Stem and Wood Properties of Norway Spruce on Drained Peatlands and Mineral Forest Lands in Southern Finland

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Abstract

Norway spruce from drained peatlands is of growing importance for forestry and forest industries in Finland, Sweden and Norway, and it has an essential role in Baltic countries and Russia, as well. In this paper, the level of and between-tree, between-stand and vertical within-tree variations in the technical quality of stems and selected morphological and physical properties of wood were studied on mature Norway spruce in naturally regenerated stands on drained peatlands, compared to naturally regenerated and planted stands on mineral forest lands, in southern Finland. In the analysis, breast height diameter and sub-region (four of them) were considered the covariants. The properties were examined separately for the vertical sections of butt logs, other logs and small-sized saw logs.

Concluded from the results, Norway spruce from drained peatlands provides at least a moderate technical potential in the butt log section for sawmill and plywood industries in southern parts of Finland. The issues of uncertainty concern mainly internal dry knots and compression wood, and possibly the heterogeneity of wood material within a log. The industrial value of upper log sections seems considerably lower. Sub-regional effects seem to be largely insignificant within the southern-finnish climatic conditions, after considering the main effects of tree size, soil type and way of regeneration.

Key words: *Picea abies*, technical quality, wood properties, saw logs, peatlands, variation

Introduction

Draining peatlands for increasing forest growth has a long tradition in Finland. Almost five million hectares of peatlands have been drained for wood production, although new areas are no longer drained. The peak in drainage was reached in the 1960's after development of the machinery for ditching, when almost 300, 000 hectares were drained (Peltola 2003). As a result, the importance of peatland timber will grow considerably during the next two decades. In general, the proportion of peatland forests of the allowable cut in Finland were estimated to grow from 14-16% to 17-26% for different species between periods 1996 – 2005 and 2016 – 2025 (Nuutinen *et al.* 2000).

Although the allowable cut from peatlands will increase mainly due to Scots pine, especially from thinnings, the proportion of the cutting potential of Norway Spruce will increase, as well. Of the total stock of spruce roundwood, ca. 15 % is currently located on peatlands (Nuutinen *et al.* 2000). In general, the saw timber percentage is 35 % on peatlands, *i.e.*, lower than on mineral forest lands, 45 %. Of all saw logs of spruce, ca. 11 % are now standing on peatlands. - In addition to Finland, the importance of peatland spruce is growing for forestry and forest industries in Sweden and Norway, and spruce from peatlands has an essential role in Baltic countries and Russia, as well.

During the 1990's, spruce became the most wanted species both for pulp and paper and sawn wood and plywood in Finland, leading gradually to the current shortage of domestic spruce. Thus, the supplies of spruce timber are raised in the forest industries. The primary strategic use of spruce roundwood is at paper mills, but also sawmills, further processing plants and plywood industries provide important use for spruce logs (Peltola 2003). However, for the technical quality, the needs of mechanical wood processing have been considered to be the most important, so far. The primary quality criteria for the ability for processing and commercial value of the stems and logs at sawmills and plywood mills are stem size, stem form, technical defects and branchiness. However, in addition to the knowledge of external quality, it is important to know the level and variation of the internal quality characteristics, such as annual ring width, wood density, proportions of heartwood and sapwood, proportion and location of compression wood, diameter and proportion of possible juvenile wood (core), and occurrence and extent of decay, and other internal defects (pitch pockets, checks).

Although the growing importance of Norway spruce from peatlands is well-known, the technical quality of timber and wood has not been widely studied until late 1990's. The lack of research is obviously due to the less important role of Norway spruce from peatlands for the forestry or forest industries, up to now.

The specific soil and nutrient conditions and the silvicultural history of peatland forests hypothetically lead to abnormal timber and wood properties (*e.g.*, Rikala 2003, Verkasalo *et al.* 2004; see also Verkasalo and Kilpeläinen 2004). Abnormally large between-stand variations, compared to the stands on mineral soils, may be expected in stand structure, tree dimensions as well as wood and timber quality. In addition, variations may be larger within stands, and are very obviously larger within trees compared to trees on mineral soils.

Branchiness of spruce trees has been widely studied in many Scandinavian and Central-European countries. However, there are only few studies concerning branchiness of peatland spruce. The most critical factors affecting branchiness are site fertility and growing space (spatial features). Since trees, especially on wet peatlands, were usually growing sparsely before the drainage, the branchiness of the trees could be worse. In general, every silvicultural treatment affecting development of the tree crown also affects stem form development (Larson 1963). However, according to Rikala (2003), peatland spruces are characteristically thin-branched. Hakkila and Rikkonen (1970) noted that the faster growth produces more branches, which could partly explain the low branchiness of peatland spruce.

Annual ring width varies a lot between trees and within a single tree, depending on tree age, site fertility and seasonal growing conditions (*e.g.*, Henttonen 1984). On peatlands, the boundary zone between woods formed before and after the drainage is very clearly distinguishable since the width of the growth rings increases after the drainage (Siren 1952, Ollinmaa 1960, 1981, Rikala 2003). Shrinkage of close-ringed wood formed mainly prior to the drainage is higher (in all three principal directions) than that of wide-ringed wood produced after the drainage (Ollinmaa 1960). Due to the risen tendency to checking and splitting, this could lead to problems in wood processing (drying, machining, installation of mechanical connectors). For spruce, increase in the growth starts after some years following the drainage, and is usually evident for about 20 years after the drainage (Ollinmaa 1960, 1981); thereafter the radial growth rate is dependent on the available nutrient resources (Seppälä 1976). In addition, the radial growth response to releasing cutting on peat-moors lasts at least 10 years, and, at least at the beginning of the period, concentrates on the lower part of the stem (Siren 1952). Within the post-drainage wood, annual ring width usually decreases toward the bark (Mikola 1950, Rikala 2003).

Wood density has a strong correlation with many wood and pulp quality properties, but also with many properties important in mechanical wood processing and products (*e.g.*, Hakkila 1966, Mäkinen *et al.* 2002, Kärkkäinen 2003). The overall density variation of spruce is relatively small compared to many other conifers (Kärkkäinen 2003). Hakkila (1968) noted that the geographical variation of the density of spruce is relatively small compared to pine in Finland.

In the radial direction, the density in the spruce stem usually decreases first from the pith toward the cambium, but begins soon to increase again (Nylinder 1953, Hakkila 1966, 1968, Olesen 1982, Rikala 2003) or increases continuosly from pith to bark (Hakkila 1966, 1979, Frimpong-Mensah 1987). However, Mäkinen *et al.* (2002) found a continuous decreasing trend of density from the pith to the bark. Similarly to mineral forest lands, wood density usually decreases while the width of the growth rings increases in the trees growing on peatlands (Ollinmaa 1960, Rikala 2003). Of all sites, the wood density of spruce is the highest on undrained swamps (Hakkila 1966, comp. Hakkila (1979). Since the growth increases after the drainage, the density of the wood decreases more (Rikala 2003) or less (Ollinmaa 1981); the effect is similar after releasing cutting on peatlands (Siren 1952) and fertilization (Hakkila 1966). In itself, the boundary region between pre-drainage and post-drainage woods has not proved to affect largely the mechanical properties despite the increase in the diameter growth (Ollinmaa 1981).

In the longitudinal direction, the density of the butt end at first decreases when moving towards the crown, but from the middle of the stem it begins to increase again (Hakkila 1966). However, the longitudinal effect has proved unclear on peatlands, partly due to small materials and probably owing to indefinite study methods (Ollinmaa 19760, 1981). It should be noted that the density is larger in the stemwood surrounding the knots than in the actual stemwood, approaching the values of branch stubs and knots (Lehtonen 1978).

High heartwood proportion is usually an advantage for the use of wood, since, for example, the heartwood has good dimension stability and it is relatively resistant to decay. However, in the manufacturing of plywood, dry heartwood increases the cutting forces needed, and may cause ripping in veneers (Rikala 2003). Heartwood proportion of spruce correlates negatively with high growth rate, high crown ratio and dominance of trees (Hakkila 1968, Hakkila and Rikkonen 1970, see also Kärkkäinen 1972). Consistent with the slow diameter growth, high heartwood proportions have been found in peatland spruces (Rikala 2003).

Peatland spruces are supposed to be prone to stem form defects (Rikala 2003, Stöd *et al.* 2004, Verkasalo *et al.* 2004). Thus, formation of compression wood should be obvious due to the soft soil (Timell 1986), but also depending on the growing location in relation to the ditches (Stöd *et al.* 2004, see also Stöd *et al.* 2003). In the study of Rikala (2003), the amount of compression wood was surprisingly small in peatland spruces, which might indicate that it is not a severe problem in managed mature stands treated with appropriate thinning regimes. However, the largely increased drying defects in sawn wood when comparing joinery drying (moisture content ca. 10%) to export drying (moisture content ca. 20 %) indicated typical drying problems caused by compression wood. The longitudinal shrinkage of compression wood, irrespective of the stand or site type, is several times that of normal wood, and leads to the curvature of the timber when dried (*e.g.*, Ollinmaa 1959, Timell 1986, Kärkkäinen 2003).

