Financial Comparison of Strip Road Alternatives in the Harvesting of Pine Stands on Drained Peatlands

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Abstract

The effects of different strip road alternatives on harvesting conditions, machine productivity and harvesting costs, stand development and net income for the forest owner during the rotation period were compared in Scots pine stands on drained peatland. The study material consisted of 12 stands, in which the average distance between ditches was 40 metres. Three different marking alternatives were studied. In the first alternative, the strip roads were located 10 metres from the ditches, and the distance between the strip roads was 20 metres. Both harvester and forwarder operated on the strip roads. In the second alternative, the strip roads for forwarder were on the ditches, and a small harvester operated on strip roads and on two narrow cutting strips between the ditches. These two alternatives were compared with the third, theoretical alternative, in which there were no actual strip roads.

The alternative markings resulted in different thinning removals as well as different growing stocks. The growing stocks were entered into the MOTTI stand simulator and the growth and yield for the rest of the rotation were simulated. Harvesting costs (including both cutting and forwarding) were calculated for Markings 1 and 2. The ditch network maintenance costs in stands, which were estimated to be in need of ditch network maintenance were included in the financial analyses.

The Marking methods were very similar with respect to growth and yield during the rotation. However, the harvesting schedules, *i.e.* the number and timing of the thinnings, differed slightly between the marking methods. The average first thinning harvesting costs in Marking 1 were 4 % lower than in Marking 2. The difference is partly caused by the larger average stem size in Marking 1, and partly by the lower productivity of cutting when using the cutting strip method. However, the alternatives did not differ statistically significantly from each other.

The results for the strip road alternatives were very similar with respect to financial performance. This result allows us to plan strip roads that are more specific to the site conditions without losing too much profitability. If there is a need for ditch network maintenance, Marking 2 is recommended. A considerable proportion of the first thinning removal comes from the strip roads, and this removal has an important effect on the harvesting costs. In this study thinning harvesters were used in the thinnings. However, medium-sized harvesters or harvester-forwarders can also be used in Marking 1. Thus, peatland harvesting can also mainly be carried out with the machinery used on mineral soil sites.

Key words: Peatlands, stand-level simulator, growth and yield, peatland harvesting

Introduction

During the next 10 years more than one million hectares of peatlands will require thinning in Finland (Nuutinen 2000). The small stem size and low removal per hectare are the main problems on peatlands, as is also the case on mineral soils. Lilleberg and Raitanen (1989) studied the structure of first thinning stands in Southern Finland using data from the National Forest Inventory (NFI). The average removal per hectare of all first thinning stands was 40.1 m^3 and the average size of trees to be removed 51 dm^3. However, in pine- dominated (*Pinus sylvestris*) stands the average removal per hectare was only 34.6 m^3. The average removal of first thinning in peatlands (private forests) is even smaller than that on mineral soils, only 29 m^3/ha (Eeronheimo 1991).

In Northern Ostrobothnia almost 45 % of the peatlands have a total tree volume of less than 80 m^3 per hectare. In these volume classes the average first thinning harvesting removal is only slightly over 20 m^3 per hectare. The average first thinning stand size on peatlands is small, only 1.6 hectares. Only 5 % of the total number of peatland stands is more than five hectares in size (Sirén *et al*. 2002).

Carrying out thinnings on peatlands is also associated with special problems. Forest transportation distances are often long and the bearing capacity of the ground is low. Harvesting is often possible only during the winter period. In southern Finland, for instance, this period is only three months long. Ditches also cause problems. They set limitations on the machines, and thinning and ditch network maintenance must be integrated.

The trees on drained peatlands are not evenly distributed. The growing stock is often concentrated near ditches. The harvesting removal in the area less than five metres from the ditches can be double than that in the centre of strip. In addition to the systematic variation in stand distribution, there is also less regular stand variation over large peatland areas (Pohjola 1983). In the first thinning, a considerable proportion of the thinning removal comes from strip roads. Thus, the location and width of and distance between strip roads have a great influence on both harvesting removal and productivity as well as on the structure of the remaining stand. Due to the strip roads the optimal tree selection is deflected. On drained peatlands, where the trees are not evenly distributed, the effect of strip road spacing can be even more important than on mineral soils. Högnäs (1985) has presented a selection procedure for the strip road alternatives on drained peatlands.

In mechanized cutting of first thinning stands, the machine operator, tree size and number of removed trees per hectare are the main factors affecting the productivity and subsequent profitability. Small harvesters can be cost competitive in first thinnings (Sirén and Aaltio 2003). With small harvesters it is possible to use the cutting strip method, which allows the use of a longer distance between forwarding strip roads (Sirén and Tanttu 2001). With the cutting strip method, the amount of tree damage is slightly considerable, but the distribution of the remaining trees is more equal than with the normal method using a strip road distance of 20 metres. On peatlands tree quality varies considerably, and a smaller number of high quality trees must be removed from the strip roads when using the cutting strip method

The productivity of forest haulage is mainly affected by hauling distance and the removal per hectare. When calculating the productivity of forwarding, the total removal is divided into different timber sortiments to be hauled separately. When the amount of strip roads is known, the density of different sortiments, *i.e.* m^3/100 metre of strip road, can be calculated (Kuitto *et al*. 1994). In forest haulage, the load carrying capacity has a significant influence on productivity. Thus, the cost competitiveness of smaller forwarding machinery (light crawlers, forwarders with load capacity less than 8 tonnes) is often poor.

The future stand development and treatments depend on the stand structure after the first thinning. Thus, the thinning intensity of the first thinning sets the conditions in which the growing stock will subsequently develop (*e.g.* Hynynen and Arola 1999). However, within a relatively large range of thinning intensities, the impact of first thinning on future stand development remains more or less the same, especially in the case of Scots pine stands (Huuskonen and Ahtikoski 2005). On peatlands the ditch network and harvesting machinery set additional demands on strip road location. Due to the strip roads it is not possible to perform optimal tree selection. In this paper the effects of different strip road alternatives on harvesting conditions, machine productivity and harvesting costs, stand development and net income for the forest owner during the rotation period are compared in drained peatland pine stands.

Material and methods

Study stands and alternative markings

The study material consisted of 12 drained peatland Scots pine stands. The stands were located in Southern Ostrobothnia, Western Finland. The material was a part of a larger material used to investigate the structure of first thinning pine stands, and consisted of pine stands for which immediate first thinning was suggested in the district forestry plans (Sirén *et al*. 2002). In this larger material the stands for the study were selected randomly by drawing lots. The experimental design included measurements of tree and stand characteristics (age, basal area, mean breast height diameter, height, stem number, tree location) as well as estimation of peat depth and condition of the ditches at the time of establishment. The biological age of the stands varied between 32 and 70 years. Stand data are presented in Table 1.

