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SAPLING DAMAGE IN MECHANIZED SELECTION CUTTINGS

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Abstract: *In Finland many forest owners live in towns, are less dependent on forest income and have multiple values in forest management. There are also sensitive forests (city forests, stream buffer zones), where selection cuttings can be alternative treatment for clearcutting. If selection cuttings are carried out in a larger extent, mechanized harvesting is needed. Mechanized harvesting in selection cuttings, especially harvesting damage, has raised questions, but research on this topic has been very low.*

Harvesting conditions in selection cutting are reasonable. The main question is, can we maintain these conditions. The future harvesting condition highly depend both on sapling damage and forest renewal. Damage of saplings in mechanized cutting of uneven-aged Norway spruce stands was studied in three stands with total area of 2.35 hectares. Harvest removals ranged 96-122 m^3/ha, from 30 to 40 % of initial basal area. Before harvesting trees higher than 2.5 m were mapped and measured. Saplings 0.5-2.5 m were measured from sample plots of 10 m^2. Removed trees were marked before cutting. Harvesting was carried out with one-grip harvester and forwarder in March-April 2007.

Factors affecting the probability of injury were studied using logistic regression models. Percentage of injured saplings was 26.6-61.0 %. Distance of sapling from the strip road, sapling height, harvested basal area at distance of 25 m from the sapling and sapling distance to nearest remaining tree explained the probability of injury. Saplings near to the strip road and higher saplings have a larger risk for damage.

Most damage occurs during felling and processing. Harvester operator can reduce sapling damage by utilizing same felling directions and strip road openings. In selection cutting the stand structure can vary a lot. If there are areas with a very small removal in the stand, it can be wise to exclude those areas. Development both in working methods and in machinery can reduce sapling damage in selection cuttings. Injury models and harvesting simulations can make a significant contribution to decision support systems for uneven-aged stands.

1. Introduction

In Finland selection cuttings are applied on a secondary scale compared to standwise thinnings and clearcuts. However, an increasing proportion of private forest owners tend to appreciate multiple values in their management decisions (Valkeapää et al., 2008). Stands dominated by Norway spruce (*Picea abies* (L.) Karst) have the highest potential for the application of uneven-aged management on a commercial scale (Valkonen and Maquire, 2005; Lähde et al., 2002). On the other hand, the risk and consequences of pathogen infections following harvesting damage is particularly large in spruce stands (Hakkila and Laiho, 1967; Isomäki and Kallio, 1974).

Knowledge on productivity, costs and silvicultural results of mechanized harvesting in thinnings in even-aged stands is based on decade-long practice and research. If selection cuttings are carried out in a larger scale, mechanized harvesting is the only feasible alternative for most forest owners living at towns. In selection management, future stand development and economy base on regeneration but also on recovery and survival of secondary growth after cutting. There is an increasing need for knowledge on sapling damage and factors affecting in selection cuttings.

Both machine operator and harvesting conditions have large influence on productivity and silvicultural results of harvesting. In mechanized cutting, the size of the removed trees and the number of removed trees/ha are the most important stand characteristics affecting productivity. In forest haulage, the type of harvesting (thinning vs. clearcutting), forest haulage distance, density of different timber sortiments (m^3/100 metre strip road) and terrain all have an effect on productivity (Kuitto et al., 1994). In addition, the type and size of the machinery affect productivity. Harvesting conditions in selection cuttings resemble those of later thinnings in even-aged stands. However, the large question is, can we maintain the relatively good harvesting conditions of selection cuttings. For this both successful harvesting and stand renewal are needed.

Harvesting damage as well as productivity and costs of mechanized harvesting in selection cuttings have raised questions in Finland (Lähde, 1983; Sirén, 2003), but there has been very little research on these topics. Selection silviculture is based on the constant presence, survival and growth of understory seedlings and saplings and trees of lower canopy layers. In even-aged thinnings, no attention is usually paid to their protection. On the contrary, cleaning is often recommended prior to thinning (Kärhä et al., 2006).

