Yield and Technical Quality of Scots Pine Saw Timber from Thinnings on Drained Peatlands and Mineral Soils in Finland

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Abstract

In this study the yield of Scots pine (*Pinus sylvestris* L.) timber suitable for mechanical wood processing from thinning operations in different drained peatland and mineral soil stands was determined calculatorily, using the data from field surveying. Additionally, the external quality of the trees was studied. The yield of saw timber was small in general, and its proportion of the thinning removal was modest. The largest yield was obtained when round construction timber – in addition to the normal timber assortments – was harvested. At its highest the yield of saw timber was 11 m^3/ha (16% of thinning removal) from drained peatlands and 18 m^3/ha (31% of thinning removal) from mineral soils. Also small-diameter and short logs increased the yield of saw timber from thinning stands as compared to the yield obtained harvesting only normal saw logs. In thinning stands the number of defect-free trees was small. The most frequent external defects were the deviations from the straight stem form. Despite the relatively poor quality of the trees, the main reason for the low saw timber yield was the small size of the harvested trees.

Key words: thinning, drained peatland, saw timber, technical quality

Introduction

In Finland, the first forest drainage measures were taken in the 1860s. At the beginning, the main purpose was to clear more land for cultivation, but since the early 20th century drainage was done in order to improve the growing conditions of trees on mires and other wetlands (Paavilainen and Päivänen 1995, Laine *et al*. 1997). Commercial drainage was at its most intensive in the 1960s and 1970s; the culmination year was 1969 when in total 294,000 hectares were drained (Figure 1). After that, the amount of first-time ditching decreased constantly. Nowadays, first-time ditching is no more done; the last efforts were made in the year 2000 on 600 hectares only. Instead, ditch cleaning and supplementary ditching – concentrated on the areas where drainage has positively affected the growth of trees – have increased to the level of 70,000–80,000 hectares per year (Finnish Statistical… 2005). The total area of drained peatlands in Finland is about 4.6 million hectares (Hökkä *et al*. 2002).

The total volume of growing stock on drained peatlands is 281 million cubic metres, the average volume being 63 cubic metres per hectare (Hökkä *et al*. 2002). According to the results from the 8th National Forest Inventory of Finland (1986–1994), the annual increment of the growing stock on drained peatlands was about 14 million cubic metres, and the mean increment 3.6 cubic metres per hectare (Hökkä *et al*. 2002). Stand productivity after drainage depends on site fertility, climatic conditions, properties of

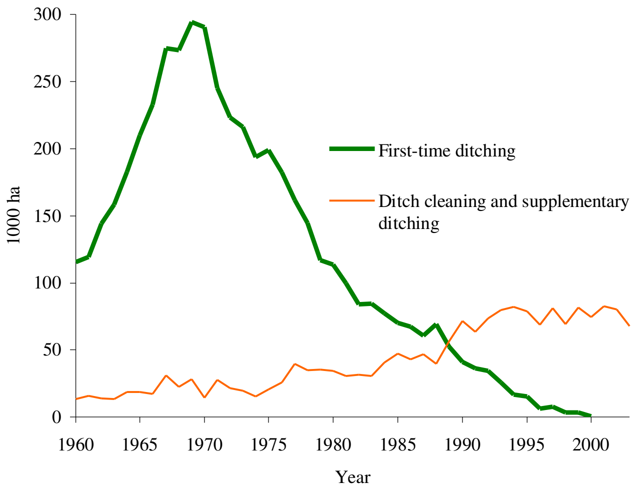

Figure 1. First-time ditching, supplementary ditching and ditch cleaning in Finland in 1960–2004. Data for the figure obtained from Finnish Statistical Yearbook of Forestry (2001, 2005)

existing growing stock, time since drainage, spacing of ditches, and thickness of the peat layer (Paavilainen and Päivänen 1995). In Northern Europe where Scots pine, Norway spruce, and birch are the main tree species on peatlands, good site fertility, high temperature sum, and large initial volume of timber in the stand tend to improve the results of drainage (Paavilainen and Päivänen 1995).

Peatland forests cover about one fifth of the total volume of Finnish forests. Their significance in the timber supply is increasing so that in 2025 about 30% of the harvesting potential is predicted to lie in peatland forests (Sirén 2000). Currently the first thinning stands cover more than half, and advanced thinning stands about one fifth of the drained peatlands (Nuutinen *et al*. 2000, Hökkä *et al*. 2002, Rikala 2003). Also in mature peatland stands small trees form most of the stand volume; this decreases the proportion of potential saw timber, and together with the often uneven stand structure, makes harvesting more challenging and increases the harvesting costs (Sirén 2000, Hökkä *et al*. 2002, Päivänen and Sipi 2002). Due to the uneven structure of the forest, strip roads and their placement strongly affect both the economy of thinning and the average quality of the stand after thinning. Thus the removal per unit area from the five-metre zone nearest to the ditch can be twice as big as the removal from the central parts of the drained area (Eeronheimo 1991).

In mineral soils the young and advanced thinning stands' proportions of the cutting potential of saw logs will increase in importance as well, since the amount of mature stands is diminishing. Besides the changes in the age structure of the forests, the supply of large logs is expected to decline as the forest taxation is nowadays based on the net incomes from forests. Also increased limitations in forest utilisation reduce the supply of timber, especially from old-growth forests.

Butt logs produce the majority of saw timber from young forests, as middle and top logs are seldom obtainable. Nevertheless, the size requirements of the normal logs are often too large for the thinning removal to meet. Logs with small dimensions – i.e. small diameter and short length – are, however, increasingly utilised at sawmills. Depending on the sawmill in question, minimum top diameters 12–15 cm and lengths 31–46 dm, for instance, are used for small-diameter logs, and diameters 10–19 cm and lengths 25–34 dm for short logs (Wall *et al*. 2005).

The first commercial thinning is, above all, a silvicultural measure which ought to be done when the tree crown has reduced significantly and the lowest branches have died. In order to increase profitability, the first thinning is often postponed until the dominant height of 13–15 metres. In such cases, intensive tending of seedling stands is necessary (Luonnonläheinen metsänhoito 1994, Huuskonen and Ahtikoski 2005). It has been noted that in tended stands neither the later development of the stand nor the stumpage earnings from the whole forest rotation period are affected negatively by the postponement of thinning (Huuskonen and Ahtikoski 2005). The first thinning is followed by one or two intermediate fellings, which are done when the basal area on the stand exceeds limits given in the silvicultural instructions. In 2004, first commercial thinnings were done on 183,000 hectares and other thinnings on 152,000 hectares (*Metla Metinfo* 2005).