A 10*20 metre sample plot (see Figure 1) located randomly on the border of the ditch. A model marking for quality thinning according to the thinning instructions of Metsäliitto (Anon. 1999) was carried out. The instructions were based on the diameter at breast height. The number of the remaining trees with a medium diameter of 13 cm was 959 trees per hectare, with a diameter of 15 cm 850 trees per hectare, and with a diameter of 17 cm 650 trees per hectare (Sirén *et al*. 2002). Quality thinning emphasizes wood quality. The best-quality trees are left growing, regardless of the canopy layer. In practice this requires that the stand is more or less homogenous with respect to tree height and diameter (Niemistö 2005). The quality thinning carried out in the 13 cm diameter class was stronger compared to the thinning recommendations of the Forestry Development Centre Tapio, which are based on the basal area of the stand (Anon. 2001). In larger diameter classes the instructions for quality thinning were similar to those of Tapio.

In model marking the trees were classified into the following classes: a) trees to be removed in the stand b) trees to be grown in the stand, c) trees to be grown, but located on the strip road and d) trees to be removed, but located on the strip road.

The technical quality of both removed and remaining trees was classified with the scale 4 (poor) to 10 (excellent). The basis for this technical quality classification is presented by Stöd *et al*. (2003). The distance of each tree from the ditch was measured at an accuracy of 1 metre. In the material the average distance between the ditches was 40 metres. Three different marking alternatives (Figure 1) were studied:

1. Strip roads located 10 metres from the ditches. Both harvester and forwarder operate on the strip roads. Distance between strip roads 20 metres (henceforth referred to as Marking 1).

2. Strip roads for forwarder are on ditches. A thinning harvester operates on the strip roads and on two narrow cutting strips between the ditches (Marking 2).

3. No actual strip roads are opened. A theoretical alternative that is in practice only possible with very small machinery (Marking 3).

The strip road width measured by the SLU-method (Björheden and Fröding 1986) in Marking 1 was 430 cm. In Marking 2 the strip road width along the ditch was 480 cm; this area is needed as the ditch network maintenance follows the cutting. The thinning harvester works on narrow cutting strips, which have no effect on the tree spacing.

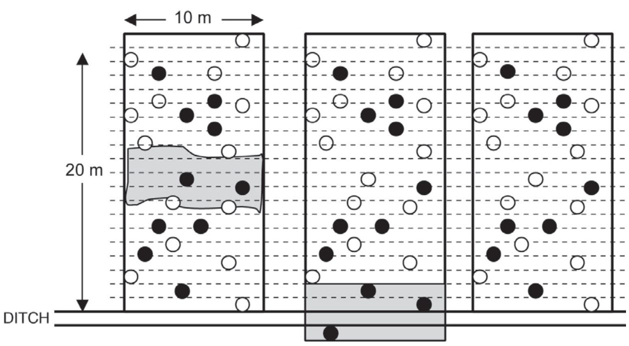

Figure 1. Alternative marking methods 1, 2 and 3. Strip roads located in the stand (on the left, Marking 1), strip road located on ditches (in the middle, Marking 2) and no strip roads (on the right, Marking 3)

Stem volumes were calculated with the KPL-programme developed at the Finnish Forest Research Institute, FFRI (Heinonen 1994). Industrial wood removal included trees with a minimum length of 3 metres of pulpwood. The minimum top diameter for pine was 6 cm, for spruce 8 cm and for birch 7 cm. The condition of the ditch network and the need for ditch network maintenance were also classified.

Table 1. Stand information

Stand	Peatland type	Age, years	Stem number, stems/ha	Basal area, m^2/ha	Volume, m^3/ha	Immediate need for ditch network maintenance
1	*Vaccinium vitis-idaea* type	32	1150	16.7	85.6	Yes
2	*Vaccinium vitis-idaea* type	54	1600	21.6	113.3	Yes
3	*Vaccinium vitis-idaea* type	70	1750	29.9	184.6	Yes
4	*Vaccinium vitis-idaea* type	52	1550	20.4	134.6	Yes
5	*Vaccinium vitis-idaea* type	54	2150	28.2	168.4	Yes
6	*Vaccinium vitis-idaea* type	41	1600	21.4	113.3	Yes
7	*Pine swamp* with shallow peat-layer	35	1850	19.5	98.8	Yes
8	*Vaccinium vitis-idaea* type	55	1350	22.4	139.0	No
9	*Vaccinium vitis-idaea* type	54	1800	21.4	126.0	No
10	*Dwarf-shrub* type	47	1200	20.5	125.2	No
11	*Vaccinium vitis-idaea* type	51	1950	20.4	106.5	Yes
12	*Vaccinium vitis-idaea* type	51	1700	18.9	95.6	No

Stand projections

The alternative markings (1, 2 and 3) resulted in different thinning removals as well as different growing stocks. The growing stocks were further fed into the MOTTI stand simulator in order to simulate growth and yield for the rest of the rotation. MOTTI is a stand-level simulator, which includes specific distance-independent tree-level models for *e.g.* natural regeneration, growth and mortality. It is designed to simulate stand development under alternative management regimes and growth conditions in Finland (Matala *et al*. 2003, Hynynen *et al*. 2005).

For a single stand MOTTI produces alternative management schedules according to the selections made by the user. The user can set unit stumpage prices as well as costs (cutting, forest haulage), management schedule, discount rate and specific constraints such as proportional log volume reductions (Hynynen *et al.* 2002). Furthermore, the user can even choose different trends for unit stumpage prices and unit costs, based on their future expectations. After setting the values and constraints the stand simulator predicts the future development of the stand over the rotation.

The simulations (by MOTTI simulator) were conducted by deriving the input data from the tree and stand characteristics of the growing stock immediately after the alternative markings 1, 2 or 3. Then the growth and yield of the stand were simulated according to the following procedures. Each stand was simulated to be managed according to the prevailing recommendations (Anon. 2001). The criterion used to simulate the intermediate thinning was that when the basal area of the stand exceeded a specific limit (tabulated against dominant height: Anon. 2001), then an intermediate thinning was simulated. In some cases this resulted in no simulated intermediate thinnings. However, in the majority of the stands intermediate thinnings were also simulated.