Modeling the damage process in mechanized selection cuttings faces serious challenges. The structure of uneven-aged stands varies a lot between and within stands, and it is quite difficult to find representative study areas. Due to large structural variation knowledge on average damage rates is less useful than in even-aged forests. In Sweden and Norway research on selective harvesting has been more active than in Finland. The largest effort has been the set of studies carried out by Fjeld and Granhus (1998) and Granhus and Fjeld (2001). It has yielded very valuable information on the damage levels, the factors involved and the research methodology. Probabilities for damage occurrence were analyzed and presented in terms of spatially explicit logistic regression models. In the study of Granhus and Fjeld (2001) harvesting intensity was quantified as removed basal area at stand level.

In this paper harvesting conditions and costs in even- and uneven-aged Norway spruce stands are first shortly compared. After that factors affecting sapling damage in selection cuttings are presented. Later this knowledge is needed in optimizing management alternatives and in improving working techniques of mechanized harvesting in selection cuttings.

2. Comparison of harvesting conditions and costs

In Table 1 harvesting conditions in even- and uneven-aged manage Norway spruce stands are compared (Surakka and Sirén, 2007). Harvesting conditions in even-aged management are simulated with Motti stand simulator (Hynynen et al., 2005). Harvesting conditions of uneven-aged stands are based on permanent study plots of Finnish Forest Research Institute at Southern Finland. Harvesting costs are calculated for mechanized harvesting with models presented by Kuitto et al. (1994). In selection cuttings productivity models for clearcutting with a reduction of 20 % are used. Cost are calculated for a forest haulage distance of 250 metres.

Table 1. Comparison of harvesting conditions and costs in even- and uneven-aged Norway spruce stand at *Myrtillus* site type (relatively fertile site).

Even-aged stand

	First thinning	2. thinning	Final felling
Dominant height, m	13.6	19.3	21.7
Diameter, cm	14.0	22.0	27.0
Age, years	36	53	62
Removal, trees/ha	1045	411	488
Number of remaining trees/ha	908	489	0
Average size if removed trees, dm^3	45	197	503
Pulp wood removal, m^3/ha	47.5	48.4	56.8
Saw logs removal, m^3/ha	0.0	32.6	188.3
Cutting costs, €/m^3	15.1	6.3	4.0
Forwarding costs, €/m^3	3.8	3.6	2.7

Uneven-aged stands

	Stand				
	A	B	C	D	Average
Before harvesting, m^3/ha	209.7	205.1	195.7	173.1	195.9
Remaining stand, m^3/ha	156.5	140.9	135.6	134.5	141.9
Removal, m^3/ha	53.3	64.3	60.1	38.6	54.1
Average size of removed trees, dm^3	195	190	599	296	320
Cutting costs, €/m^3	6.78	6.84	4.00	5.99	5.90
Forwarding costs, €/m^3	3.80	4.06	3.03	3.25	3.54

Harvesting conditions on there uneven-aged study stands seem to be quite good. Especially sizes of removed trees are favorable, but also removals/ha are reasonable. However, the essential question is, can we maintain these relatively good harvesting conditions. Effects of timing, intensity and structure of treatments and knowledge concerning harvesting damage must all be linked with forest renewal to draw synthesis on management practices and future harvesting conditions. In this paper focus is on sapling damage in mechanized selection cuttings. These damage models can be later used in Motti stand simulator ((Hynynen et al., 2002; Hynynen et al., 2005) comparing forest management alternatives.

3. Sapling damage

3.1 Study stands, measurements and damage modeling

Following results on sapling damage (Surakka et al., 2010) are based on harvesting experiments on three Norway spruce (*Picea abies*) dominated uneven-aged stands during spring 2007. The stands (stands A, B and C, 1.08, 0.85 and 0.42 hectares respectively) were earlier harvested motor-manually in 1987. After that the stands A and B were harvested again in 1999, A mechanically with one-grip harvester and B motor-manually. All these harvesting operations were single tree cuttings, aiming to an uneven-aged structure.