Tending and first thinning measures strongly affect the quality development of the trees in an individual stand. Thus the most common first thinning method nowadays is thinning-for-quality. In quality thinning the trees with the best potential to produce high-quality saw timber are selected to be grown until the final felling, and the smallest trees as well as those of the poorest quality are removed. Rather than the removal, good quality of the remaining trees is emphasized (Vuokila 1982, Niemistö 1994, Lilleberg 1995). In later thinnings, the quality of stand can be improved only by removing the poorest trees. With regard to wood, instead of suitability for certain end-uses, the term 'quality' is often used to express the grade of a single property. Because quality cannot be defined unambiguously, it can express factors such as absence of particular defects (Lämsä *et al*. 1990, Kellomäki *et al*. 1992, Perstorper *et al*. 1995, Kärkkäinen 2003).

Defects in the trees are often classified as either external or internal even though it would be more descriptive to separate the defects in the stem and in the wood (Kärkkäinen 2003). External defects may be divided into stem form defects, branchiness, wounds and scars, decay, and other defects. Deviations in the stem form, like crook, sweep and ovality, reduce the sawn timber yield, increase warp and cause cross grain. Ground frost, planting errors, and mechanical damages, among other things, cause crooks and sweep; the latter one being common especially on peatlands where ground is soft and sagging happens (Kärkkäinen 2003).

In the leaning or crooked stems, reaction wood is often formed. Several properties of reaction wood are markedly different from those of normal wood (*Forest Products Laboratory* 1999). It is, for example, abnormally heavy. Due to its darker colour, reaction wood is classified as a discolouration in sawmill industry. Additionally, it causes warp, makes wood machining more difficult, and decreases the tensile strength and the impact bending strength (Zobel and van Buijtenen 1989, Forest Products Laboratory 1999, Saranpää 2002, Kärkkäinen 2003). Nevertheless, most of the negative effects of reaction wood are related to its severe forms (Zobel and van Buijtenen 1989).

Other significant internal defects are knots, decay, discolouration and different checks and splits. Because of the adverse effect on wood processing, knots are considered as defects. Knots affect the strength properties, machineability and drying of sawn timber (Desch 1981, Forest Products Laboratory 1999). In addition, their negative impact on the appearance and surface treatment of boards is clear. Because of the slow growth of the trees prior to the drainage, short whorl intervals resulting in numerous knots may be expected in trees growing in drained peatlands. In the butt log section, the knots are most probably dry but small in diameter. The knots formed after the drainage are likely to be rather similar to those of the trees growing on mineral soils.

Because of the correlation between the external and internal quality of trees, the latter can be predicted by means of the former. For example, the breast-height diameter and branch diameter of pine have been noted to be positively correlated (Varmola 1996). Therefore the diameter distribution in which small trees are emphasized produces wood material with smaller proportion of knots than the distribution emphasizing large-diameter trees (Hakkila *et al*. 1972, Varmola 1980, Vuokila 1982, Kellomäki and Väisänen 1986, Salminen and Varmola 1990). The largest branch diameter affects the external quality of log, whereas knottiness is the most important factor when determining the quality class of a piece of sawn timber; in the grading rules for sawn timber the maximum size and number of knots according to their qualities and locations are given (Lämsä *et al*. 1990, *Pohjoismainen sahatavara*... 1994).

In most cases diameter of the thickest branch is considered the best pine log quality indicator because its variation, such as between different site types, is greater than that of the average branch diameter (Uusvaara 1991). The most important factor affecting branch size is stand fertility: the higher the content of nutrients in the ground, the thicker the branches. Stand fertility also affects the rate of growth as branches tend to be thicker in the fast-grown trees than in the slow-grown trees (Lämsä *et al*. 1990).

According to Uusitalo (1997) the best quality predictors for pine butt log are dead branch height, breast-height diameter, and early growth rate. The thicker the branches grow early in life, the longer self-pruning takes. As a consequence, the dead branch height is low and the stem quality stays poor even when though diameter of stem is growing (Uusitalo 1997). In sawtimber trees also the quality of the second and the third log can be predicted using the dead branch height, but, where young trees are concerned, it cannot be considered as a good quality indicator because self-pruning of trees has not started yet (Uusitalo 1994, Jouhiaho and Uusitalo 2001).

The main objective of this study was to determine the yield of Scots pine (*Pinus sylvestris* L.) timber suitable for mechanical wood processing from thinning operations in different drained peatland and mineral soil stands. Bucking results of five different combinations of timber assortments were compared, and the external (technical) properties of the trees were studied. In addition, the factors, which affected the yield of saw timber and the quality were determined.

Materials and methods

Materials

The data were collected from 280 drained peatland and mineral soil stands from Southern (Päijät-Häme and Uusimaa regions), Eastern (Etelä-Savo, North Karelia), Western (Ostrobothnia), and Northern (Lapland) Finland. The sample stands were selected according to the following criteria of silvicultural status: no thinning or fertilisation, at least mild seedling stand tending, and the need for the first commercial thinning or second thinning within five years. On selected stands Scots pine covered at least 70% of the basal area before thinning. Based on visual pre-evaluation, small saw logs should be potentially available in thinning operation. The stands, which met the requirements were selected among the stands pointed by the sawmills participating in the study, the Local Forest Management Associations, the Finnish Forest and Park Service offices, and among the forests administrated by the Finnish Forest Research Institute in each region.

Data contained stands from four different site types both in drained peatlands and in mineral soils (Table 1). The site types were chosen taking into consideration their distribution on the geographical areas as well as on the procurement areas of the sawmills, covering typical fertility levels in each region. In drained peatlands the site types – from the most fertile to the least fertile – were herb-rich transformed type (Rhtkg), *Vaccinium myrtillus* transformed type (Mtkg), *Vaccinium vitis-idaea* transformed type (Ptkg) and dwarf-shrub transformed type (Vatkg) (Saarenmaa 1997). The drained peatland stands were either transforming or transformed

Table 1. Number of experimental first and second thinning stands and sample trees in drained peatland and mineral soil site types. * = Combined with *Vaccinium myrtillus* transformed type, ** = combined with *Myrtillus* type