The final cutting was simulated when the stand age exceeded either 90 or 110 years, depending on the site type. In those stands where there was an immediate need for ditch network maintenance (see Table 1), the ditching was simulated by MOTTI at the time of the establishment. During the growth process after the establishment ditch network maintenance was simulated according to the "Model3b" logistic regression model (Hökkä *et al.* 2000).

Three timber assortments were applied in second thinning and final cutting: pulpwood, sawlogs and small-diameter sawlogs. The dimensional criteria for different timber assortments were: minimum diameter of sawlogs logs 14.5 cm and minimum length 3.1 m, 7 cm and 3.0 m for pulpwood logs and 12 cm and 3.5 m for small-diameter sawlogs. Small-diameter sawlog is a relatively new timber assortment in Finland but during the last few years, it has been widely applied in forestry on drained peatlands, especially in young stands. In regions where small-diameter sawlogs can be processed in sawmills, small-diameter sawlogs have been found to improve cutting incomes, when compared to cutting incomes consisting of traditional timber assortments, *i.e.* pulpwood and sawlogs.

There were a total of 36 simulations (12 stands * 3 marking methods) covering the whole rotation period. The overall principles of the combination method, *i.*e. ex post measurements combined with MOTTI stand simulations, are presented in a flowchart in Figure 2.

Harvesting and ditch network maintenance costs

Calculatory harvesting costs were used in the study. Harvesting costs (including both cutting and forwarding) were calculated for Marking 1 and 2. Marking 3 can be seen as a theoretical alternative, which illustrates the effects of mechanized harvesting on spacing and thinning removals. In thinnings, the cutting costs were calculated for a thinning harvester (Prosilva Ässä 810) by using the results as the long-term follow-up study (Sirén and Aaltio 2003).

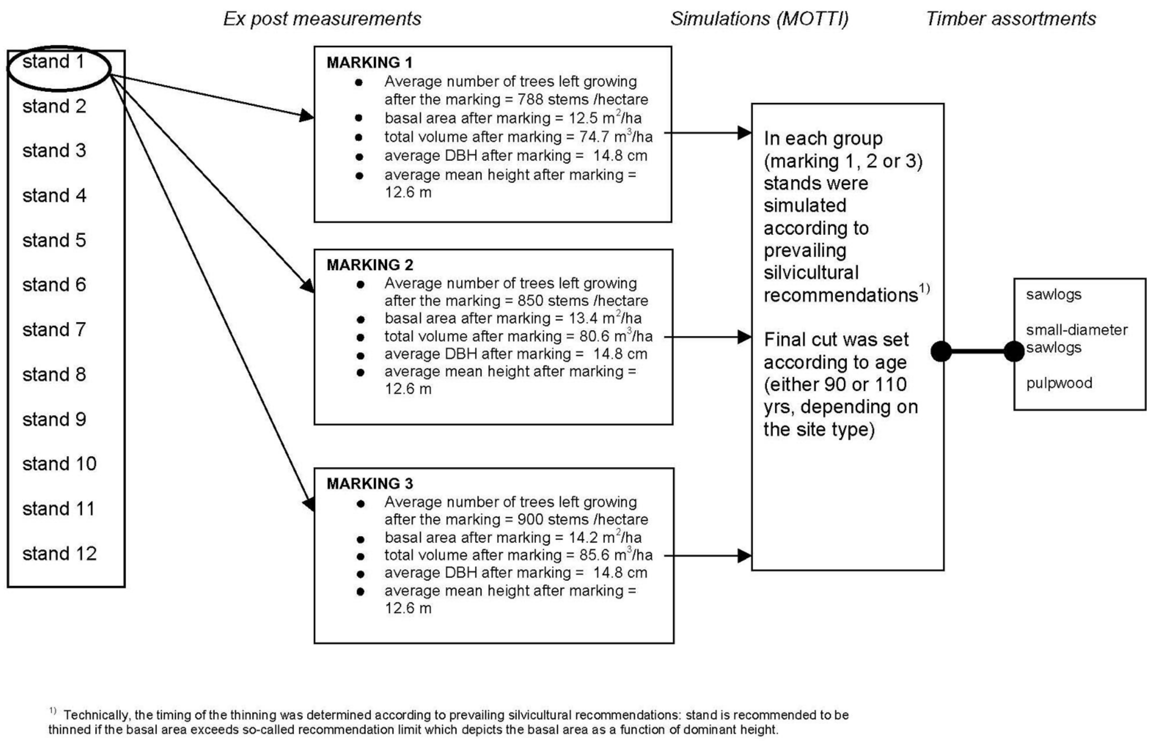

Figure 2. A flowchart showing the ex post measurements, simulation sets and applied timber assortment alternatives. Each stand was marked according to three different markings (1, 2 or 3) at the time of the first thinning, and then simulated to the rotation according to the prevailing silvicultural recommendations incorporated with three timber assortments.

When the cutting strip method is used (Marking 2), the harvester productivity is lower on the cutting strips than on the actual strip roads (Sirén and Tanttu 2001, Brunberg 1997). There is a limited amount of work space on the cutting strips (especially in first thinnings), and the timber must be placed within the reach of a forwarder. In the productivity calculations the harvester productivity was estimated to be 5 % lower on cutting strips than on actual strip roads. An operating cost of 63 € per E_{15} hours was used for the thinning harvester. In final cutting the productivity was calculated for a medium-sized one-grip harvester by using the model presented by Kuitto *et al.* (1994). An operating cost of 70 € per E_{15} hours was used for the medium-sized harvester.

The productivity of forwarding was calculated for a medium-sized forwarder using the results of Kuitto *et al.* (1994). A forest haulage distance of 250 metres was used. The small-size logs were supposed to be hauled in the same loads with pulpwood. If removal of the assortment was lower than one load per hectare, timber was supposed to be hauled in the same loads with the pulpwood. Load sizes of 11.6 m^3 for pulpwood and 12.8 m^3 for sawlogs were used. An operating cost of 50 € per E_{15} hours was used for the forwarder.

Ditch network maintenance costs were also included into the financial analyses, and they were derived from the Finnish Statistical Yearbook of Forestry 2004 (Anon. 2004a). The costs reflected the average costs of ditch network maintenance for the year 2003 of the South-Ostrobothnia Forestry Center, the cost value being 145 €/ha.