It is generally known (*e.g.*, Kärkkäinen and Raivonen 1977, Timell 1986, Kärkkäinen 2003) that the mechanical strength of green compression wood is even greater than that of normal wood, in particular at a given level of density. Drying increases the mechanical strength, but much less in compression wood than in normal wood, Thus, dried compression wood has a much lower tension strength and, especially, bending strength; however, compression strength and possibly bending strength are at the similar level (see also Ollinmaa 1959). In addition, dry compression wood is brittle, although relatively hard (Ollinmaa 1959, Timell 1986, Kärkkäinen 2003), and prone to checking (Ollinmaa 1960).

The aim of this paper is to study the level of and between-tree, between-stand and vertical within-tree variations in the technical quality of stems and selected morphological and physical properties of wood in mature Norway spruce in naturally regenerated stands on drained peatlands, compared to naturally regenerated and planted stands on mineral forest lands, in southern Finland. In the analysis, breast height diameter and sub-region, four of them, were considered the covariants. The wood properties were selected from the standpoint of saw and plywood milling industries, but they can be related partly to paper industries, as well. The properties were examined separately for the vertical sections of butt logs, other logs and small-sized saw logs. The properties were selected into the study from the viewpoint of sawmill and plywood industries, on the one hand, and they should be regulated in silviculture and forest management, and controlled, at least to some extent, in wood procurement and processing.

Study Data and Methods

Stand and Tree Materials

In this paper, the data of a large research project of the Finnish Forest Research Institute on predicting and controlling the properties and quality of trees and logs of Norway spruce for mechanical wood processing from 1994-98 was re-processed and analysed. In total, 240 saw timber trees were sampled from 48 spruce-dominated mature or nearly mature stands in southern Finland, *i.e.*, five trees per stand. The stands were located on the lands of private forest owners, forest industries, Finnish Forest and Park Service and Finnish Forest Research Institute, and managed as conventional commercial forests.

The sample of stands was evenly allocated into four sub-regions in the southern half of Finland: 1) southern Finland, coastal area (inferior quality region, maritime climate), 2) southern Finland, inland (superior quality region, higher soil fertility), 3) western Finland, Suomenselkä (moderate quality region, higher altitude (200 to 300 m above sea level), 4) eastern Finland, Savo (good quality region, higher soil fertility) (Figure 1). Sub-region selection was based on expertise of researchers and guiding group; sub-regions 2 and 4 were considered to represent good production regions of spruce in Finland, whereas sub-regions 1 and 3 were considered marginal regions for the production.

For each sub-region, the sample of the stands was evenly divided by soil and regeneration types into: 1) mineral forest lands, naturally regenerated stands, 2) mineral forest lands, planted stands, 3) fertile drained peatlands, naturally regenerated stands. Soil fertility was, in each stand, at the level of *Vaccinium myrtillus* type (MT) or *Oxalis-Myrtillus* type (OMT), which correspond to semi-fertile and fertile soil types in Finland. In each stand, principles of good silviculture of the time had been applied during the rotation period, *i.e.*, performing appropriate tending, spacing and thinning operations in accordance with the instructions given by the Central Forestry Board TAPIO. The years of silvicultural operations and timber cuttings were recorded for each stand. The targeted range of age of the

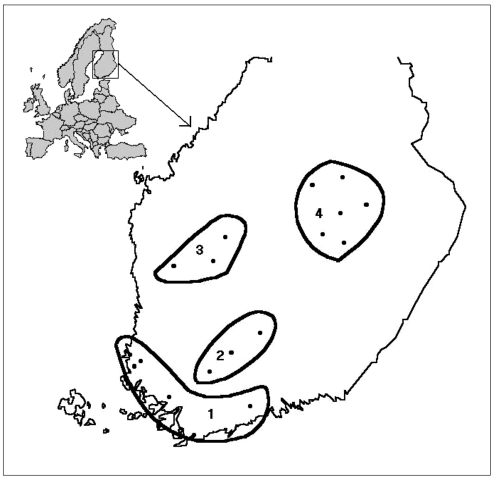

Figure 1. Geographic sub-samples: 1) southern Finland, coastal area, 2) southern Finland, inland, 3) western Finland, Suomenselkä, 4) eastern Finland, Savo

stands was set to imitate conventional clear-cutting age, which were ca. 50-120 years for each sub-region.

In tree sampling, entire range of diameter distribution of the saw timber trees was covered in individual stands with the pre-set minimum and maximum of 18 and 45 cm, respectively. Only dominant and co-dominant, visually healthy trees, whose neighbouring trees were all spruces and which met the minimum commercial requirements for saw timber trees were accepted. However, limits for knottiness could be exceeded; this was even desirable for the objectives. Trees meeting all these requirements were sorted by descending dbh (diameter at breast height) into five groups. Of each group, one tree was selected to the actual sample of trees by random sampling. Means and standard deviations of selected properties for the sample trees by using the aforementioned classification are shown in Table 1.

Field and Laboratory Measurements

Square sample plots of 30 metres by 30 metres were placed into a visually representative part of each stand. The following stand-level factors were determined for each plot: soil type, spacing (number of trees per hectare), basal area and its distribution by tree species, and mean age, height and dbh of spruces among dominant trees. Dbh was measured on all trees of each plot for the dbh distribution.

The following factors were determined for each of the five sample trees on a plot: biological crown type (five categories) and crown level class (four categories), both by using the classification by Ilvessalo (1929), biological age at the stump, tree height, lower level of dead branches, lower limit of living crown, lowest dead branch, lowest living branch, the most significant external defects and their heights, diameters (o.b.) at the fixed heights in a tree (0.1, 0.5, 1.3, 2, 3, 4, 5, 6, 8, 10… metres), maximum crown width and its compass reading, perpendicular-to-the-maximum crown width and its compass reading, and distances and their compass readings to the closest five trees. Vertical locations of and average branch angles in all whorls and the types and diameters of their branches were recorded to the 6-cm diameter.

Laboratory measurements were performed on sample discs at the before-mentioned heights from all sample trees for diameters (o.b. and u.b.), bark thickness, cross-sectional geometry, pith eccentricity, and extent of heartwood from minimum and maximum diameter of heartwood and extent of compression wood. For the sample whorls (over-healed, self-pruned and un-pruned) closest to the before-mentioned wood samples, the diameters and quality of knots were measured from 20 cm long sample pieces on the surface under bark and at consecutive 3-cm distances perpendicular to the stem axis. For the analysis of annual rings and basic density, 3 cm thick and 5 cm wide sample piec-

Table 1. Means ($\bar{x}$) and standard deviations (sd) of selected properties of sample trees by sub-region and type of soil and regeneration of the stand. Regions: see Figure 1

Soil and regeneration type	Sub-region	N	Dbh, cm		Age, years		Height, m		Volume (o.b.), dm^3	
			$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Drained	1	20	27.6	6.8	89	27	23.9	3.0	769	424
peatland,	2	20	27.1	4.9	99	34	23.0	2.7	715	324
natural	3	20	26.4	4.5	126	25	21.7	2.5	595	281
regeneration	4	20	23.8	4.3	107	16	20.1	2.3	473	224
	Total	80	26.2	5.0	111	26	22.0	2.9	627	321
Mineral	1	20	30.6	8.3	86	24	24.4	2.6	930	501
forest land,	2	25	26.9	6.5	81	28	23.4	3.4	698	371
natural	3	25	27.6	5.2	108	21	22.5	2.3	664	256
regeneration	4	20	27.3	5.9	102	13	22.9	2.8	705	318
	Total	90	28.0	6.5	94	25	23.2	2.9	742	375
Mineral	1	20	24.9	4.9	66	10	24.1	3.2	653	337
forest land,	2	15	24.3	4.5	57	12	22.3	2.4	528	233
planted	3	15	25.4	3.8	70	6	21.8	2.9	571	249
	4	20	29.6	5.8	66	8	24.6	3.0	962	348
	Total	70	26.2	5.2	65	10	23.4	3.1	668	325

es were sawn from sample discs from heights of 1, 4, 8, 12 and 16 metres and up to 10 cm diameter.

Generating the Internal Structure for Sample Trees

Field and laboratory data were used to generate the external and internal structure of trees by computer calculations. The stem curve over and under bark and the limit between heartwood and sapwood was generated for each sample tree by polynomial spline functions based on diameters on the sample discs at the before-mentioned heights, and total tree height (Lahtinen and Laasasenaho 1979). For the limit of heartwood and sapwood, means of minimum and maximum diameter on each disc were used. The area of compression wood was planimetrically measured at each disc by using visual evaluation of the boundaries and the zones of compression wood were assessed into trees by linear smoothing from the consecutive measurements on discs.