Before harvesting, the commercially valuable tree species of a height more than 2.5 m were mapped and measured. Smaller trees of height 0.5 to 2.5 m were measured from a sample. Sample plots of 10 m^2 were laid out on a square grid, where both line and plot interval was 7.07 m. Tree characteristics recorded were species, height and an estimation of whether a tree was able to develop to a commercially valuable tree or not.

Location of striproads and trees to be felled were decided before harvesting. Almost the whole striproad network was the same used in previous harvestings. Distance between striproads varied a lot, having average distance of 25, 27 and 23 m in stands A, B and C respectively. Volumes in study stands are summarized in Table 2.

Table 2. Stand characteristics before and after cutting.

		Stand		
		A	B	C
Before cutting	Volume, m^3/ha	289	296	295
	Basal area, m^2/ha	27.9	29.2	31.1
	Stems/ha, h > 2.5 m	766	1021	1262
	Saplings $0.5 \leq h \leq 2.5$ m			
	All	1220	1819	1012
	Coniferous	1065	1392	852
Remaining stand	Volume, m^3/ha	185	200	173
	Basal area, m^2/ha	18.3	20.3	18.7
	Stems/ha, h > 2.5 m	625	891	947
Removal	Volume, m^3/ha	104	96	122
	Basal area, m^2/ha	9.6	8.9	12.4
	Stems/ ha, h > 2.5 m	141	130	315

Harvesting was carried out by using a one-grip harvester and a forwarder. Cutting was done in late March 2007 and forwarding in early April 2007. Temperature was -1 to 13 ºC, snow depth 0 to 20 cm, and visibility good during the cutting. Two harvester operators carried out the cuttings. All operators were skilled, each having at least 15 years experience of driving a harvester. Both harvester and forwarder drivers were guided to avoid damage on both taller trees and seedlings. The harvester operators were guided to fell the marked trees away from the strip roads. Harvester was stopped after every processed tree to give the monitoring team enough time for measurements.

After harvesting, possible injuries were assessed for each tree measured before harvesting. All smaller trees of 0.5 to 2.5 m were assessed from the original 10 m^2 sample plots. Factors affecting the overall probability of injury, and the probability of a severe injury (sapling has died or will die), were studied using logistic regression models.

3.2 Model for injury probability

The model explaining the probability of sapling injury is:

logit (y) = -2.8870 -0.1226 x STRIPDIST + 0.5399 x HEIGHT + 0.2489 x GHARV + 0.4231 x REMADIST (1)

where

STRIPDIST = distance (m) of sapling from the middle strip road
HEIGHT = sapling height
GHARV = harvested basal area (m^2/ha) at distance of 25 m from the sapling
REMADIST = distance of sapling to nearest remaining tree

With classification threshold 0.5 for the fitted injury probabilities p_i, the rate of correct classification was 73%. Sapling injury probability for saplings at different distances (m) from strip roads with different harvested removals (m^2/ha) is presented in Figure 1.

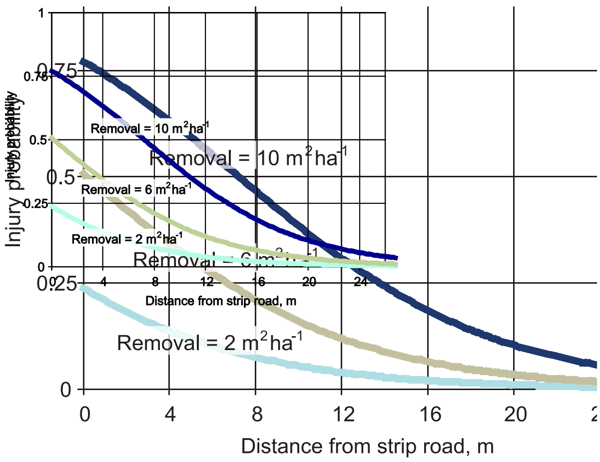

Figure 1. Sapling injury probability for saplings at different distances (m) from strip roads with different harvested removals (m^2/ha).