Financial analyses

The main aim of the study was to examine whether alternative marking methods (1, 2 and 3) differ statistically significantly from each other with regard to financial performance. The financial performance was determined separately for the first thinning (i.e. original marking) and for the whole rotation as follows. The cutting income of the first thinning in each stand was calculated. The removal of the first thinning consisted of only pulpwood. The calculation was based on the average delivery prices of the South-Ostrobothnia Forestry Centre for the year 2004 (for Scots pine sawlogs 46.29, pulpwood 23.64 and small-diameter sawlogs 30.00 €/m^3). The harvesting costs were then subtracted from the cutting income in order to obtain the net revenue of the first thinning. The harvesting costs were calculated for two harvesting alternatives, as described earlier. Net revenues of the first thinning, simulated intermediate thinning and final cutting were summed up for the whole rotation.

In the financial analyses the decision point was set to the time when the original marking took place, i.e. to the same year when the experiments were established. This chosen time point (t_0, average of 49.5 years) is relevant because it represents the time when the decision to apply alternative marking methods at the first thinning is made. Thus, the net revenues associated with the original marking were not discounted but were determined as current values. Instead, we discounted the net revenues of the simulated intermediate thinning and final cutting. Equation 1 was used for determining the financial performance for the whole rotation:

$$NR_i = (CI^{t_0} - TC^{t_0}) + \sum_{t_1}^{T} \frac{(CI^t_{i,f} - TC^t{}_{i,f})}{(1+\frac{p}{100})^t} - \sum_{n_1}^{N} \frac{DC^n}{(1+\frac{p}{100})^n} \quad (1)$$

where NR_i = total net revenue for the rotation at stand *i, i* = 1,2,…12;
CI^{t0} = cutting income (valued by delivery prices) of the first thinning, at decision point t_0;
TC^{t0} = harvesting costs associated with the first thinning, at decision point t_0;
$CI^t_{i,f}$ = cutting income from simulated intermediate thinning (i) or final cutting (f) at time t_1 or T, respectively;
$TC^t_{i,f}$ = harvesting costs associated with the simulated intermediate thinning (i) or final cutting (f) at time t_1 or T, respectively;
t_0 = decision point;
t_1 = time for the simulated intermediate thinning;
T = time for the simulated final cutting; note that $t_0 < t_1$ and $t_1 < T$;
p= discount rate, here from 2% to 6%;
DC^n = ditch network maintenance costs occurring in year *n;*
(Note that if $n_1 = t_0$, then the ditching occurred at the time of the establishment, indicating that $n_1 = t_0 = 0$, i.e. the decision point, otherwise $n > t_0$), cost value 145 €/ha.

NR_i reflects the so-called feasibility approach, in which the net revenues cannot be directed to only one agent at a time. Instead, the net revenues determine whether the activity as such, is profitable as an entity. Further analyses are needed for when the profitability from *e.g.* the private forest owner's viewpoint is being determined. In general, the feasibility approach only determines the "overall profitability", and ignores the separate profitabilities of each agent involved in the activity. However, the feasibility approach is very powerful – it tells, in the first place, whether there are any economical incentives explorable for the individual agents, such as private forest owners or forest companies.

In the sensitivity analysis it was tested, how much could be paid, at maximum, for the harvesting costs of the first thinning in Marking 3 so that the net revenues of Marking 3 would just break-even with the net revenues of *a)* Marking 1 or *b)* Marking 2. In the sensitivity analysis it was assumed, that the harvesting costs of the second thinning and the final cutting for Marking 3 would reflect the averages of Markings 1 and 2, determined as €/cubic metre. This assumption was justified, because finding out the differences between alternative markings at the first thinning was a matter of special interest. This sensitivity analysis made it possible to gain further insight on the applicability of very small machinery at the first thinning on drained peatlands.

Results

Structure of the first thinning stands

The number of trees, volume, and basal area before thinning and after thinning in the alternative markings (1, 2 and 3) at the first thinning are presented in Table 2. In Marking 1 the average removal was 39 % of the growing stock and 17 % of the removal came from strip roads. In Marking 2 the average removal was 31 % of the growing stock and 8 % of the removal came from strip roads. In Marking 3 the average removal was 27 % of the growing stock, and there were no trees removed because of strip roads. When strip roads are opened, trees belonging to the "trees to be grown" are also removed. The number of such trees was 113 trees per hectare (8.9 m^3/ha) in Marking 1, and 50 trees per hectare (5.0 m^3/ha) in Marking 2.

The diameter distributions of the removed and remaining trees with alternative markings are presented in Figure 3.

Table 2. Stand volumes, stem numbers and basal areas of stands after alternative markings (M1 = Marking 1, M2 = Marking 2, M3 = Marking 3)

Stand	Volume, m^3/ha			Stem number, stems/ha			Basal area, m^2/ha		
	M1	**M2**	**M3**	**M1**	**M2**	**M3**	**M1**	**M2**	**M3**
1	70.9	72.5	74.6	700	750	800	13.2	13.5	14.0
2	68.8	56.1	68.8	750	600	750	12.1	9.9	12.1
3	94.0	109.1	109.1	850	950	950	15.1	17.3	17.3
4	73.5	94.0	94.0	800	950	950	11.0	14.0	14.0
5	92.5	110.3	110.3	700	800	800	13.8	16.2	16.2
6	62.9	58.9	67.9	800	750	850	11.4	10.7	12.3
7	60.6	65.8	71.8	900	1000	1050	11.2	12.1	13.2
8	102.1	90.5	102.1	700	600	700	15.5	13.6	15.5
9	70.3	70.8	83.0	900	950	1050	11.8	11.6	13.6
10	82.7	103.2	103.2	650	800	800	13.3	16.3	16.3
11	61.1	61.9	68.5	800	900	950	10.4	10.9	11.9
12	57.5	73.5	73.5	900	1150	1150	11.2	14.2	14.2
Average, all stands	74.7	80.6	85.6	788	850	900	12.5	13.4	14.2

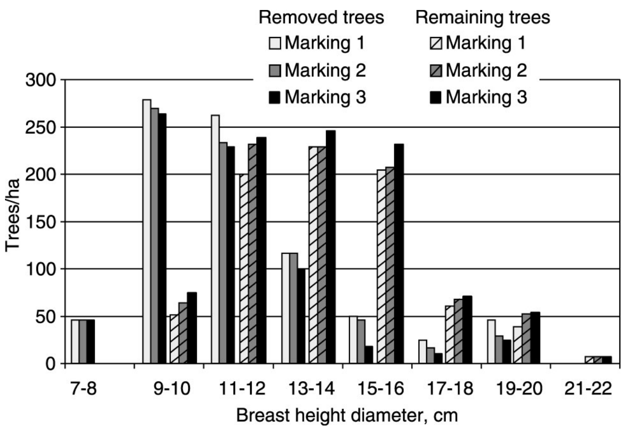

Figure 3. Diameter distributions of removed and remaining trees in the first thinning

The average score for the technical quality of the trees before first thinning was 7.41. The average score for the remaining trees was 7.50 in Marking 1, 7.54 in Marking 2 and 7.53 in Marking 3. The average score for the removed trees was 7.30 (Marking 1), 7.24 (Marking 2) and 7.23 (Marking 3).