Statistical procedures

Between-tree and between-stand variation in the stem size, form factors and stem and wood quality properties were first examined by simple statistical parameters. The results were smoothed for breast height diameter classes in the different soil and regeneration types by using linear regression prediction models, with dbh as the only predictor, except for the volumetric variables where non-linear polynomal functions were applied. The effects of soil and regeneration type, sub-region and dbh were studied by using analysis of covariance. These factors are commonly used in planning of timber harvesting and transport and adjusting flows of different wood assortments to different industries, calculating and comparing of costs, volume, quality and value for wood procurement, sorting and usage.

Results

Tree Size and Stem Form Characteristics

Peatland spruces were on average smaller than spruces grown on mineral forest lands (Table 2). The differences in slenderness (h/dbh) were marginal and tapering (dbh - d_6) was at the same level, though the smaller height of peatland spruces (Table 2 and Table 3). The volumes of the entire stem and other log sections (above 5 m to the diameter 16 cm, o.b.) were marginally smaller on peatlands. The volume of the butt log section (5 metres from the butt) and the volume of the small-sized log section (from diameter 16 cm to diameter 10 cm, o.b.) were both equal in different soil and regeneration types. The differences between volumes were marginal for trees smaller than 30 cm (dbh) (Figure 2). It is notable that both the between-tree and between-stand variations were smaller for each property on peatlands compared to mineral forest lands, especially to naturally regenerated trees.

Branch Height Characteristics

There were no differences in the branch height characteristics between peatland spruces and naturally

Table 2. Means ($\bar{x}$) and standard deviations between stems (s_r) and stands (s_m) for the properties of tree size and stem form in different soil and regeneration types

Stem or log property	Drained peatland, natural regeneration			Mineral forest land, natural regeneration			Mineral forest land, planted		
	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m
Age (years)	115	23	15	94	25	12	64	10	10
Dbh (cm)	26.1	5.0	2.5	28.0	6.5	4.3	26.2	5.2	4.0
Volume (dm^3)									
- Entire stem	627	299	187	742	375	278	668	323	247
- Butt log section	272	103	57	317	142	101	277	107	79
- Other log section	275	210	135	348	250	188	311	235	179
- Small-sized log section	76	20	8	72	17	9	76	18	9
Slenderness	0.87	0.10	0.05	0.86	0.13	0.08	0.91	0.10	0.08
Taper (cm)	3.3	1.0	0.5	3.4	1.2	0.8	3.3	1.0	0.6

Table 3. Analyses of covariance on the effects of soil and regeneration type, sub-region and dbh on the properties of tree size and stem form. Test results with p < 0.05 were considered statistically significant (bold) and test results with 0.05 < p < 0.15 were considered as trends (italic)

Stem or log property	Constant		Soil and regeneration type		Sub-region		Dbh	
	F	P	F	P	F	P	F	p
Volume (dm^3)								
- Entire stem	204.8	0.000	1.5	0.230	**4.5**	**0.008**	**597.8**	**0.000**
- Butt log section	610.1	0.000	3.7	0.180	1.0	0.373	**2442.8**	**0.000**
- Other log section	176.0	0.000	1.8	0.180	**3.6**	**0.022**	**341.0**	**0.000**
- Small-sized log section	523.4	0.000	0.035	0.966	*2.7*	*0.058*	**90.1**	**0.000**
Total height (m)	18.6	0.000	**7.3**	**0.001**	**3.5**	**0.017**	**347.0**	**0.000**
Slenderness	370.0	0.000	*2.1*	*0.132*	**3.1**	**0.036**	**23.4**	**0.000**
Taper (cm)	2.5	0.124	0.8	0.465	1.1	0.372	**12.2**	**0.001**

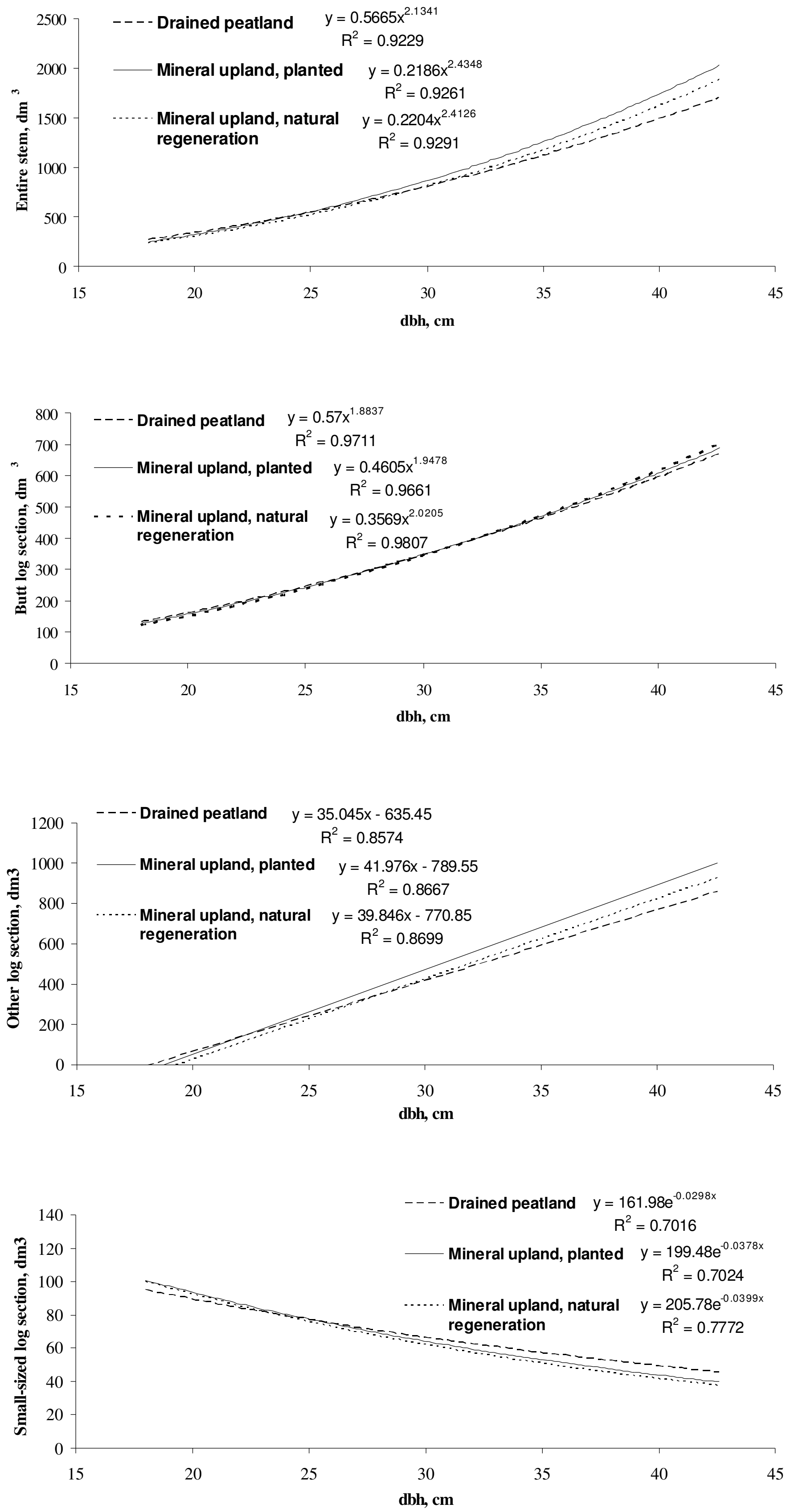

Figure 2. Relationships of stem volume (o.b.) to dbh in the different vertical sections of Norway spruce trees in different soil and regeneration types

generated spruces on mineral forest lands (Table 4). However, the lowest dead knots were lower and lower limits of living crown were higher in planted spruces on mineral forest lands (Table 4 and Table 5). The length of the knot-free butt section was very short in all soil and regeneration types. Individual dead knots occurred regularly very high within the living crown (Figure 3). Similarly to stem size and stem form characteristics, both the between-tree and between-stand variations were smaller for each branch height characteristic on peatlands compared to mineral forest lands, especially to naturally regenerated trees.

spruces in other soil and regeneration types (Table 8, Table 9, Figure 5). However, there were no differences between naturally regenerated spruces grown on peatlands or mineral forest lands. The between-tree variations were larger on peatlands than on mineral forest lands, except the reverse result for the sound knots above the butt log section. On the contrary, the between-stand variations were smaller on peatlands than on mineral forest lands, except the larger average diameter of dead knots above the butt log section on peatlands compared to mineral forest lands.

