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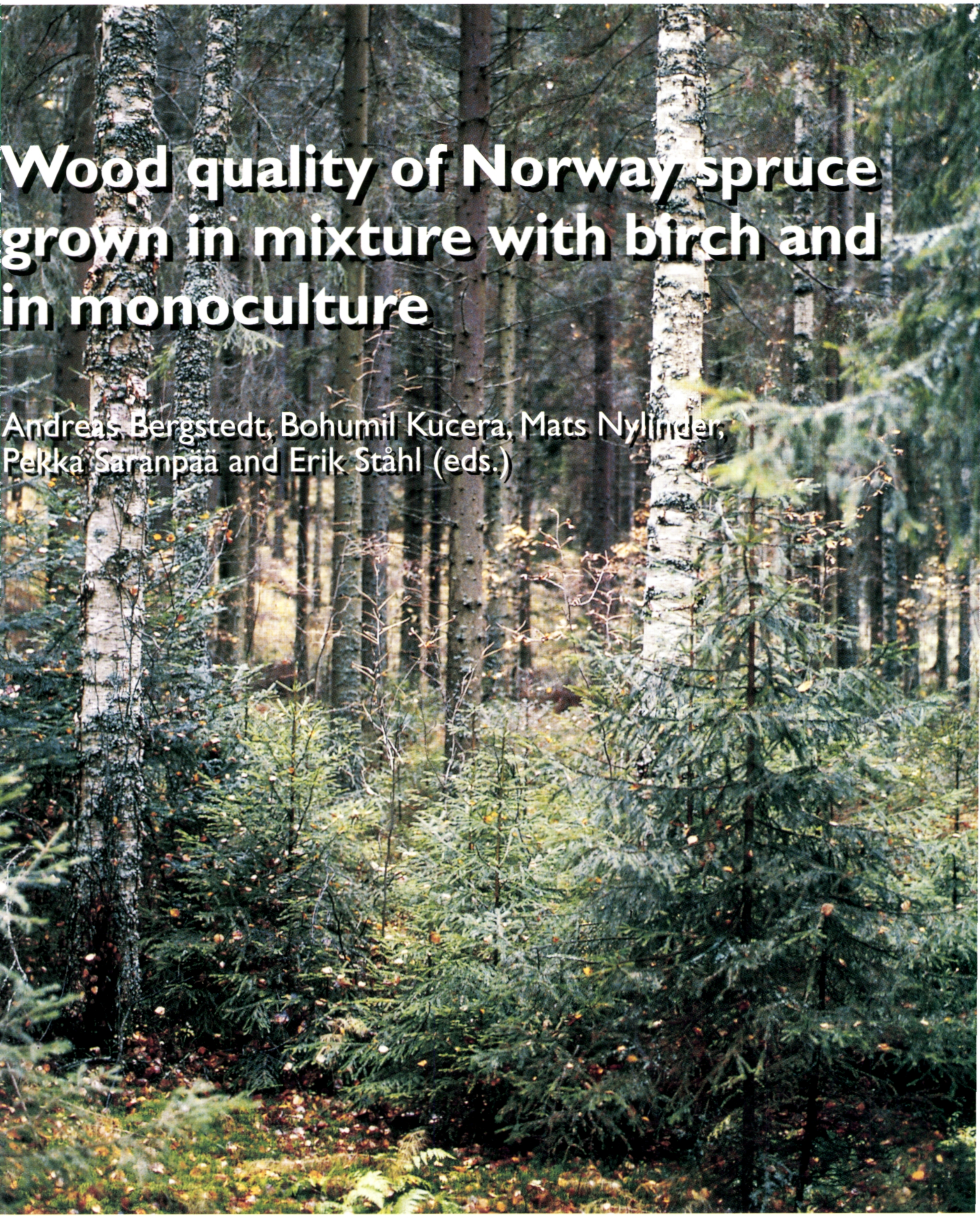

Wood quality of Norway spruce grown in mixture with birch and in monoculture

Andreas Bergstedt, Bohumil Kucera, Mats Nylinder, Pekka Saranpää and Erik Ståhl (eds.)

VANTAAN TUTKIMUSKESKUS – VANTAA RESEARCH CENTRE

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The project SNS-61 "Wood properties in mixed stands" was initiated by the members of "Nordiska Samarbetsgruppen för Virkeslära (NSV)" in 1997, and the project has been carried out as a co-operative work between the members in Denmark, Finland, Norway and Sweden. The study material was collected from stands in Finland, Norway and Sweden representing Norway spruce in monoculture and mixed with birch. Both stands representing a medium site class and a high productivity/site class were selected. Some of the plots were within experimental stands measured during their lifetime, others were situated in commercial stands with a fairly well documented record of silviculture. Altogether 36 stems for monocultures and 36 stems from mixed stands were studied. This report includes results of the variation of growth ring width, basic density and spiral grain; quality of sawn goods; and strength properties of small clear wood samples as well as structural timber. No significant differences in the wood quality of Norway spruce were found between monocultures and mixed stands.