Site type	First thinning	Second thinning
	Number of stands *(Number of sample trees)*	
Herb-rich transformed type (Rhtkg)	-	1 *(45)**
Vaccinium myrtillus transformed type (Mtkg)	18 *(591)*	1 *(44)*
Vaccinium vitis-idaea transformed type (Ptkg)	37 *(1324)*	16 *(752)*
Dwarf-shrub transformed type (Vatkg)	5 *(193)*	1 *(40)*
Drained peatlands, total	60 *(2108)*	19 *(881)*
Oxalis-Myrtillus type (OMT)	2 *(59)***	-
Myrtillus type (MT)	37 *(1460)*	5 *(246)*
Vaccinium type (VT)	80 *(3163)*	42 *(1933)*
Calluna type (CT)	24 *(982)*	11 *(494)*
Mineral soils, total	143 *(5664)*	58 *(2673)*
Total	203 *(7772)*	77 *(3554)*

drained mires. In mineral soils the site types from the richest in nutrients to the poorest in nutrients were *Oxalis-Myrtillus* type (OMT), *Myrtillus* type (MT), *Vaccinium* type (VT) and *Calluna* type (CT) (Saarenmaa 1997). In order to enable enough sample stands and trees for reliable results in each stratum, the herb-rich and *Vaccinium myrtillus* transformed types' second thinning stands were combined, as well as the *Oxalis-Myrtillus* and *Myrtillus* types' first thinning stands (Table 1).

The number of sample plots established in the stand varied between 1 and 8, depending on the size of the stand. On drained peatlands the sample plots were rectangular; the longer side equalled half of the distance between the ditches, and the shorter side followed the edge of the ditch. The minimum area of sample plot was 80 m^2. On mineral soils the area of circular sample plot was 50 m^2 in the first thinning stands, and 200 m^2 in the second thinning stands.

Basal area, the number of stems per hectare, average stem volume, and the stand volume were calculated relying on the measurements from sample plots (Table 2). Peat layer thickness was recorded as the average value of 2–3 measurements from each drained peatland stand. Data from the forestry plan for the stand, or if it was not available, drilled increment cores in two medium size trees were utilised to determine the average stand age.

All pines with the breast-height diameter of at least 7 cm on each sample plot were sample trees. The breast-height diameter, height, crown height (*i.e.* distance from the butt end of the stem to lower limit

Table 2. Average values of the stand properties in drained peatlands and mineral soils

Property	Rhtkg + Mtkg 1st thinning	Rhtkg + Mtkg 2nd thinning	Ptkg 1st thinning	Ptkg 2nd thinning	Vatkg 1st thinning	Vatkg 2nd thinning
Basal area (m^2/ha)	25.6	31.2	23.1	26.7	22.9	35.5
Stems/ha	1895	1784	1785	1307	1803	1905
Stem volume (dm^3)	88.9	129.9	86.7	163.7	77.3	131.7
Volume (m^3/ha)	164.7	224.9	146.2	193.8	141.5	251.0
Age (yrs)	43	70	52	69	73	104
Peat layer (cm)	72	33	69	59	82	100
Property	**OMT + MT 1st thinning**	**OMT + MT 2nd thinning**	**VT 1st thinning**	**VT 2nd thinning**	**CT 1st thinning**	**CT 2nd thinning**
Basal area (m^2/ha)	27.6	26.2	26.7	23.9	27.1	22.9
Stems/ha	1984	1048	1928	1055	2077	1075
Stem volume (dm^3)	90.8	186.3	98.5	186.5	81.6	160.8
Volume (m^3/ha)	180.0	195.1	176.1	183.5	170.8	160.6
Age (yrs)	30	71	41	73	52	78

of the live crown), dead branch height (*i.e.* height of the lowest dead branch), diameter of the thickest live branch, and the diameter of the thickest dead branch were measured or estimated from each sample tree (Table 3). Moreover, stem parts suitable for mechanical wood processing were measured after visual determination. Stem section met the quality requirements of saw timber if it was free from the following defects: twist, crook, sweep, change of leading shoot, vertical branch, visible decay, stem scar, oversized (> 30 mm) live or dead branch.

Table 3. Average values of the properties of trees in drained peatlands and mineral soils

Property	Rhtkg + Mtkg 1st thinning	Rhtkg + Mtkg 2nd thinning	Ptkg 1st thinning	Ptkg 2nd thinning	Vatkg 1st thinning	Vatkg 2nd thinning
Breast-height diameter (cm)	12.8	14.3	12.6	16.2	12.1	14.9
Height (m)	11.6	13.1	11.3	13.8	11.0	13.4
Crown height (m)	6.1	6.9	5.9	8.2	6.4	8.0
Dead branch height (m)	1.0	1.6	1.3	2.3	1.7	2.4
Thickest live branch (mm)	23	27	23	29	23	27
Thickest dead branch (mm)	17	20	16	23	17	20
Property	**OMT + MT 1st thinning**	**OMT + MT 2nd thinning**	**VT 1st thinning**	**VT 2nd thinning**	**CT 1st thinning**	**CT 2nd thinning**
Breast-height diameter (cm)	12.9	17.1	13.0	16.8	12.6	16.3
Height (m)	11.8	13.7	12.1	14.5	11.4	13.2
Crown height (m)	6.0	7.7	6.3	8.4	5.8	7.1
Dead branch height (m)	0.4	1.6	1.0	2.3	1.3	3.1
Thickest live branch (mm)	22	32	23	27	21	25
Thickest dead branch (mm)	18	23	19	20	18	21

Methods

Actual thinnings were not done in this study; instead, the trees to be removed from each stand were selected using a computer program, which took into account the information collected in the forest. The removable trees were selected according to the principles of thinning from below completed with the quality thinning. Thinning intensity in each stand was defined using the thinning models presented by Niemistö (1992), which are based on the average breast-height diameter and the number of stems after thinning.

Taper curves of sample trees were constructed using the models based on the breast-height diameter and height of the trees (Laasasenaho 1982). Bucking was done using the simulator, which took into account the dimensions and the defects of the trees, the stem parts' suitability for mechanical processing, and the proportional values of the timber assortments (Figure 2) (Kilpeläinen 2002). Timber assortments, their diameter and length combinations, and the unit values or the value relations between the combinations were given as value tables in the simulator.

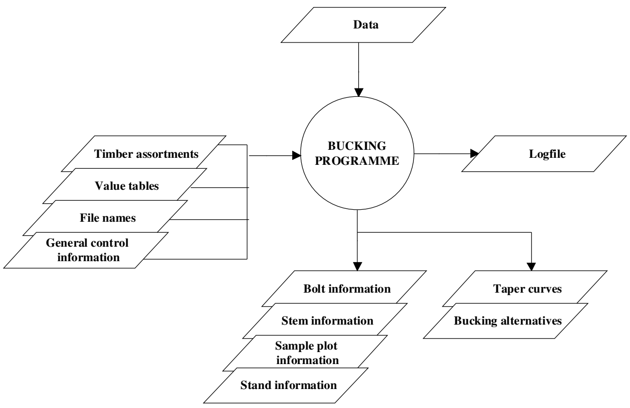

Figure 2. Operational principle of the bucking simulator (Kilpeläinen 2002)

The aim in the value based bucking was to maximise the value of each stem. It was possible to define the timber assortments (max. 30 different) as well as their properties such as log length and top diameter, unit price, and the defects that were not allowed. The stem parts that contained defects were classified as pulpwood, jump butts or jump cuts. If the required minimum top diameter of any timber assortment was not achieved, the stem part was classified as wastewood.