Table 4. Means ($\bar{x}$) and standard deviations between stems (s_r) and stands (s_m) for external branch height characteristics (m), compared to the total height, in different soil and regeneration types

Branch height characteristic	Drained peatland, natural regeneration			Mineral forest land, natural regeneration			Mineral forest land, planted		
	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m
Lowest knot bump	0.24	0.43	0.21	0.22	0.50	0.29	0.21	0.58	0.24
Lowest dead knot	1.15	0.91	0.63	1.40	1.23	1.03	0.53	0.60	0.43
Lower limit of living crown	8.3	2.7	1.9	7.3	2.7	1.8	9.0	2.5	1.9
Highest dead knot	14.8	3.2	2.2	16.0	4.0	3.0	14.9	3.3	2.0
Total height	22.0	2.9	2.2	23.2	2.9	2.2	23.4	3.0	2.6

Table 5. Analyses of covariance on the effects of soil and regeneration type, sub-region and dbh on the properties of external branch height characteristics. Test results with $p < 0.05$ were considered statistically significant (bold) and test results with $0.05 < p < 0.15$ were considered as trends (italic)

Stem property	Constant		Soil and regeneration type		Sub-region		Dbh	
	F	P	F	P	F	P	F	p
External branch height (m)								
- Lowest knot bump	3.6	0.064	0.1	0.888	*2.5*	*0.076*	1.1	0.294
- Lowest dead knot	0.4	0.538	**5.4**	**0.008**	**5.7**	**0.002**	0.4	0.441
- Lower limit of living crown	11.6	0.001	**3.6**	**0.036**	1.3	0.304	0.4	0.551
- Highest dead knot	2.7	0.108	0.2	0.840	*2.8*	*0.051*	**36.1**	**0.000**

Knottiness of Logs

There were, both on average and by diameter class, less knot bumps per unit length in planted spruces compared to naturally regenerated spruces on mineral forest lands and peatlands (Table 6, Table 7, Figure 4). Peatland spruces had more dead knots in the section of other logs and small-sized logs than spruces grown on mineral forest lands, but no difference could be observed in the butt log section. There were no clear differences between the occurrence of sound knots and spike knots in their average number. In the butt log section, the between-tree variations were smaller in the butt log section but larger in the upper sections on peatlands than on mineral forest lands. The results for between-stand variations mainly followed similar guidelines. The most important exceptions concerned the occurrence of sound knots in the upper parts where the between-stand variations were smaller on peatlands.

Maximum knot diameters were smaller in planted spruces grown on mineral forest lands than in

Wood Properties

The soil or regeneration did not have any effects on the proportions of heartwood and diameter of sapwood (Table 10, Table 11). Annual ring width was smaller in peatland spruces than in spruces grown on mineral forest lands, where it was much larger in planted spruces than in naturally regenerated spruces (Figure 6). On average, basic density was the highest in naturally regenerated spruces on mineral forest lands in all vertical sections (Figure 7), though the most narrow year rings in peatland spruces. However, in a given diameter class, density was the highest for peatland spruces, especially in the diameter below 30 cm. No differences were observed in the other log section, and the difference was marginal in the small-sized log section. In butt log section, there was, on average, more compression wood in peatland spruces than in spruces from mineral forest lands, but the difference was marginal in a given diameter class. No effects of soil and regeneration type were observed in upper vertical sections.

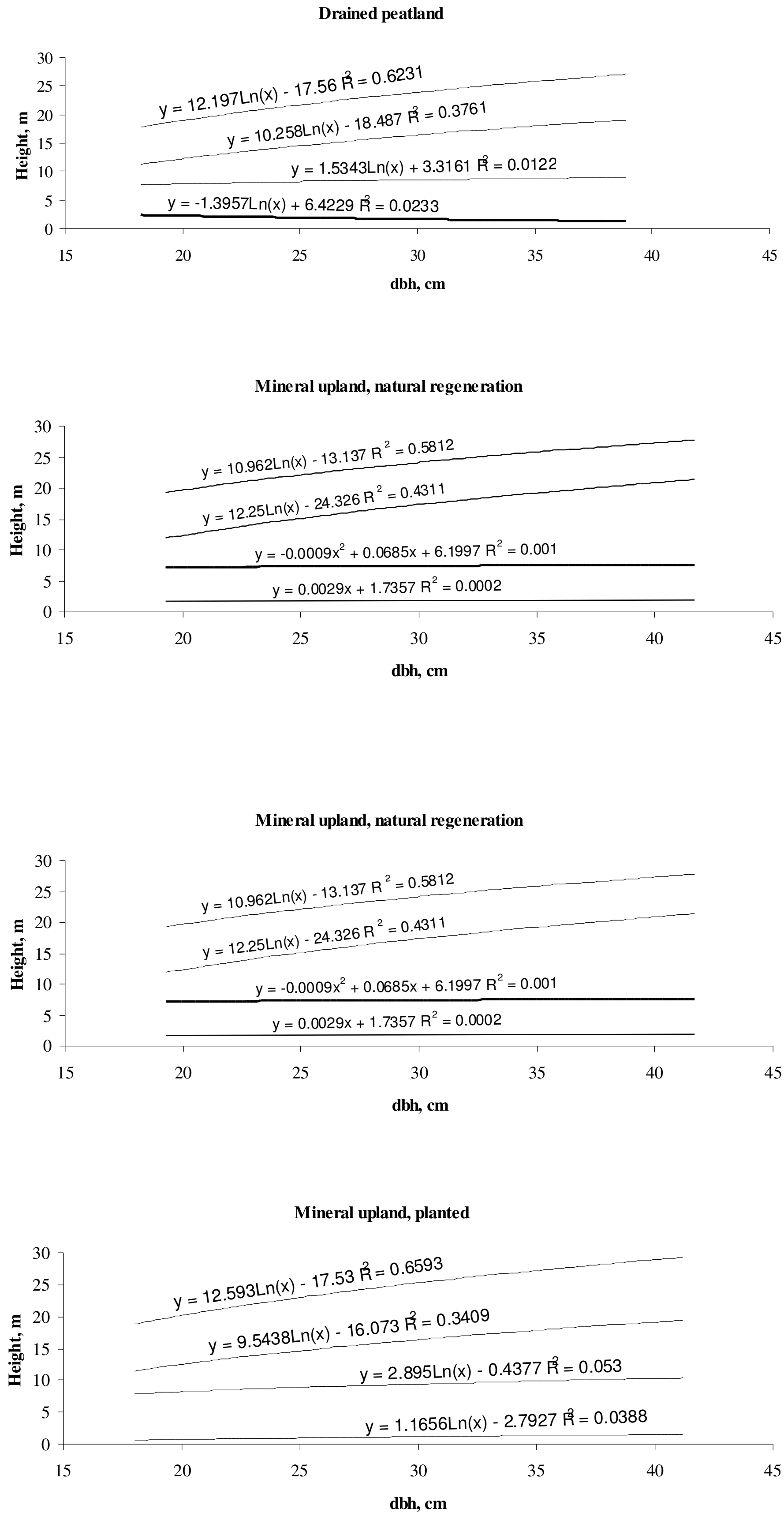

Figure 3. Relationships of branch height characteristics to dbh of Norway spruce trees in different soil and regeneration types. Branch height characteristics from bottom to top: lowest dead knot, lower limit of living crown, highest dead knot and total height of tree

Table 6. Means ($\bar{x}$) and standard deviations between stems (s_r) and stands (s_m) for the number of knots per length unit (n/m) in different soil and regeneration types, by vertical stem section and knot type

Vertical stem section and knot type	Drained peatland, natural regeneration			Mineral forest land, natural regeneration			Mineral forest land, planted		
	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m
Butt log section									
- Knot bumps	5.4	2.9	1.9	5.1	3.5	2.7	2.4	2.1	1.5
- Dead knots	10.5	3.3	2.0	10.0	3.8	3.0	11.0	2.9	2.1
- Sound knots	0.096	0.25	0.13	0.28	0.58	0.27	0.18	0.82	0.46
- Spike knots	0.013	0.060	0.029	0.022	0.063	0.031	0.021	0.070	0.026
Other log section									
- Knot bumps	0.31	0.58	0.40	0.23	0.42	0.32	0.11	0.26	0.12
- Dead knots	8.8	9.1	3.7	5.9	2.9	1.7	6.1	2.8	1.4
- Sound knots	3.5	2.6	1.3	4.6	2.7	1.7	3.0	2.3	1.7
- Spike knots	0.048	0.133	0.047	0.020	0.052	0.027	0.051	0.112	0.066
Small-sized log section									
- Knot bumps	0.073	0.207	0.199	0.031	0.120	0.047	0.020	0.089	0.042
- Dead knots	2.4	2.6	1.0	1.8	2.2	1.3	1.3	1.7	1.1
- Sound knots	10.2	3.3	1.4	10.5	3.5	2.0	9.5	3.2	2.2
- Spike knots	0.044	0.113	0.054	0.041	0.093	0.052	0.069	0.128	0.062

Table 7. Analyses of covariance on the effects of soil and regeneration type, sub-region and dbh for the number of knots per length unit (n/m). Test results with p < 0.05 were considered statistically significant (bold) and test results with 0.05 < p < 0.15 were considered as trends (italic)