Simulated stand development

Each stand was simulated according to the prevailing silvicultural recommendations after the first thinning, resulting in a total of 36 different simulations for rotation. The cutting removals of alternative markings 1, 2 and 3 did not differ (statistically significantly) from each other in the first thinning or in the final cutting. However, the cutting removal of Marking 1 at the second thinning was statistically significantly different than the cutting removal of Marking 2. At the second thinning the average cutting removal of Marking 1 was 42.2 cubic metres/hectare whereas in the Marking 2 the corresponding value was 64.0 cubic metres/hectare (Figure 4). The average values were tested by both the non-parametric Mann-Whitney U-test as well as with the t-test procedure for independent samples, with the significance level set to 0.05 (Anon. 2004b).

Harvesting conditions, productivity and costs

Average stem volume, removals (m^3 per hectare and per 100 metres of strip road) in first thinnings, second thinnings and final cuttings are presented in Table 3.

The average cutting productivity in the first thinning was 6.1 m^3/hour (5.1-7.4 m^3/hour) in Marking 1 and 5.7 m^3/hour (4.9-6.9 m^3/hour) in Marking 2. The productivity in forwarding was 13.3 m^3/hour (10.4-14.4 m^3/hour) in Marking 1 and 14.1 m^3/hour (12.0-15.0 m^3/hour) in Marking 2.

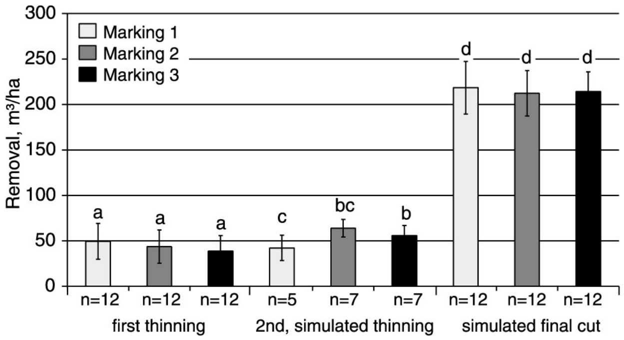

Figure 4. Average cutting removals associated with alternative markings 1, 2 and 3 at the first thinning, simulated second thinning and final cutting. The lines in the bars indicate the standard deviation, and the small letters above the bars represent the results of the statistical analyses. The same letters associated with the first thinning or second thinning or final cutting show non-significant statistical differences ($p > 0.05$), whereas different letters indicate statistically significant differences ($p < 0.05$) between the markings. The sample size (n) of the second simulated thinning differed between the alternative markings 1, 2 and 3 due to the procedure applied: intermediate thinning was set to be executed exogeneously, according to the prevailing silvicultural recommendations

In the second thinning the average cutting productivity was 12.3 m^3/hour (11.4-13.0 m^3/hour) in Marking 1 and 12.0 m3/hour (10.3-13.7 m^3/hour) in Marking 2. The productivity of forwarding was 12.3 m^3/hour (11.3-13.1 m^3/hour) in Marking 1 and 12.8 m^3/hour (12.1-13.5 m^3/hour) in Marking 2.

In the final cutting the average productivity was 18.6 m^3/hour (16.2-20.2 m^3/hour) in Marking 1, and 18.9 m^3/hour (16.1-20.8 m^3/hour) in Marking 2, and the productivity of forwarding 18.1 m^3/hour (17.6-18.5) and 18.2 (17.7-18.5 m^3/hour), respectively. Harvesting costs are presented in Table 4.

Table 4. Harvesting costs, €/m^3

Stand	Marking 1 Cutting	Marking 1 Forest haulage	Marking 1 Harvesting total	Marking 2 Cutting	Marking 2 Forest haulage	Marking 2 Harvesting total
First thinning						
1	12.25	4.80	17.05	12.88	4.15	17.03
2	10.86	3.78	14.64	11.11	3.40	14.52
3	8.48	3.47	11.95	9.19	3.34	12.52
4	9.29	3.62	12.91	10.50	3.51	14.01
5	10.85	3.53	14.38	12.07	3.40	15.47
6	10.22	3.71	13.93	10.71	3.42	14.13
7	11.67	3.87	15.54	12.40	3.59	15.99
8	10.58	3.89	14.47	10.66	3.45	14.12
9	10.28	3.66	13.94	10.65	3.41	14.06
10	9.49	3.81	13.29	11.25	3.78	15.03
11	9.41	3.56	12.96	10.28	3.44	13.72
12	11.15	3.87	15.02	12.28	3.78	16.06
Average *⁾ stands 1, 6, 7, 10, 12	10.96	4.01	14.97	11.90	3.75	15.65
Average **⁾ stands 2, 3, 8, 9, 11	9.92	3.67	13.59	10.38	3.41	13.79
Average, all stands	10.38	3.80	14.18	11.16	3.56	14.72
Second thinning						
1	5.15	4.46	9.61	5.21	3.66	8.87
4	-	-	-	5.12	3.96	9.08
5	-	-	-	4.62	3.89	8.51
6	4.85	4.05	8.90	4.59	3.86	8.45
7	5.11	4.06	9.17	5.27	3.89	9.16
10	5.02	4.06	9.08	5.50	4.17	9.67
12	5.52	3.83	9.35	6.09	3.70	9.79
Average *⁾ stands 1, 6, 7, 10, 12	5.13	4.09	9.22	5.31	3.86	9.17
Average, all stands	5.13	4.09	9.22	5.20	3.88	9.08
Final cutting						
1	3.53	2.74	6.27	3.08	2.76	5.84
2	3.74	2.77	6.50	3.27	2.77	6.04
3	4.32	2.86	7.18	3.91	2.84	6.75
4	3.72	2.77	6.49	3.15	2.77	5.92
5	3.47	2.72	6.19	3.11	2.74	5.85
6	3.51	2.76	6.27	3.06	2.75	5.82
7	3.46	2.73	6.19	3.03	2.73	5.75
8	3.64	2.76	6.40	3.21	2.76	5.97
9	4.24	2.83	7.07	3.77	2.82	6.59
10	3.77	2.80	6.57	3.43	2.82	6.25
11	4.08	2.80	6.89	3.58	2.80	6.38
12	3.87	2.84	6.71	3.67	2.85	6.53
Average *⁾ stands 1, 6, 7, 10, 12	3.63	2.77	6.40	3.25	2.78	6.04
Average **⁾ stands 2, 3, 8, 9, 11	4.00	2.81	6.81	3.55	2,80	6.35
Average, all stands	3.78	2.78	6.56	3.36	2.79	6.14