Five different combinations of timber assortments were used in bucking simulation:

1) Grade I butt log, other saw log, pulpwood, wastewood

2) Grade I butt log, other saw log, small-diameter log, pulpwood, wastewood

3) Grade I butt log, other saw log, short log, pulpwood, wastewood

4) Grade I butt log, other saw log, small-diameter log, short log, pulpwood, wastewood

5) Grade I butt log, other saw log, round construction timber, pulpwood, wastewood.

Round construction timber is round small-sized timber utilised e.g. in yard equipment, fences, playgrounds and agricultural buildings (Perälä 1997, Ranta-Maunus 1999). The dimensions of the timber assortments are shown in Table 4.

Table 4. Minimum top diameters (over bark) and lengths (minimum–maximum) of timber assortments. For logs and round construction timber the length was fixed at every three decimetres between the minimum and the maximum. For pulpwood all lengths between the minimum and the maximum were possible

Timber assortment	Top diameter (mm)	Length (dm)
Grade I butt log	180	31–40
Other saw log	150	37–61
Small-diameter log	120	37–46
Short log	100	25–34
Round construction timber	70	25–61
Pulpwood	70	25–55

Bucking simulator calculated the yield of different timber assortments for each bolt and stem, and for the sample plots and the respective stands. In addition, the simulator produced the number of bolts per hectare by timber assortments and cut-off heights, butt and top diameters of the bolts, and the bolt volumes and values at all mentioned levels of calculation. These results were utilised to calculate the average yields of *timber suitable for mechanical wood processing* (henceforth referred to briefly as *saw timber*), *i.e.* logs and round construction timber from the first and the second thinning stands and different site types.

The yield of saw timber from the five different combinations was analysed using two statistical methods: first, logistic regression in order to determine the stand properties which affected the probability to harvest saw timber, and second, the analysis of variance to study which properties affected the volume of potential saw timber. Combination one was excluded from the analyses since it produced mainly pulpwood. Only the stands from which saw timber was obtained were included in the analysis of variance.

In logistic regression the dependent variable was binary, indicating whether or not saw timber was harvested from the stand. The independent variables were: the mean breast-height diameter and mean height of sample trees, both weighted by the basal area, stand volume before thinning, percentage of defected trees on the stand before thinning, type of thinning (first thinning, second thinning), site (drained peatland, mineral soil), site type (herb-rich transformed type, *V. myrtillus* transformed type, *V. vitis-idaea* transformed type, dwarf-shrub transformed type, *Oxalis-Myrtillus* type, *Myrtillus* type, *Vaccinium* type and *Calluna* type). The logit of a multiple logistic regression model is the following (Hosmer and Lemeshow 1989):

$$g(x) = \beta_0 + \beta_1 x_1 + ... + \sum_{u=1}^{k_j - 1} \beta_{ju} D_{ju} + \beta_p x_p , \quad (1)$$

where D_{ju} = dummy variable, u = 1, 2, …, k_j-1.

The effect of the aforementioned independent variables on the yield of saw timber was tested using the analysis of variance. The continuous variables were included into the analysis as covariates, and the categorical variables as fixed factors. The interactions of independent variables were also tested. The following logarithmic transformation – which is useful especially when some of the observed values are small numbers – of the dependent variable was utilised (Zar 1984):

$$X' = \log (X + 1), \quad (2)$$

where X = yield (m^3/ha) of saw timber.

The external quality of trees was defined on the basis of defects and branchiness. Factors, which were expected to affect the proportions of the most common defects were studied using the analysis of variance (mixed model). The factors were: site, type of thinning, site type, and stand, which was the random effect factor. According to statistical theory, percentages or proportions often form a binomial distribution, and deviation from normality is great especially for small and large percentages (Zar 1984, Ranta *et al*. 1994). Thus arcsine transformation was done in order to obtain normal distribution of the dependent variables (Zar 1984):

$$p' = \arcsin \sqrt{p} \quad (3)$$

where p = proportion of sample trees (range 0–1).

Results

Yield of saw timber

In drained peatlands approximately 29% of pines removed in the first thinning met the quality requirements of saw timber at least partly. Amongst the trees in the second thinning the percentage was 34%. Taking both the quality and size requirements into account markedly decreased the proportion of saw timber trees; where the first thinning was concerned, no more than 13% of the removed trees were suitable for mechanical processing. In second thinning stands, a maximum of 27% of trees met the general size and quality requirements of saw timber.

The yields of grade I butt log and other saw log were close to zero (Table 5). Both in the first and in the second thinning the yield of saw timber from dwarf-shrub transformed type was the largest. The bucking option including round construction timber on average always produced the largest yield, 4.5 m^3/ha. The proportion of saw timber of the thinning removal was the largest – 6% – in dwarf-shrub transformed type and the smallest – 2% – in herb-rich transformed type–*V. myrtillus* transformed type. The average amount of wastewood from drained peatlands was 8.5 m^3/ha.

Table 5. Average yields (m^3/ha) of timber assortments from drained peatland stands in different bucking combinations. Butt log = grade I butt log, log = other saw log

Combination	Timber assortments	Drained peatland site type					
		Rhtkg + Mtkg		Ptkg		Vatkg	
		1st thinning	2nd thinning	1st thinning	2nd thinning	1st thinning	2nd thinning
		Yield, m^3/ha					
1)	Butt log, log	0.0	0.0	0.1	0.1	0.0	0.0
	Pulpwood	46.1	52.0	38.1	51.3	54.2	47.6
2)	Butt log, log	0.0	0.0	0.1	0.1	0.0	0.0
	Small-diameter log	0.0	1.1	0.1	0.9	0.0	3.5
	Pulpwood	46.1	50.8	38.1	50.3	54.2	44.1
3)	Butt log, log	0.0	0.0	0.1	0.1	0.0	0.0
	Short log	0.5	3.6	0.5	3.8	4.1	4.1
	Pulpwood	45.6	48.4	37.6	47.5	50.1	43.5
4)	Butt log, log	0.0	0.0	0.1	0.1	0.0	0.0
	Small-diameter log	0.0	1.1	0.1	0.9	0.0	3.5
	Short log	0.5	2.2	0.4	2.8	4.1	0.0
	Pulpwood	45.6	48.6	37.6	47.5	50.1	44.1
5)	Butt log, log	0.0	0,0	0.1	0.1	0.0	0.0
	Round construction timber	2.1	8.5	2.9	7.2	10.7	9.6
	Pulpwood	43.9	43.3	35.1	44.0	43.3	38.0

In mineral soils 56% of the trees removed in the first thinning met the quality requirements of saw timber. In second thinning stands the proportion was 58%. In the first thinning stands a maximum of 36%, and in the second thinning stands a maximum of 45% of the removed trees met the quality and size requirements of saw timber.