Stem or log property	Constant		Soil and regeneration type		Sub-region		Dbh	
	F	P	F	P	F	P	F	p
Butt log section								
- Knot bumps	0.0	0.927	**10.3**	**0.000**	**3.5**	**0.024**	*3.9*	*0.056*
- Dead knots	50.3	0.000	0.4	0.644	0.4	0.782	**8.4**	**0.006**
- Sound knots	3.0	0.086	*2.4*	*0.091*	0.8	0.483	1.3	0.255
- Spike knots	4.5	0.034	0.9	0.428	0.8	0.510	*2.5*	*0.115*
Other log section								
- Knot bumps	0.1	0.721	**5.2**	**0.006**	**7.5**	**0.000**	0.4	0.523
- Dead knots	16.9	0.000	**6.2**	**0.005**	1.0	0.421	*2.5*	*0.124*
- Sound knots	4.3	0.045	**3.3**	**0.049**	*2.4*	*0.080*	**23.1**	**0.000**
- Spike knots	0.8	0.388	*2.2*	*0.114*	0.7	0.576	0.1	0.898
Small-sized log section								
- Knot bumps	0.1	0.788	**4.0**	**0.020**	**7.1**	**0.000**	0.1	0.764
- Dead knots	12.8	0.001	*3.1*	*0.055*	0.9	0.468	**4.8**	**0.034**
- Sound knots	1.1	0.294	1.1	0.335	**3.4**	**0.027**	**32.7**	**0.000**
- Spike knots	0.6	0.430	1.2	0.291	*1.9*	*0.128*	*2.9*	*0.090*

Table 8. Means ($\bar{x}$) and standard deviations between stems (s_r) and stands (s_m) for maximum knot diameters (mm) on different soil and regeneration types, by vertical stem section

Vertical stem section and knot type	Drained peatland, natural regeneration			Mineral forest land, natural regeneration			Mineral forest land, planted		
	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m
Butt log section									
- Dead knot	19.0	7.4	3.8	18.9	6.0	4.9	18.6	6.8	4.2
Other log section									
- Dead knot	26.2	10.0	5.3	25.3	9.2	4.4	23.5	5.6	3.6
- Sound knot	31.8	6.1	3.2	34.2	9.1	5.3	30.0	5.5	3.8
Small-sized log section									
- Dead knot	15.1	4.3	4.1	14.3	4.0	3.6	10.1	3.8	3.0
- Sound knot	24.2	5.3	3.2	24.5	6.1	3.8	21.1	3.2	2.0

Table 9. Analyses of covariance on the effects of soil and regeneration type, sub-region and dbh on for maximum knot diameters (mm). Test results with p < 0.05 were considered statistically significant (bold) and test results with 0.05 < p < 0.15 were considered as trends (italic)

Stem or log property	Constant		Soil and regeneration type		Sub-region		Dbh	
	F	P	F	P	F	P	F	p
Butt log section								
- Dead knot	5.3	0.027	0.1	0.910	0.8	0.522	*2.9*	*0.096*
Other log section								
- Dead knot	5.9	0.019	1.6	0.198	0.0	1.000	**8.4**	**0.006**
- Sound knot	7.2	0.010	**5.1**	**0.010**	1.1	0.308	**5.1**	**0.000**
Small-sized log section								
- Dead knot	0.8	0.375	**6.2**	**0.002**	0.2	0.875	**25.6**	**0.000**
- Sound knot	0.0	0.958	**12.1**	**0.000**	*2.3*	*0.076*	**102.6**	**0.000**

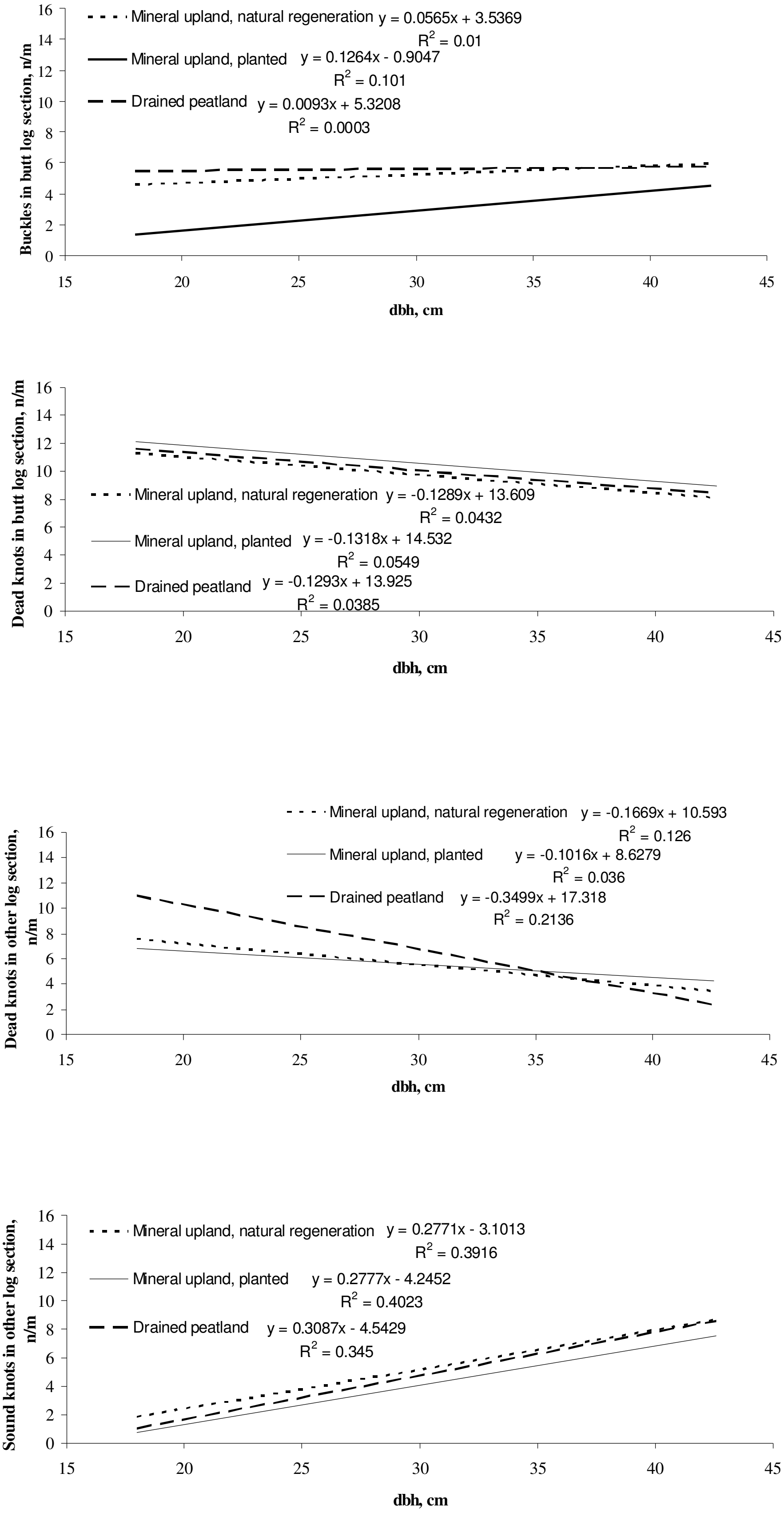

Figure 4. Relationships of knottiness characteristics of butt log section and other log section to dbh of Norway spruce trees in different soil and regeneration types