3.3 Model for injury severity

Injured saplings were classified to ´dead or dying´ and ´injured but surviving´. The model for injury severity is following:

logit (y) = - 0.6375 + 5.2032 x STRIPDIST $^{-0.5}$ - 0.7925 x HEIGHT (2)

where

STRIPDIST = distance (m) of sapling from the middle of strip road
HEIGHT = sapling height

Probability for injury severity class at different distances from strip road is presented in Figure 2.

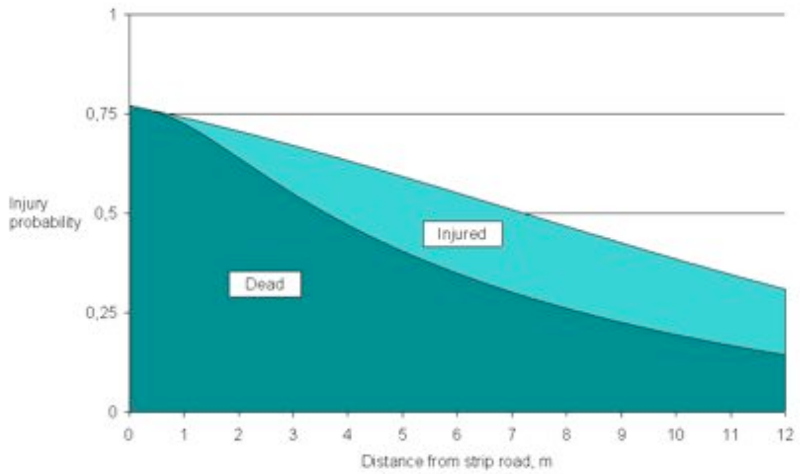

Figure 2. Probability for injury severity at different distances from strip road.

4. Discussion

In Finland there is a lively discussion on different forest management practices, and many forest owners highly rate multiple values in their management decisions. In selection forestry the future stand development and economy base on regeneration but also on recovery and survival of secondary growth after cutting. If selection cuttings will be carried out in a larger extent, mechanized harvesting is a necessity.

Our study was carried out in late winter under mild weather, which is a recommended season for selection cuttings (Granhus and Fjeld, 2001). However, due to early spring, there was very little snow cover at the end of the harvesting operation. If the cutting is carried out during summer, there is an increased risk for root rot (Piri et al., 2008).

Earlier Granhus and Fjeld (2001) found that injury of saplings depends both on forest conditions and on operational characteristics. In their study sapling height and spatial distribution of saplings relative to the strip roads and larger trees of the residual stand qualified forest conditions, whereas operational characteristics were quantified by operational method and harvest intensity. When cutting was carried out with harvester, the mean percent of saplings injured was higher than with motor-manual cutting.

In our study the probability of sapling injury was explained by distance of the sapling from the strip road, sapling height, harvested basal area at a distance of 25 m from sapling and distance of sapling to nearest remaining trees. These explaining variables are logic and describe the damage process in harvester work. With increasing amount of work risk for damage increases. Saplings near by strip roads have a heavy risk to be left under slash or logs.

The harvester operator avoids damages to large remaining trees. Thus saplings near by remaining large trees have a smaller damage risk than saplings in the more open places. This same finding was made by Granhus and Fjeld (2001). With typical removal in selection cuttings (60-70 m^3/ha) about one third of saplings will damage, and one third of these damaged saplings will survive. However, number of remaining saplings and their spatial distribution together with renewal determines the stand development.

Most damage occur during felling and processing. This finding raises a question, could a harvester operator avoid damage with working technique, or should we develop our machinery more suitable for selection cuttings. Gingras (1990) has noted, that there are two approaches for reducing injury rates. The first consists of modifying existing systems, and the second requires the use of new technology. Modern harvesting machinery is not developed for selection cuttings. During processing a tree act like a

´scarifier`, and felling and processing of a large tree exposes a high number of saplings. Earlier in the late 1970s we had harvesters, which processed trees in vertical position. With these harvesters amount of sapling damage was moderate in seed tree cutting (Mäkelä, 1990). Development both in working methods and in machinery can reduce sapling damage in future selection cuttings.

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