The biggest saw timber yield was obtained from *Calluna* type (Table 6). Also on mineral soils the combination, which included round construction timber, on average produced the largest yield, 12.1 m^3/ha. In *Calluna* type stands the proportion of saw timber of the thinning removal was the largest, 11%. On

Table 6. Average yields (m^3/ha) of timber assortments from mineral soil stands in different bucking combinations. Butt log = grade I butt log, log = other saw log.

Combina-tion	Timber assortments	Mineral soil site type OMT + MT		VT		CT	
		1st thinning	2nd thinning	1st thinning	2nd thinning	1st thinning	2nd thinning
		Yield, m^3/ha					
1)	Butt log, log	0.5	0.5	0.4	1.0	0.2	1.8
	Pulpwood	55.6	51.6	55.8	41.8	65.9	34.4
2)	Butt log, log	0.5	0.5	0.4	1.0	0.2	1.8
	Small-diameter log	0.6	2.2	0.9	2.3	1.1	2.3
	Pulpwood	54.9	49.5	54.7	39.3	64.6	31.5
3)	Butt log, log	0.5	0.5	0.4	1.0	0.2	1.8
	Short log	2.2	7.3	4.4	5.7	5.8	6.0
	Pulpwood	53.4	44.3	51.3	36.0	59.9	28.3
4)	Butt log, log	0.5	0.5	0.4	1.0	0.2	1.8
	Small-diameter log	0.6	2.2	0.8	2.3	0.9	1.7
	Short log	1.6	5.4	3.6	3.3	4.9	4.3
	Pulpwood	53.4	44.0	51.2	36.1	59.8	28.0
5)	Butt log, log	0.5	0.5	0.4	1.0	0.2	1.8
	Round constrution timber	6.8	10.5	11.5	9.5	20.9	10.7
	Pulpwood	48.7	40.9	43.9	32.1	44.3	23.4

the other hand, the smallest saw timber proportion, 5%, was obtained in *Myrtillus* type stands. The approximate amount of wastewood from mineral soils was 6.6 m^3/ha.

In comparison to the corresponding drained peatland site types, the mineral soils produced more saw timber (Tables 5 and 6). The difference between the sites was notable especially in the fifth combination, in which the yield of saw timber from the mineral soils was about 5.5 m^3/ha larger than from the drained peatlands.

Logistic regression showed that the type of thinning significantly affected the likelihood of saw timber in all combinations (Table 7). According to the regression coefficients, regardless of the combination of timber assortments it was more likely to harvest saw timber from the second than from the first thinning stands. In addition to the type of thinning, in combination 2 the stand volume, and in the other combinations the basal area of stand before thinning had a positive effect on the probability to obtain saw timber. In combination 5 also the percentage of defected trees and the site affected the likelihood of saw timber. Drained peatlands and the stands in which the percentage of defected trees was high were less likely to produce saw timber than the mineral soils and the stands in which the trees were of high quality.

Logistic regression model for combination 5 classified 86% of all studied stands correctly. However, only 46% of the stands, which did not produce

Table 7. Estimated logistic regression coefficients (B), standard error (S.E.), degrees of freedom (df), odds ratio, and the logarithmic likelihood function for models describing the probability to harvest pine saw timber in different bucking combinations. *** = $p \leq 0.001$, ** = $p \leq 0.01$, * = $p \leq 0.05$. Type of thinning: 0 = first; 1 = second. Site: 0 = mineral soils; 1 = drained peatlands

Combi-nation	Variable	B	S.E.	df	Odds ratio	Log-likelihood
1)	*Not tested*					
2)	Constant	-5.244^{***}	0.736	1	0.005	247.968
	Type of thinning	1.453^{***}	0.325	1	4.275	
	Stand volume (m^3/ha)	0.020^{***}	0.004	1	1.020	
3), 4)	Constant	5.471^{***}	0.844	1	0.004	303.805
	Type of thinning	1.903^{***}	0.356	1	6.707	
	Basal area of stand (m^2/ha)	0.206^{***}	0.032	1	1.229	
5)	Constant	7.884^{*}	3.338	1	2654.492	175.071
	Type of thinning	1.704^{**}	0.535	1	5.497	
	Basal area of stand (m^2/ha)	0.288^{***}	0.053	1	1.333	
	Percentage of defected trees (%)	-0.141^{***}	0.036	1	0.868	
	Site	-1.364^{**}	0.396	1	0.256	

saw timber, were correctly classified. The second best overall classification percentage, 81%, was obtained in the model for the second combination; 95% of the stands which did not produce saw timber but only 40% of the stands in the opposite case were correctly classified. In combinations 3 and 4 the model classified correctly 74 % of the stands from which saw timber was obtained and 69% of the stands, which did not produce timber suitable for mechanical wood processing.

The effect of different stand properties on the amount of potential saw timber was tested using the analysis of variance. The stand volume before thinning was noted to affect the yield in combinations 2, 4 and 5 (Table 8). In all cases the parameter estimate calculated for the stand volume was positive, which indicated that the greater the volume before thinning, the larger also the yield of saw timber. Additionally to the stand volume, the percentage of trees containing butt sweep affected the yield in combination 2. As expected, the defect in the possible log section affected yield negatively. In combination 4 the other significant variable was the site; according to the parameter estimate, mineral soils produced more saw timber than drained peatlands. Where combination 5 was concerned, besides the stand volume, the site type influenced the yield; *Calluna* type being the reference level also produced most saw timber. From the herb-rich transformed type–*V. myrtillus* transformed type the yield of saw timber was the smallest. In combination 3 both significant variables – basal area of the stand before thinning and average height of the removed trees weighted by the basal area