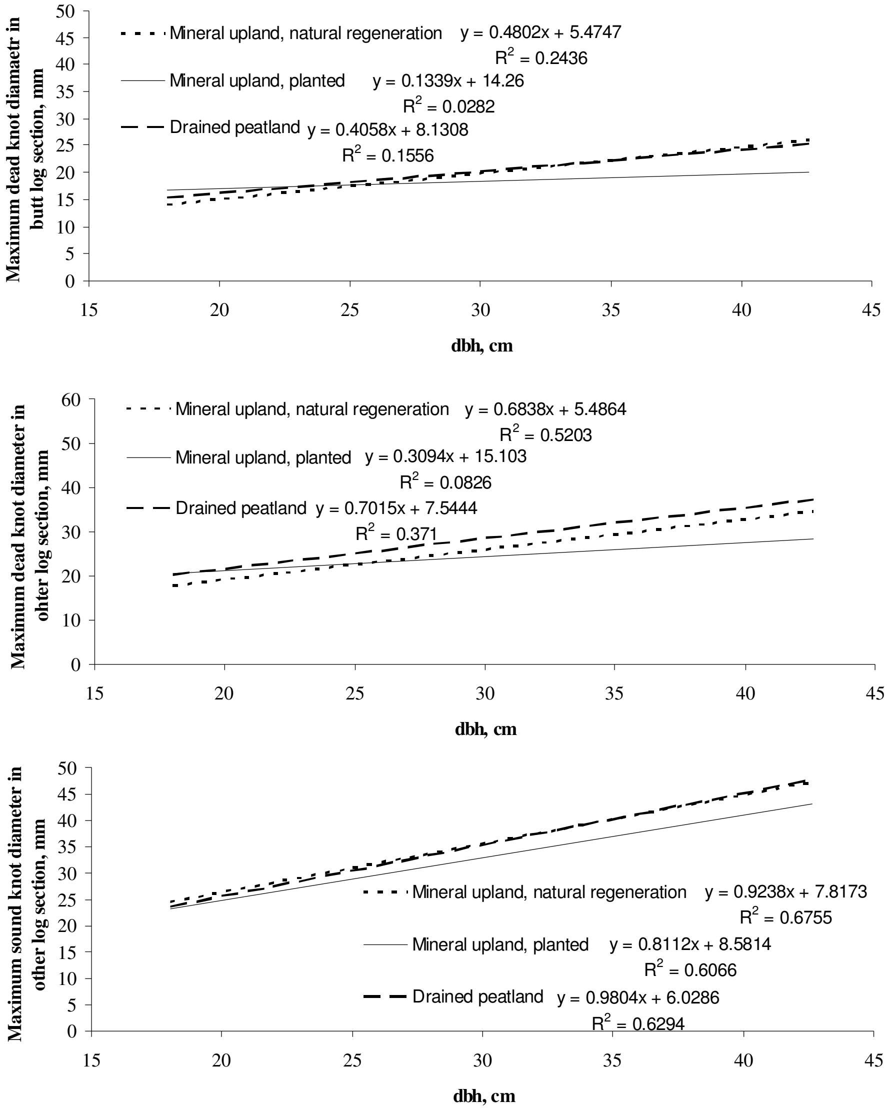

Figure 5. Relationships of maximum knot diameters in butt log section and other log section to dbh of Norway spruce trees in different soil and regeneration types

Table 10. Means ($\bar{x}$) and standard deviations between stems (s_r) and stands (s_m) for the wood properties in different soil and regeneration types, by vertical stem section

Wood property and vertical stem section	Drained peatland, natural regeneration			Mineral forest land, natural regeneration			Mineral forest land, planted		
	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m	$\bar{x}$	s_r	s_m
Annual ring width (mm)									
- Butt log section	1.83	0.53	0.48	2.27	0.64	0.58	3.05	0.71	0.62
- Other log section	2.12	0.64	0.59	2.32	0.77	0.64	3.15	0.92	0.53
- Small-sized log section	2.10	0.66	0.62	2.29	0.70	0.61	3.80	0.61	0.55
Basic density (kg/m^3)									
- Butt log section	377.8	33.8	18.5	383.0	30.7	22.1	365.8	29.1	14.8
- Other log section	363.2	69.6	27.7	375.1	57.3	30.9	350.7	76.4	30.4
- Small-sized log section	381.6	37.2	29.8	393.0	27.1	20.3	374.5	28.7	24.0
Heartwood percentage									
- Butt log section	42.0	10.8	7.9	41.6	10.8	7.2	41.8	9.0	4.0
- Other log section	33.3	11.7	8.8	34.7	10.0	7.0	31.6	11.1	5.6
- Small-sized log section	14.4	8.0	5.3	16.2	9.4	4.9	13.3	8.0	4.6
Sapwood diameter at top end of log (cm)									
- Butt log section	3.6	0.9	0.5	3.4	1.0	0.6	3.4	1.0	0.6
- Other log section	3.8	0.9	0.6	3.4	0.8	0.5	4.1	1.0	0.5
- Small-sized log section	4.4	0.8	0.5	4.2	0.9	0.5	4.9	1.2	0.5
Compression wood percentage									
- Butt log section	10.5	7.0	5.2	7.9	6.0	3.8	7.8	7.0	4.2
- Other log section	4.8	5.0	3.2	5.7	5.0	3.4	6.1	6.0	3.2
- Small-sized log section	4.5	4.5	3.5	3.5	3.3	2.8	6.0	6.0	3.5

Table 11. Analyses of co-variance on the effects of soil and regeneration type, sub-region and dbh on the wood properties. Test results with $p < 0.05$ were considered statistically significant (bold) and test results with $0.05 < p < 0.15$ were considered as trends (italic)

Wood property	Constant		Soil and regeneration type		Sub-region		Dbh	
	F	P	F	p	F	P	F	p
Annual ring width (mm)								
- Butt log section	10.4	0.003	**19.9**	**0.000**	*2.5*	*0.077*	0.8	0.364
- Other log section	5.8	0.021	**12.5**	**0.000**	*1.9*	*0.138*	*2.3*	*0.135*
- Small-sized log section	16.1	0.000	**21.0**	**0.000**	**8.5**	**0.000**	**17.0**	**0.000**
Basic density (kg/m^3)								
- Butt log section	361.2	0.000	**3.8**	**0.030**	1.5	0.224	0.5	0.466
- Other log section	96.7	0.000	1.8	0.176	0.8	0.487	1.7	0.201
- Small-sized log section	635.5	0.000	*2.4*	*0.092*	1.1	0.339	0.6	0.427
Heartwood percentage								
- Butt log section	7.8	0.008	0.9	0.421	*2.5*	*0.075*	**16.3**	**0.000**
- Other log section	1.2	0.271	0.2	0.790	1.6	0.215	**13.3**	**0.001**
- Small-sized log section	7.9	0.008	1.3	0.294	1.8	0.156	0.0	0.939
Sapwood diameter at top end of log (cm)								
- Butt log section	28.9	0.000	0.8	0.448	**3.8**	**0.017**	*2.8*	*0.103*
- Other log section	47.5	0.000	1.7	0.203	0.9	0.471	0.0	0.839
- Small-sized log section	45.2	0.000	0.5	0.521	1.2	0.284	0.0	0.839
Compression wood percentage								
- Butt log section	12.1	0.001	*2.2*	*0.121*	**4.8**	**0.006**	*2.2*	*0.148*
- Other log section	1.7	0.205	0.693	0.506	**4.5**	**0.008**	0.165	0.686
- Small-sized log section	1.3	0.411	0.551	0.473	2.1	0.198	0.188	0.535

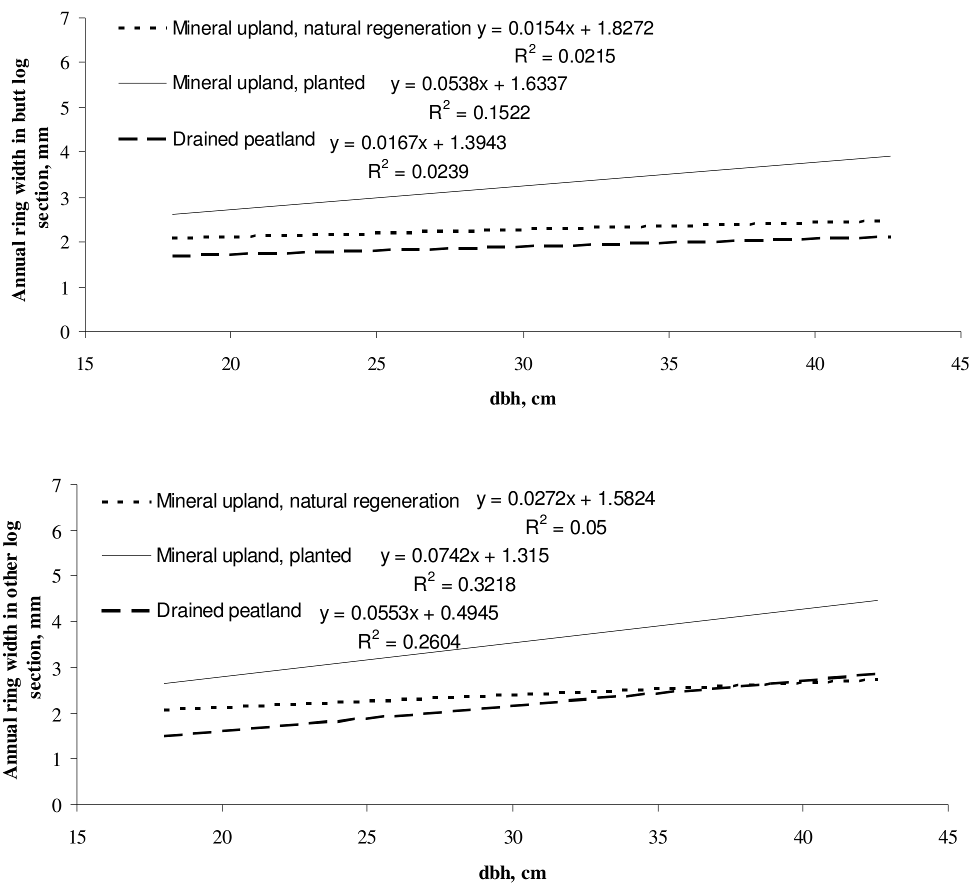

Figure 6. Relationships of annual ring width in butt log section and other log section to dbh of Norway spruce trees in different soil and regeneration types