Table 3. Average stem volumes, removals (m^3 per hectare and m^3 per 100 metres of strip road) in alternative markings (M1 = Marking 1, M2 = Marking 2) in first thinnings, second thinnings and final cuttings. Minimum and maximum in parentheses

	Stem volume, dm^3/tree M1	Stem volume, dm^3/tree M2	Removal, m^3/ha M1	Removal, m^3/ha M2	Removal, m^3/100 meters of strip road M1	Removal, m^3/100 meters of strip road M2
First thinning *⁾ stands 1, 6, 7, 10, 12	52 (33-77)	46 (33-64)	36.8 (14.7-50.4)	28.9 (13.1-54.3)	7.4 (2.9-10.1)	11.6 (5.3-21.7)
First thinning , stands 2, 3, 8, 9, 11 **⁾	70 (52-101)	71 (57-94)	59.8 (36.9-90.6)	57.3 (48.5-75.6)	12.0 (7.4-18.1)	22.9 (19.4-30.2
First thinning , all stands	62 (33-101)	58 (33-94)	51.6 (14.7-90.6)	44.2 (13.1-75.6)	10.3 (2.9-18.1)	17.7 (5.3-30.2)
Second thinning *⁾ stands 1, 6, 7, 10, 12	242 (202-272)	225 (155-305)	42.2 (28.1-57.0)	62.8 (49.3-72.9)	8.4 (5.6-11.4)	12.6 (9.9-14.6)
Second thinning , all stands	242 (202-272)	238 (155-305)	42.2 (28.1-57.0)	64.0 (49.3-72.9)	8.4 (5.6-11.4)	12.8 (9.9-14.6)
Final cutting *⁾ stands 1, 6, 7, 10, 12	362 (317-392)	375 (277-417)	201.3 (168.5-231.9)	197.6 (169.9-246.3)	40.3 (33.7-46.4)	39.5 (34.0-49.3)
Final cutting **⁾ stands 2, 3, 8, 9, 11	280 (243-376)	293 (247-431)	219.5 (196.6-236.8)	225.9 (210.5-241.7)	43.9 (39.3-47.4)	45,2 (42.1-48.3)
Final cutting, all stands	325 (235-392)	344 (230-431)	218.4 (168.5-264.9)	212.4 (169.9-246.3)	43.7 (33.7-53.0)	42.5 (34.0-49.3)

*⁾ = Second thinning in both markings; **⁾ = No second thinning

Financial performance

The revenues were calculated separately for the first thinning (not discounted) and the whole rotation (discounted with 2-6 %) by simply subtracting the harvesting costs from the cutting incomes. The difference between the net revenue of Marking 1 and the net revenue of Marking 2 was non-significant (*i.e.* $p > 0.05$) in the first thinning (Figure 5). In addition, there was no significant difference between the net revenues of Markings 1 and 2 for the whole rotation either, when applying a discount rate of 3 % to 5 % (Figure 6).

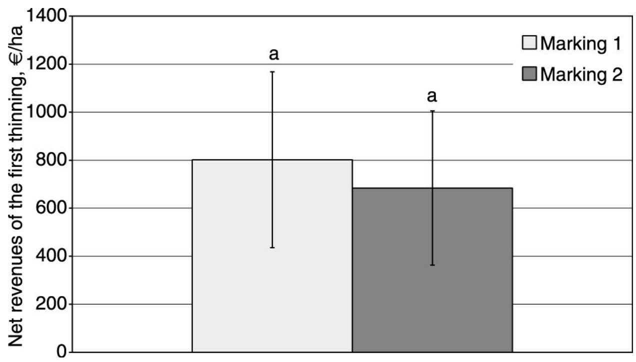

Figure 5. Net revenues according to Marking 1 and 2. The letters above bars indicate the results of statistical analyses: the same letter (here an a) refers to a non-significant difference. Standard deviations are presented by vertical lines

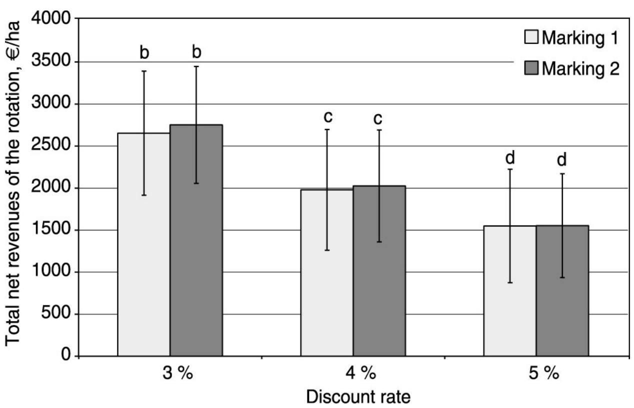

Figure 6. Discounted total net revenues for Marking 1 and 2, whole rotation. The letters associated with each bar (discount rate) indicate the results of statistical analyses: the same letter refers to a non-significant difference in total net revenue, €/ha. Standard deviations are presented by vertical lines

The sensitivity analysis resulted in that the harvesting costs of Marking 3 in the first thinning should not exceed 13.9 €/cubic metre or 9.9 €/cubic metre in order to break-even with the total net revenues of Marking 1 and 2, respectively (discount rate 3 %). The original harvesting costs at the first thinning for Markings 1 and 2 were 14.2 and 14.7 €/cubic metre, respectively. Thus, the unit harvesting costs of Marking 3 should be lower than the corresponding values of Markings 1 and 2. Furthermore, given that Marking 3 is a method that requires very small machinery, and the fact that small machinery is most likely to increase the unit costs rather than to decrease them, we can reject the idea of Marking 3 as a suitable method for use in the first thinning on drained peatlands.