Table 8. Parameter estimates (B), and standard errors (S.E.) for analysis of variance on the yield (transformation $X' = \log(X + 1)$) of saw timber in different bucking combinations. $^{***} = p \leq 0.001$, $^{**} = p \leq 0.01$, $^{*} = p \leq 0.05$

Combination	Variable	B	S.E.
1)	*Not tested*		
2)	Intercept	0.573***	0.150
	Stand volume (m^3/ha)	0.002**	0.001
	Percentage of trees containing butt sweep (%)	–0.006**	0.002
3)	Intercept	–0.284	0.178
	Basal area of stand (m^2/ha)	0.020***	0.005
	Average tree height (m)	0.041***	0.010
4)	Intercept	–0.039	0.760
	Stand volume (m^3/ha)	0.189***	0.000
	Site: Mineral soils	0.004**	0.003
5)	Intercept	0.366***	0.088
	Stand volume (m^3/ha)	0.005***	0.000
	Site type: Rhtkg + Mtkg	–0.711***	0.096
	Site type: Ptkg	–0.457***	0.071
	Site type: Vatkg	–0.267*	0.125
	Site type: OMT + MT	–0.381***	0.071
	Site type:VT	–0.304***	0.056

– had positive effect on the yield. Thus, the large average size of trees increased the volume of saw timber from the stand.

Quality of trees

External defects

In unthinned stands the most common defects were sweep in the butt end of the stem, change of the leading shoot, and twist (Figure 3). In drained peatlands 7% and in mineral soils 9% of sample trees were free from external defects. The proportion of non-defective trees was largest in dwarf-shrub transformed type and *Vaccinium* type stands. Unexpectedly, there was no notable difference in general quality between the first and second thinning stands.

Analysis of variance showed that the frequency of the most common defects – butt sweep, change of leading shoot, and twist – differed between the types of thinning (Table 9). Contrary to the presupposition, the proportion of butt sweep was higher in the second thinning stands (43%) than in the first thinning stands (33%). In addition to the type of thinning, also the site type affected the proportion of butt sweep. Pairwise comparisons showed a difference between *Myrtillus* (30%) and *Vaccinium* (39%) types, as well as between *Myrtillus* and *Calluna* (42%) types. Even mild sweep was noted in this study, which could partly explain the unexpected higher percentages of the defect in the advanced thinning stands and in the site types poor in nutrients. However, the differences between the strata were probably mainly caused by the original quality of

Table 9. Results from the analysis of variance on the proportions (transformation $p' = \arcsin\sqrt{p}$) of trees containing butt sweep, change of leading shoot, and twist. Df_1 = numerator degrees of freedom, df_2 = denominator degrees of freedom, F = F value. $^{***} = p \leq 0.001$, $^{**} = p \leq 0.01$, $^{*} = p \leq 0.05$

Dependent variable	Variable	df_1	df_2	F
Proportion of trees with butt sweep	Intercept***	1	271	892.986
	Type of thinning***	1	271	13.673
	Site type*	5	271	2.984
Proportion of trees with change of leading shoot	Intercept***	1	276	1025.972
	Type of thinning***	1	276	18.290
Proportion of trees with twist	Intercept***	1	276	576.441
	Type of thinning**	1	276	12.288

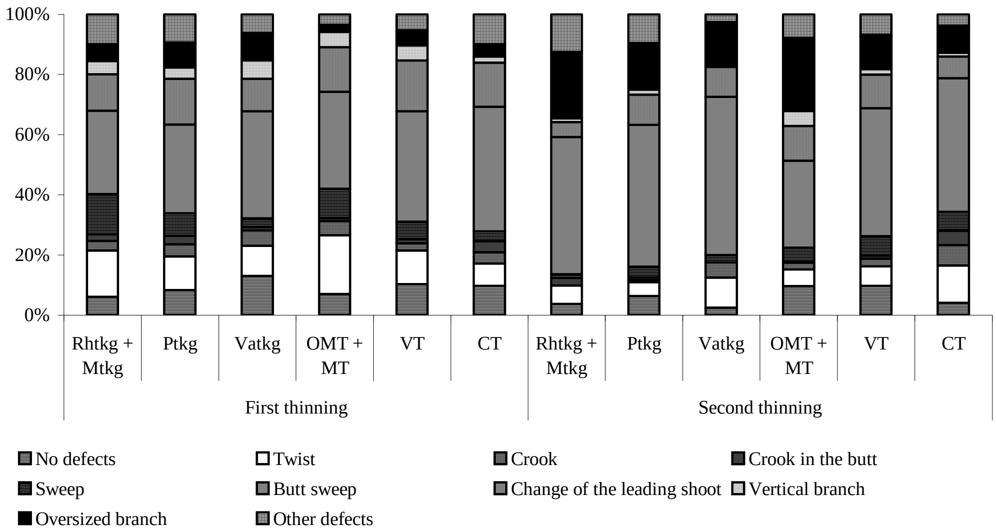

Figure 3. Proportions of the defects in drained peatland and mineral soil site types

stand, and the decisions made at the stage of the first thinning concerning the seriousness of different defects. Because the amount of sweep had not been measured, the precise order of superiority of the site types or the types of thinning could not be defined. Where the change of leading shoot and twist were concerned, both defects were more frequent in the first thinning stands (15% and 14%, respectively) than in the second thinning stands (10% and 7%). Thus a major proportion of the trees containing these defects had been removed from the current second thinning stands while carrying out the first thinning, or their proportion was low from the beginning.

Branchiness

As shown in the previous chapter, oversized (> 30 mm) branches were fairly uncommon in the thinning stands. In unthinned drained peatland stands the diameters of the thickest live and dead branches on average were 27 mm and 20 mm, and in mineral soils 26 mm and 21 mm. Variation of branch diameters was relatively small between the drained peatland site types (Table 3). In mineral soils the differences were somewhat larger, especially where the second thinnings were concerned.

Branches of the removed sample trees were relatively small in diameter. In drained peatlands the thickest live and dead branches on average were 20 mm and 16 mm. Where mineral soils were concerned, the respective diameters were 20 mm and 17 mm. Thus the branches – even in the second thinning trees – were small in relation to the limits given in the quality requirements of normal pine logs; e.g. the maximum branch diameters 50–70 mm are used for live branches, 40 mm for dead or vertical branches, and 30 mm for decayed branches. The quality requirements of small-diameter and short logs as well as those of round construction timber naturally vary according to the sawmill and the end use in question. Basically the branch diameters accepted in the quality requirements of small-sized timber assortments are the same as for the large logs.