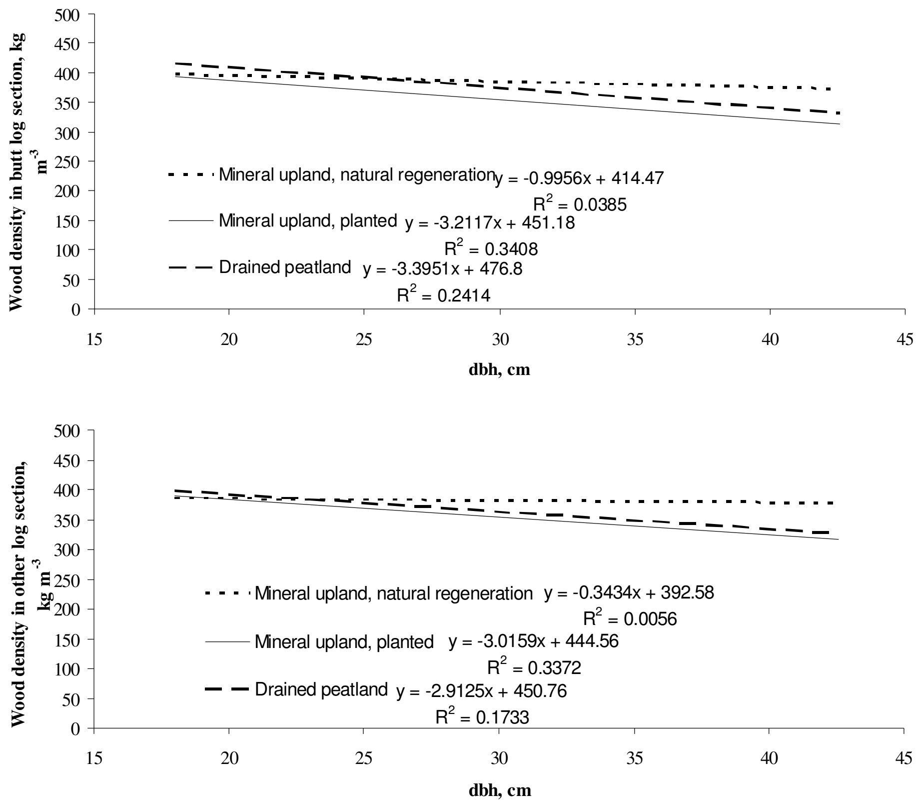

Figure 7. Relationships of basic density in butt log section and other log section to dbh of Norway spruce trees in different soil and regeneration types

On peatlands, the between-tree variations were smaller in annual ring width but much larger in basic density compared to mineral forest lands. The differences in the between-stand variations were unclear between the soil and regeneration types. The between-stand variations in annual ring width were only a little smaller than the between-tree variations, whereas this difference was much larger in basic density.

In heartwood percentage and sapwood diameter, both the between-tree and between-stand variations seemed similar regardless of soil and regeneration type (Figure 8). In compression wood percentage, the between-tree variation was a little smaller for naturally regenerated spruces on mineral forest lands compared to other soil and regeneration types. No clear differences could be seen in the between-stand variation.

Discussion and conclusions

In the study, levels of and variations in the technical (external) quality and selected wood properties of Norway spruce were compared between naturally regenerated stands on drained peatlands and naturally regenerated and planted mineral forest land stands in southern Finland. Technical properties covered tree size and stem form factors, branch height characteristics and knottiness characteristics of vertical log sections. Internal properties included annual ring width, basic density, heartwood proportion, sapwood width and proportion of compression wood. The data represented spruce stands of good forest management in commercial forests. For some properties of technical quality, the stands were of better quality than on average in southern Finland, since extremely crooked and sweeped stems as well as occurrence of decay were deliberately avoided in the sampling of the original data. Otherwise the data can be considered representative for the mature Southern-Finnish spruce that is used for the raw material of sawmill and plywood industries.

Consistent with the current knowledge from the Finnish practical forestry, Norway spruces grown on peatlands are generally old for their biological age. Despite this fact, in this study peatland spruces were smaller for the dimensions, compared to spruces grown on mineral forest lands. However, the stem form factors, such as slenderness and taper, were similar regardless of soil type. The result is in accordance with Rikala (2003), although, Siren (1952) found that release cutting on peat-moors leads to a decrease in the form factor. It should be considered that, *e.g.*, according to Rikala (2003) the volume functions of Laasasenaho (1982) that were used in this study slightly underestimate the true stem volume of peatland spruce.

No remarkable differences could be observed in branch height characteristics of the stems and knotti-

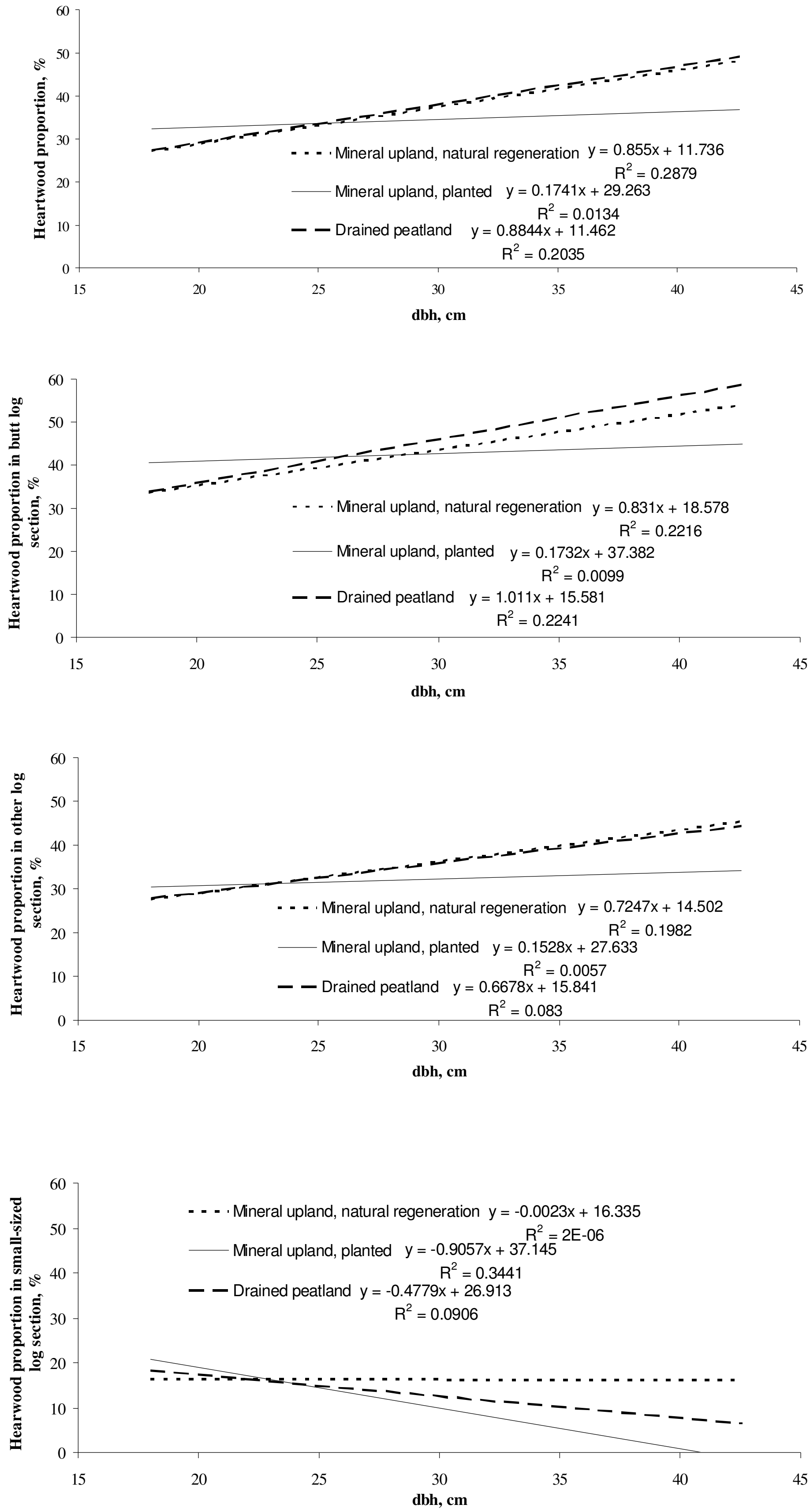

Figure 8. Relationships of heartwood percentage in entire stem, butt log section, other log section and small-sized log section to dbh of Norway spruce trees in different soil and regeneration types

ness of vertical log sections between the soil and regeneration types. Effects of vertical location were also in good accordance with the abundant previous research. The height and the lower limit of living crown were at a lower level, and the length of the knot-free butt section was only slightly shorter than in the study of Rikala (2003). The large data set of Hakkila *et al.* (1972) from the 5th National Forest Inventory of Finland represents spruces from all soil and regeneration types. In comparison to that data, the spruces, on average, were 4-6 m taller and the lower limit of living crown was 2.5-3.3 m higher, but the first dead branches were ca. 2 m lower in the respective diameter class, depending on the soil and regeneration type. In the forest inventory of standing stock, knots cannot be observed very accurately. Thus, the aforementioned differences in the external branchiness heights between this study and Hakkila *et al.* (1972) are probably overestimates. Knot-free butt logs are obviously scarcely available from peatland spruces, because the length of the clear base was mostly less than one metre in a tree. Truly sound-knotted top logs seem to be very few, as well, owing to the frequent dead knots locating high within the living crown However, Rikala (2003) concluded that the butt logs of large peatland spruces are of at least moderate, or even excellent quality for saw milling.

