28 (5.6)</td>
</tr>
</tbody>
</table>

Table 5. Mean distribution of damaged trees on different distances from skid road edge.

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

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