The relative proportion of branchless stem section of the tree height was largest in dwarf-shrub transformed type (15% in 1st thinning, 18% in 2nd thinning) and in *Calluna* type (11%, 23%) (Figure 4). As shown above, at a given fertility level the proportion of branchless section was larger in drained peatlands than in mineral soils, especially in the first thinnings. The average length of the branchless stem section was 1.4 metres only. The smallest proportion of stem section with dead branches was found in *V. vitis-idaea* transformed type (40%, 42%) and in *Calluna* type (39%, 31%). The average length of dead branch section was 5.3 metres. The crown length on average was 5.9 metres, and it covered approximately 47% of the tree height.

Self-pruning normally occurs rapidly in trees growing in fertile and not dense stands. In this study, however, clear effect of stand fertility or density on the rate of self-pruning was not noted. Self-pruning had been fastest in *V. vitis-idaea* transformed type stands and in *Calluna* type stands. In general, differences between site types were small at this stage of the tree growth.

Discussion and conclusions

The data of the study consisted of 280 Scots pine dominated the first and second thinning stands from which in total 11,326 sample trees were measured. This enabled a rather good potential to generalise the results in Finland. In each part of the country the

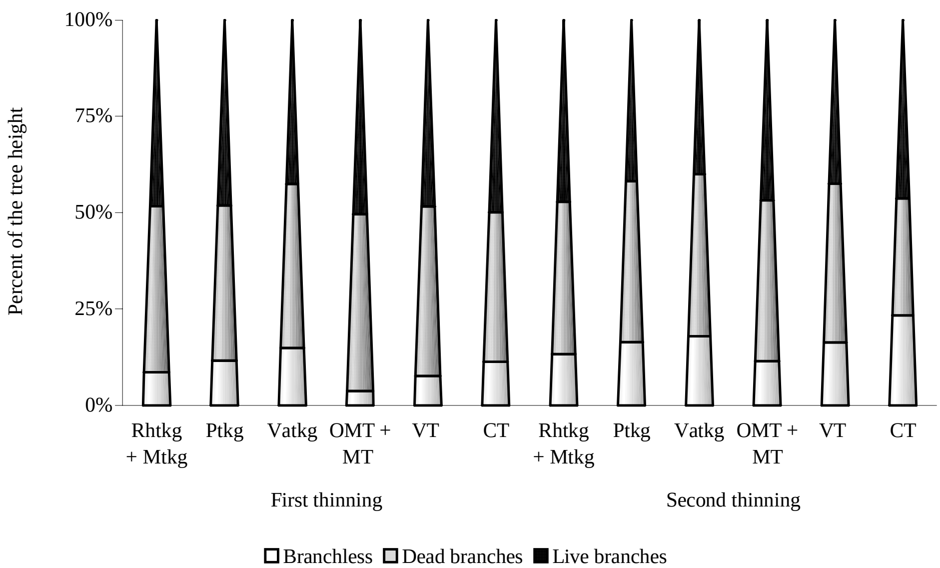

Figure 4. Relative length of the branchless stem section, and the sections with dead and live branches

measurements were concentrated on the most common site types, thus describing the typical thinning stands in the area in question. The silvicultural status of the studied forests was, however, somewhat higher than that of the thinning forests in general. Since the field surveying required subjective estimation of branch diameters and defects, the same directions for measuring and estimation were followed throughout the study, in order to avoid errors caused by several persons doing the field survey. In some stands the sample plots had to be located subjectively, on places well representing the stand. It should also be taken into account that due to the relatively small size of the sample plots, occasional big trees probably affected the volume estimate more than what was their actual effect on the stand volume.

The yield of saw timber from thinning forests was low in general. In the studied thinning stands the yield of high-grade butt logs and other saw logs seldom exceeded zero. Harvesting small-sized timber assortments such as small-diameter logs, short logs or round construction timber besides the conventional saw logs increased the yield. Volume of saw timber was clearly largest when additional timber assortment was round construction timber. Short logs, in turn, increased the yield more than small-diameter logs. However, harvesting both the small-diameter and short logs simultaneously did not markedly affect the yield.

According to Wall *et al*. (2005) it is most reasonable to harvest only one small-sized timber assortment in addition to the conventional saw logs from thinnings. Firstly, the yield of individual timber assortment is often small. Secondly, productivity of harvesting and transport decreases since a larger number of timber assortments requires more sorting. Wall *et al*. (2005) discovered that harvesting costs on average were 14% higher when short logs had been harvested instead of the normal timber assortments. Higher costs were mainly caused by less productive cutting and underutilisation of the transport capacity. Using several different log lengths for the small-sized timber assortments in bucking was observed as having no value since 95% of the largest possible yield of saw timber was achieved using only two different lengths of small-diameter or short logs.

To sum up, in thinning operations mineral soils produced more saw timber than drained peatlands. The largest yield was obtained from site types poor in nutrients; at its highest, the yield of saw timber was 11 m^3/ha (16% of the removal) from dwarf-shrub transformed type stands, and 18 m^3/ha (31% of the removal) from *Calluna* type stands. The properties of *Calluna* type stands did not differ significantly from those of the other mineral soil site types, meanwhile the bigger yield from dwarf-shrub transformed type was presumably due to the smaller proportion of defect-free trees and somewhat higher number of stems on the stand before thinning compared to the other drained peatland site types.

The results were comparable with those of the study by Wall *et al*. (2005), in which the procurement and sawmilling of Scots pine from thinnings were studied. In that study the saw timber's proportion of thinning removal was highest from dwarf-shrub transformed type stands (10%, on average) and *Vaccinium* type stands (20%) when the potential timber assortments harvested were normal saw log, small-diameter log and short log. The yield of saw timber from first thinnings was low: 2–5 m^3/ha from drained peatlands and 4–8 m^3/ha from mineral soils, at different site fertility levels (Wall *et al*. 2005). From second thinning stands the yield was 0–7 m^3/ha from drained peatlands and 8–12 m^3/ha from mineral soils.

In the study by Verkasalo and Kilpeläinen (2004) the yield of normal pine saw logs from final fellings was 89 m^3/ha (55% of the removal). Harvesting also small-diameter and short logs increased the yield up to 112 m^3/ha (69%). Thus despite the somewhat lower quality – especially the stem form – of the trees compared to the trees in mineral soils, the recovery of saw timber from final fellings in drained peatlands was reasonable.