Rikala (2003) concluded, based on visual observations, that peatland spruces are exceptionally thin-branched, though the pre-assumptions that the branch size does not depend decisively on the soil type but, instead, on the site fertility and stand density. However, according to this study, there were remarkable amounts of dead knots especially in the upper log sections of peatland spruces. Accordingly, the maximum knot diameters were in this study, on average, 4 mm and 7 mm larger for dead knots in butt logs and other logs, respectively, and 6 mm larger for sound knots in other logs than in the study of Rikala (2003). In comparison to the data of Hakkila *et al.* (1972) in the respective average diameter class, the maximum knot diameters were ca. 3 mm larger in this study in peatland spruces and naturally regenerated spruces from mineral forest lands, but only 1 mm larger in planted spruces from mineral soils.

The small annual ring width favoured peatland spruce in all vertical sections of the stems, both on average and in a given diameter class. This is very consistent with the results of Siren (1952), Ollinmaa (1960, 1981), Hakkila (1966), Seppälä (1976) and Rikala (2003). In this study, the average ring widths of the butt logs and upper logs were somewhat larger than in the old study of Siren (1952), but considerably smaller than in the new study of Rikala (2003). The large post-drainage increase in ring width, shown by Siren (1952), Ollinmaa (1960, 1981), Seppälä (1976) and Rikala (2003), was not considered in this study. This might be of much greater importance for the modern utilization of peatland wood than the actual ring width. However, the scope of the problem might be overestimated from the viewpoint of mechanical and machining properties, as well, concluded from Ollinmaa (1981). The effects of release cutting, heavy thinnings and fertilization are probably larger for the heterogeneity of wood than the effect of drainage (*e.g*., Siren 1952, Hakkila 1966).

Otherwise, when comparing peatland spruces to spruces grown on mineral forest lands, actual differences in wood properties could be observed only in the butt log section. Here, basic density was the highest, on average, in naturally regenerated spruces from mineral forest lands, whereas the highest level in a given dbh class was found in peatland spruces.

According to Kärkkäinen (2003), the basic density of Finnish spruce logs is usually 370-380 kg/m^3, the lowest and highest values being ca. 365 kg/m^3 (fast-grown spruce from plantations) and more than 400 kg/m^3 (old, slow-grown spruce). Hakkila (1966) found the highest basic density of spruce of all sites on undrained mires, 385 kg/m^3 for logs and 393 kg/m^3 for pulpwood, the values being clearly higher than those from drained peatlands in this study. Even a higher average was reported by Hakkila (1979) for spruces from all mires, 414 kg/m^3. Rikala (2003) reported the basic density of spruce on drained fertile peatlands of 374 kg/m^3 for butt logs and 371 kg/m^3 for other logs; the values being a little lower for butt logs but higher for other logs than in this study. For all soil and regeneration types, the effects of vertical location on the basic density were consistent with the well-known trend for Norway spruce: the density decreases from the base to the middle of the stem, and turns to rise toward the top (*e.g*., Kärkkäinen 2003).

In this study, heartwood proportion was at a typical level for Norway spruce, or a little higher, in all vertical sections for all soil and regeneration types, compared to most of the previous studies (Kärkkäinen 1972, 2003). However, the proportion was low on drained peatlands compared to Rikala (2003) who reported as high average values as of 53 % for butt logs and 36 % for other logs. Similarly to Rikala (2003), no clear evidence was obtained that the peatland spruces would have more heartwood than spruces from mineral forest lands although some results indicate that higher tree age, slow growth rate and suppressed position correlate with high heartwood proportion (*e.g*. Sellin 1994). Heartwood proportion decreased rapidly and sapwood width increased a little by rising vertical location, the changes being the most prominent in peatland spruces.

In butt logs, peatland spruces had more compression wood than spruces grown on mineral forest lands. However, there was a slight reverse difference in upper vertical sections, especially compared to planted spruces. It is most important that the difference between butt logs and other logs was much larger on peatlands than on mineral forest lands. Compression wood percentage was the only wood property studied where regional differences could be detected, with the higher percentage than on average in the coastal region of southern Finland and higher altitudes of western Finland, probably due to high frequency of leaning stems.

The high levels of compression wood percentage were possibly due to the method of measurements, in part. On the other hand, crooked and sweeped trees, which usually contain compression wood with the highest probability, were avoided in sampling. Thus, compression wood is an issue that must always be considered in the management and utilization of peatland spruce. *E.g*., in the simulation study of Verkasalo *et al*. (2004), considering the reaction of wood to grading and pricing decreased the gross unit value of spruce lumber by 10 % in volume-oriented sawmill production and by 15 % in end-use oriented sawmill production, compared to the theoretical situation where no reaction in wood occurred in the particular lot of lumber.

Rikala (2003) concluded that compression wood is not a severe problem in managed, mature spruce stands where the stems with bad stem form have been removed in thinnings, regardless of soil type. On peatlands, he found compression wood in only 13 % of all disc samples cut along the length of mature spruces. The findings were typically from the base of the stems, but compression wood occurred to some extent in all stem sections.

Concluded from the results on the stem and wood properties studied here, Norway spruce from drained peatlands has smaller stem and log dimensions and more crooks and sweep, which result in smaller timber and log recovery per hectare and lower log grades in commercial final cuttings, compared to spruce from mineral soils. For wood, the issues of uncertainty concern mainly internal dry knots and compression wood, and possibly the heterogeneity of wood material within a log for ring width, density and occurrence of compression wood, resulting in reduced wood properties in mechanical processing and wood products. The main reasons for the lack of homogeneity are obviously in the differences between the woods grown prior and after the drainage. In itself, the prior-to-drainage wood has narrow rings, high density, obviously high strength and stiffness, high heartwood content and very low juvenile wood content, but lots of small dry knots and often compression wood.

In all, Norway spruce from drained peatlands provides at least a moderate technical potential for the butt log section for sawmill and plywood industries in southern parts of Finland. However, the most promising uses seem to be in construction where high strength and stiffness, good stability and even moisture content are appreciated - instead of high-value joinery or furniture products where visual appearance and superior tooling properties are the first priorities. The industrial value of upper log sections seems considerably lower, owing to the knottiness, crooks and the resultant flaws in wood. Considering Norway spruce in general, sub-regional differences in the stem and wood properties seem to be largely insignificant within the southern-finnish climatic conditions, after considering the main effects of tree size, soil type and the way of regeneration.

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СВОЙСТВА СТВОЛОВ И ДРЕВЕСИНЫ СПЕЛОЙ ЕЛИ ОБЫКНОВЕННОЙ НА ОСУШЕННЫХ ТОРФЯНИКАХ И МИНЕРАЛЬНЫХ ЛЕСНЫХ ЗЕМЛЯХ ЮЖНОЙ ФИНЛЯНДИИ

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Резюме

Ель обыкновенная *(Picea abies)* из осушенных торфяников имеет все возрастающее значение для лесного хозяйства и лесопромышленного комплекса Финляндии, Швеции и Норвегии, а также играет существенную роль в странах Балтии и России. В данной работе сравнивалась спелая ель обыкновенная из древостоев естественного возобновления на осушенных торфяниках с елью из древостоев естественного возобновления и плантаций на минеральных лесных землях в Южной Финляндии. Был исследован уровень отклонений технических качеств стволов и выбранных морфологических свойств древесины как между деревьями и между древостоями, так и вертикально, внутри дерева. При анализе диаметр на высоте груди и суб-регион (четыре из них) рассматривались как коварианты. Свойства проверялись отдельно для вертикальных секций комлевых бревен, иных бревен и пиловочников малых диаметров. Изучаемые свойства выбраны, в первую очередь, с точки зрения лесопильной и фанерной промышленности; они должны регулироваться в лесоводстве и лесопользовании и контролироваться, в какой-то мере, при поставке и в процессе обработки древесины.

Исходя из результатов изучения свойств древесины, ель обыкновенная из осушенных торфяников обеспечивает, по меньшей мере, посредственный технический потенциал в комлевой части бревна для лесопильной и фанерной промышленности в южных районах Финляндии. Проблемы неопределенности касаются, в основном, свойств сухих сучков и креневой древесины и, возможно, неоднородности материала древесины внутри бревна. Промышленная ценность верхних секций бревна представляется достаточно низкой. После учета основных факторов, таких как толщина дерева, тип почвы и способа возобновления леса, влияние суб-региона в пределах климатических условий Южной Финляндии представляются незначительными.

Ключевые слова: *Picea abies*, техническое качество, свойства древесины, пиловочник, торфяник, вариация