Discussion

The study material consisted of 12 stands located in Southern Ostrobothnia, Western Finland. The stands represented Vaccinium vitis-idaea site types 1 and 2, and dwarf-shrub types, which are classified as nutrient-normal and nutrient-poor peatlands, respectively. Furthermore, these kinds of peatland are the most common peatland forest site types in Finland, and especially in Southern Ostrobothnia. However, the moisture status of these peatlands can vary drastically between individual stands, indicating that ditch network maintenance is essential. There was an immediate need for ditch network maintenance in two-thirds of the stands. The average distance between ditches in the study stands was 40 metres, which is a very common spacing on this kind of peatland.

The studied marking methods can also be interpreted by saying that they reflect different approaches and prevailing conditions with regard to conducting a first thinning on drained peatlands. Marking 1 is seen to be suitable for drained peatlands where the ditches are in good condition, whereas Marking 2 is an adequate method when the moisture conditions require drainage maintenance. In the latter case (Marking 2), thinning and ditch network maintenance are in most cases carried out simultaneously so that, immediately after thinning, the ditches are re-opened from blocks and they are usually also deepened. Marking 3 is more or less a theoretical alternative, reflecting the effects of Marking 1 and 2 on the removal and remaining stand. However, there is no general rule to be followed. Instead, specific site characteristics such as moisture conditions, spatial structure of the trees (spacing) and declination, ultimately determine which marking method for thinning is the most suitable in each case.

The Motti stand simulator was used to simulate the future development of stands. In earlier studies (e.g. Matala *et al.* 2003, Ahtikoski *et al.* 2004) the growth predictions of MOTTI stand simulator have proved to be unbiased (i.e. residuals showing no clear pattern), and to give surprisingly low absolute errors compared to observed values (Ahtikoski *et al.* 2004). These results from the earlier studies suggest that MOTTI is a reliable tool for stand projections. However, in this study the MOTTI projections were not validated for two distinct reasons. First, there was not a sufficiently long growth period reported and measured for validation purposes in any of the stands of this study. Second, no independent data similar to that of this study with respect to the experimental design and the same forests site types could be found.

The growth and yield results showed that Marking methods 1 and 2 did not differ significantly from each other: the total yield of commercial wood (incl. pulpwood, small-diameter sawlogs and sawlogs) was app. 286 m^3/ha for Marking 1 and 293 m^3/ha for Marking 2. Furthermore, the total yield of sawlogs was 142 m^3/ha for Marking 1 and 146 m^3/ha for Marking 2. For Marking 3 the figures were 286 (total) and 144 m^3/ha (sawlogs). The removal of small-diameter sawlogs for Marking methods 1, 2 and 3 were 8.8, 10.8 and 12.2 m^3/ha, respectively. However, the total removal as well as the net revenue of the simulated intermediate thinning in Markings 2 and 1 differed significantly (Mann-Whitney U test: $p = 0.045$ for removal, and $p = 0.030$ for net revenue). There were seven stands in which the intermediate thinning was simulated according to Marking 2, and five stands according to Marking 1. The total removal of commercial wood for Marking 2 was 64 m^3/ha, and for Marking 1 42 m^3/ha, the net revenues being 1632 and 1055 €/ha, respectively. This is due to the fact that the criterion used to simulate an intermediate thinning was solely based on specific, exogenous limits determined by the prevailing silvicultural recommendations - small differences between Marking 2 and 1 in the growing stock at the beginning of the simulation could lead to relatively different harvesting schedules during the rotation. On the other hand, this statistically significant difference in both the total removal and the net revenue of the intermediate thinning was smoothed out during the rotation, as mentioned earlier.

Due to the fact that the growth and yield results were similar for each Marking method (1, 2 and 3), and the fact that the harvesting schedules did not differ drastically from each other, it could be expected that the financial results would also be similar. It turned out that this argument was true: the net revenues of the alternative markings did not differ statistically significantly either in the first thinning, or when the profitability was determined for the rotation. This result can be interpreted by stating that the decision-makers in practical forestry can put more effort on planning strip roads (so that specific site conditions are taken into account) without loosing too much on profitability. Stated differently, the clear implication is that the first thinning on pine-dominated drained peatlands can also be conducted profitably by simply emphasizing the site-specific harvesting conditions.

The average first thinning harvesting costs in Marking 1 were 4 % lower than those in Marking 2. The difference is caused partly by the 7 dm^3 larger average stem size in Marking 1, and partly by the lower productivity of cutting when using the cutting strip method. The costs of forest haulage in first thinning were 6 % lower in Marking 2 than in Marking 1 due to the 72 % higher timber density (m^3 per 100 m strip road) with the cutting strip method. The harvesting costs in stands with a second thinning were near each other with Markings 1 and 2. In Marking 1 the average stem size was 17 % higher than in Marking 2 and the cutting costs were 4 % lower, but this difference was compensated by the differences in costs in forwarding caused by the 33 % lower strip road density of removal with Marking 1. In final cutting the average stem size was 18 dm^3 smaller in Marking 1 than in Marking 2 resulting in 10 % higher cutting costs in Marking 1. There were no differences in forwarding costs between Marking 1 and 2 in final cutting.

A considerable proportion of the first thinning removal, in the first thinning pine stands more than one third of the total removal, comes from strip roads, when the distance of strip roads is 20 metres (Tanttu *et al.* 2002). The removal from strip roads thus has an important effect on the harvesting productivity. As the financial performance during the rotation period is not significantly disturbed by strip roads, there is no need to use very small machinery that do not need strip road openings in harvesting. The poor economic competitiveness of small forwarding machinery (*e.g.* light crawlers) has been reported in many studies (Mäkelä 1990, Högnäs 1984, 1986, Hänninen and Kumpare 1986).

The effect of stem quality on the financial attractiveness of the alternative markings was not studied. In fact, this would not have been possible because including the monetary value of stem quality into the financial analyses would have required that the stems had actually been cut according to each marking – in this study the development after the model marking to rotation was simulated using a stand simulator. However, the average scores for the technical quality of removed and the remaining trees in the first thinning describe the quality of the operation. There was a clear difference in the quality of removed and remaining trees in all the markings. Thus the operation was successful. There were no actual differences in the quality scores of the remaining trees in the different markings.