As a whole, the size requirements of normal saw logs were too strict for the trees at the thinning stage. Obtaining normal pine saw log requires the breast-height diameter of 19 cm, minimum (Wall *et al*. 2005). For small-sized and short logs the corresponding diameter requirements are 15 cm and 11 cm, respectively. In this study the average breast-height diameter of sample trees was 13.9 cm; thus most of them did not meet the minimum top diameter of normal or small-sized log even at the breast-height. Even small changes in the tree size markedly affect the saw timber yield; if the yield of saw timber expected from thinning is greater than 5 m^3/ha, and the timber assortments harvested are high-grade butt logs, other saw logs, small-diameter logs and short logs, the mean breast-height diameter in the stand should be at least 15 cm and the mean height 13 m (Wall *et al*. 2005). The yield of 20 m^3/ha requires a breast-height diameter 16–18 cm and a height 15–16 m. Wall *et al*. (2005) also noted that the increment in the stand volume increases the yield of saw timber proportionally more in drained peatlands than in mineral soils. Thus postponement of thinning can be recommended when aiming at saw timber assortments.

When normal saw logs and round construction timber were harvested, the influence of tree size on the yield was weaker than in the other studied combinations. Again, the yield of normal logs was modest, and round construction timber, which is obtainable from relatively small trees, produced most of the yield. In the aforementioned combination the yield of saw timber was approximately 75% higher and, the yield of pulpwood approximately 15% smaller than in the other combinations. Thus a part of pulpwood could be utilised in mechanical wood processing as round construction timber.

According to the estimations by Eeronheimo (1991), the total removal from thinnings on drained peatlands is generally small, about 29 m^3/ha. In this study the thinning removal was larger: approximately 46 m^3/ha from the first thinning stands and 51 m^3/ha from the second thinning stands. These levels of removal appear reliable for the first thinnings but exceptionally low for the second thinnings compared to the normal yield in industrial forest operations, which indicated that the yield of saw timber from the second thinning stands was somewhat underestimated in this study. In the study by Wall *et al*. (2005) the average removal was 47 m^3/ha from first thinning stands and 55 m^3/ha from second thinning stands.

The quality of trees affected the likelihood of saw timber especially when the small-sized timber assortments were harvested. The results showed also the importance of the tree size and spacing in the forest on the probability of saw timber, which, in turn, underlined the importance of pre-commercial thinnings during the sapling and pole stages of the stand. The simulated yield of saw timber was most strongly affected by the amount of timber on the stand before thinning. Instead, the effect of the tree quality on the volume of timber suitable for mechanical processing was smaller than expected.

In this study the quality of sample trees was graded against strict criteria. Therefore, compared to the simulations, the stands in question probably produce more saw timber in real thinnings. The most common defects noticed in the trees were the deviations from the straight stem form. Additionally, the defects appeared mainly in the butt end of the stem, i.e. in the possible log section. Even though the size and quality requirements of timber vary according to the end use, especially the straightness of stem is crucial for small-sized saw timber (Wall *et al*. 2005). The results showed also that the average quality was not invariably better on the second thinning stands than on the first thinning stands.

Especially where pine is concerned, high site fertility normally has a negative effect on the quality of trees (Kärkkäinen and Uusivaara 1982, Lämsä *et al*. 1990, Hakkila *et al*. 2002, Kärkkäinen 2003). High nutrient content accelerates the growth rate, which in turn lowers the quality, as wood density, for example, decreases and branches grow larger. Regardless of its reason, the high rate of growth affects the quality negatively, in many respects. In this study, clear effect of the site fertility was noticed as the branch diameters increased along with the nutrient content of the site type. Mostly the thickest branches did not, however, exceed the limits given in the quality requirements of normal timber assortments.

In comparison to the results from final felling stands, the studied thinning forests were relatively poor in quality. For example the study by Verkasalo and Kilpeläinen (2004) showed that almost one third of the mature trees in drained peatlands were defect-free. A difference in the tree quality between the drained peatlands and mineral soils was observed also in final felling stands; trees growing on drained peatlands contained more stem form defects, and in addition, the living crown was shorter and the dead knot section longer than on mineral soils. Riekkinen (2004) studied the visible stem quality of mature Scots pines in different parts of Finland and Sweden; in all areas stem form defects were more common than, for example, big knots or surface defects. In Finland the percentage of sample trees with a stem form defect was 40–50%.

In the study by Päivänen and Sipi (2002) as well as in the study by Rikala (2003) no great difference between mature drained peatland and mineral soil stands in the average quality of pine sawn timber was noted. Where the drained peatlands were concerned, sawn timber from butt logs appeared to be of high quality, whereas the quality of sawn timber from middle and top logs was generally poor.

Successful thinning improves the quality of the stand. In this study, the simulated thinnings were proved to follow the principles of quality thinning since the most defected trees were removed. However, the results showed that the thinning does not necessarily decrease the proportions of all defects; oversized branches, for example, are often more common in the remaining trees than in the removed trees as the former are normally bigger in size. The effect of thinning on the quality of the stand is discussed in more detail in studies such as Verkasalo *et al*. 2005.

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ОБЪЁМ И КАЧЕСТВО ПИЛОВОЧНИКА СОСНЫ ОБЫКНОВЕННОЙ, ЗАГОТАВЛИВАЕМОГО РУБКАМИ УХОДА НА ОСУШЕННЫХ ТОРФЯНИКАХ И МИНЕРАЛЬНЫХ ПОЧВАХ ФИНЛЯНДИИ

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Резюме

В данном исследовании, используя полевые данные, был вычислен объём пиловочного сырья, полученного из сосны обыкновенной (*Pinus sylvestris* L.) в результате промежуточного пользования на различных делянках в условиях осушенного торфяника и минеральных почв. Было также исследовано внешнее качество деревьев. Фактический объём пиловочника, был, в общем, небольшим, и его доля от общего объёма промежуточного пользования была низкой. Наибольший объём выхода сортиментов при промежуточном пользовании был достигнут тогда, когда в дополнение к стандартному пиловочнику заготавливались тонкомерные сортименты, используемые в строительстве. Наибольший объём выхода пиловочника на осушенных торфяниках составил 11 м^3/га (16 % от общего объёма промежуточного пользования) и на минеральных почвах 18 м^3/га (31 % от общего объёма промежуточного пользования). Заготовка тонкомерных и короткомерных сортиментов также позволила увеличить объём выхода сортиментов по сравнению с методом, когда заготавливался только стандартный пиловочник. На делянках, отведённых для промежуточного пользования, количество деревьев без повреждений было небольшим. Самым распространённым внешним пороком являлось отклонение от прямой линии ствола. Несмотря на относительно низкое качество древостоя, главной причиной низкого объёма выхода пиловочника являлся малый размер срубленных деревьев.

Ключевые слова: рубки ухода, осушенный торфяник, пиловочник, техническое качество