On drained peatlands the quality of the trees is influenced by the location of the trees. Stöd *et al.* (2003) studied the quality of the remaining and removed trees in the first thinnings. The study material for peatlands included the same stands as in this study, but up to these there were 3 more stands included in the material. Before thinning more than 60 % of the trees had no technical defects. The most common defects were crooks. The quality and size of the trees varied according to the distance between the tree and the ditch. The number of good quality trees increased with increasing distance to the ditch. Defects that affected the stem straightness were especially common near the ditches. The diameter of the trees was the largest near ditches (Stöd 2004).

When strip roads were located 10 metres from the ditches (Marking 1 in this study) the proportion of non-defective trees was higher among the remaining trees (65 %) than among the harvested trees (58 %). Approximately 78 % of the harvested trees and 90 % of the remaining trees contained a log section. Thus a fairly good stem quality can also be obtained from drained peatlands (Stöd 2004). If the best possible technical quality of the remaining trees is the goal, then the optimal place for strip roads would be 13-16 metres from the ditch (Stöd *et al.* 2003), when the distance between the ditches is 40 metres.

In the productivity calculations the harvester productivity was estimated to be 5 % lower on cutting strips than on actual strip roads. There are several studies on the influence of working method on productivity. For example, on a first thinning pine bog the productivity of small harvester was 9 % lower with the cutting strip method than when using a 20 metre strip road distance (Sirén and Tanttu 2001). Ryynänen (1994) compared cutting methods employing a farm tractor-based cutting machine with distances of 20 and 30 metres between the strip roads. The productivity of work (E_0) with a 20 metre strip road distance was 108 trees compared to 81 trees with the cutting strip method. The productivity difference was primarily caused by the time consumed in moving along the cutting strips. In a Swedish study (Brunberg 1997) the effective time consumption per tree was 3.4 cmin higher in cutting strips than in forwarding strip roads. With the cutting strip method, the productivity of forwarding rises due to the higher density of the timber. However, the difference in forwarding costs does not totally balance the overall cost difference.

There are also secondary costs of harvesting caused by harvesting damage (tree damage, soil damage, windfalls *etc*.). These were not included in this study. The economic consequences of harvesting damage are difficult to estimate, but they can have an effect on the economy of different harvesting alternatives.

Sirén and Tanttu (2001) studied harvester-forwarder and thinning harvesters in the first thinning of pine bog and also compared the total economy of the cutting strip method and the method using normal 20 metre strip road distance with thinning harvesters. The costs of harvesting damage was calculated by the model presented by Kokko and Sirén (1996). The mean damage percentage with a harvester-forwarder was 2.2 and with a thinning harvester including forwarding 3.6. Using the cutting strip method with thinning harvesters, the amount of tree damage was more than double that of the method using a strip road distance of 20 metres. Damaged trees were concentrated near the cutting strips. With the cutting strip method and a 30 m forwarding strip distance, the distribution of the remaining trees was more even than with a 20 metre strip road distance. The number of the remaining trees on the cutting strip area did not differ from the density outside the forwarding strip road area. Thus the cutting strips were actual “ghost” strips, as they were earlier culled. The total costs of these methods, including harvesting costs and costs caused by damage, were very similar. Use of the cutting strip method can be recommended in pine stands with high variation in tree quality.

Finally, there were no great differences in the financial performance of the different strip road alternatives on peatland harvesting. It is not necessary to use very light machinery (f. ex. light crawlers) that do not require strip road openings. A considerable proportion of the first thinning removal comes from strip roads, and this removal has an important effect on the harvesting costs. In this study thinning harvesters were used in the thinnings. However, medium-sized harvesters or harvester-forwarders can also be used in Marking 1. Thus peatland harvesting can mainly be carried out with the same machinery as that used on mineral soils. The major challenge, but also the possibility, in peatland harvesting is co-operation between the forest owners, forestry organizations and industry. This co-operation enables integration of the operations and the creation of reasonable conditions for harvesting.

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ФИНАНСОВАЯ ОЦЕНКА АЛЬТЕРНАТИВНЫХ СХЕМ ВОЛОКОВ ПРИ ЛЕСОЗАГОТОВКАХ В СОСНОВЫХ ДРЕВОСТОЯХ НА ОСУШЕННЫХ БОЛОТАХ

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Резюме

Была проведена сравнительная оценка различных альтернатив волоков на условия лесозаготовок, производительность техники, развитие древостоя и чистую прибыль лесовладельца за оборот рубки в сосновых древостоях на осушенных болотах. Объектом исследования послужили 12 участков, на которых среднее расстояние между дренажными канавами составляло 40 метров. Были рассмотрены три разных альтернативы. Первая альтернатива: волоки располагались в 10 метрах от канав, длина волока составляла 20 метров. И харвестер, и форвардер работали на волоках. При второй альтернативе волоки для форвардера располагались на канавах, а небольшой харвестер работал на волоках и двух узких полосах между канавами. Эти две альтернативы сравнивались с третьей, теоретической альтернативой, при которой волоки отсутствовали.

Альтернативная организация участков привела к различным объемам рубок ухода и к различным количествам древесины на корню. Затем объемы древесины на корню были введены в симулятор МОТТИ, и был смоделирован рост и выход древесины на остающееся время оборота рубки. Были рассчитаны издержки на лесозаготовку (и валку, и трелевку) по Вариантам 1 и 2. Расходы на содержание сети дренажных канав были включены в финансовый анализ по древостоям, в которых содержание сети дренажных канав считалось необходимым.

По параметрам роста и выхода древесины за оборот рубки варианты оказались очень похожи. Однако графики лесозаготовок, т.е. количество и сроки проходов рубками ухода, немного отличались между Вариантами. Средние затраты на лесозаготовку в ходе первой рубки ухода по Варианту 1 были на 4% ниже, чем при варианте 2. Разница частично обусловлена более высоким средним размером ствола по Варианту 1, частично – более низкой продуктивностью валки при сплошных полосных рубках. Однако, по статистическим параметрам данные альтернативы больших различий не имели.

С финансовой точки зрения результаты были очень похожи между альтернативами волоков. Данный результат позволяет нам планировать волоки более приближенно к условиям лесосеки, не теряя при этом прибыльности в обоих случаях. Если есть потребность в содержании сети дренажных канав, то рекомендуется Вариант 2. В данном исследовании для проведения рубок ухода применялись харвестеры, предназначенные для рубок ухода. Однако при Варианте 1 можно использовать также харвестеры среднего размера и форвардеры. Таким образом, лесозаготовка на болотах может проводиться с помощью той же техники, что используется на минеральных почвах.

Ключевые слова: болота, модель на уровне древостоя, рост и выход, лесозаготовка на болотах