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Preface

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During the last decades clear cutting systems and regeneration by planting has been the dominating silvicultural system for spruce in Nordic forestry. Broad-leaved trees have often been removed in pre-commercial thinning operations to facilitate the volume production of spruce. This implies intensive and costly silvicultural treatments because the natural regeneration of early-successional tree species, especially birch, tends to be dense.

In recent years there has been a growing interest for forestry based on mixed stands. Shelterwood methods have been suggested as preferable for regenerating spruce, especially with birch in the upper strata and the more shade tolerant spruce in the lower. Several studies have reported that a birch shelterwood can reduce frost damages on understorey spruce. Additionally, it has been claimed that mixtures of tree species promote biodiversity and enhance recreational values. However, the knowledge about how wood properties of spruce are affected by birch in mixed stands is sparse.

The main objective of the studies within the frame of the present project was to compare fundamental wood properties of spruce grown in mixtures with birch and spruce grown in monocultures.

The material sampled for the investigations were collected from stands assumed to be representative for spruce grown in monocultures and in mixed stands. A study of wood samples originating from stands with well-documented silvicultural treatments would have been desirable. However, it became apparent that such stands were hard to obtain for this study. Thus, with the available material, it was not a straightforward task to isolate and analyse various growth-related effects on wood properties. This emphasises that it is important to establish well-designed experimental plots for future research on wood properties.

This project was made possible through financial support by the Nordic Forest Research Cooperation Committee (SNS).

Finally, I would like to acknowledge the researchers in the Nordic countries for their contributions and efforts, that created the results published in this project.

Bohumil Kucera
Project leader

Introduction

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Background

Mixed stands comprising two or several species may be preferable to monocultures for a number of reasons. Biodiversity is higher and the mixed stands are expected to be ecologically more stable, thus minimizing the risk of damage due to climatic extremes or pest outbreaks. This stability, in turn, leads to reduced economic risks. The economic output may even be improved compared to monocultures, when species subject to commercial thinnings at an early age are mixed with species having high value only when they are old.

In Scandinavia mixed stands of birch (*Betula pendula* Roth. or *B. pubescens* Ehrh.) and Norway spruce (*Picea abies* (L.) Karst.) occur naturally. Establishing a monoculture of e.g. Norway spruce from natural regeneration often requires extensive culling of birch that emerge between the spruce seedlings. During 1960–70 it was commonplace to eradicate the birch in naturally regenerated stands. Today birch pulpwood is in demand, and it is argued that the birch may have a beneficial effect on the quality of the spruce timber, as branch development and early diameter growth are restricted in the densely stocked mixed stands.

A few studies have been concerned with the production in mixed stands compared to monocultures (Agestam 1985, Frivold 1982). In general, the long-term yield of spruce in mixed stands has shown not to be influenced by the mixture of birch and the total yield has even proved to be increasing (Mielikäinen 1985, Tham 1987, 1994).

Despite the increasing attention paid to mixed stands and biodiversity in the Nordic countries, surprisingly little is known about the wood quality of Norway spruce grown in mixture with birch. Among the few studies, Bergqvist (1998) payed attention to wood density and found only insignificant effects of different treatments of birch shelterwood. The main objective of the present study is to investigate differences in wood quality between Norway spruce monocultures and mixed spruce/birch stands grown under similar conditions. The study is concerned with growth response by the trees (diameter increment, spiral grain), physical properties (basic density), appearance (visual grading) and mechanical properties (bending strength, modulus of elasticity). The findings are reported in separate papers within the present issue.

Climatic conditions and forest management traditions differ widely among the Nordic countries and for this reason the trees included in the study exhibit different growth patterns. Thus, involving three Nordic countries in the investigations of wood quality inevitably leads to very large variations within the sample material. The large variation may partly veil the possible differences between spruce grown in monoculture and in mixed stands of spruce/birch. This should be borne in mind when interpreting the results of the study.

Selection and processing of sample trees

The trees originated from stands in Finland, Norway and Sweden representing growth of Norway spruce in monoculture and mixed with birch. Four sample plots were established in each country (Fig. 1), two representing a medium site class (plot 1 and 2) and two on soil with a high productivity/site class (plot 3 and 4). Some of the plots were within experimental stands measured during their lifetime, others were situated in commercial stands with a fairly well documented record of silviculture. All were founded on natural regeneration except for two planted monocultures of spruce (No. 4 in Sweden and Finland).

Within each country and site class one plot with birch and one without birch were selected. Plots within the same country and site class were situated close to each other and were chosen with the aim of similarity in every respect except species composition: pure spruce or spruce/birch mixture. However, silvicultural treatment varies among the countries: In Sweden the mixed stands had been thinned 5–8 times while the monocultures had been thinned 2–3 times. The stands with high site class had been thinned more frequently than the ones representing medium site class. In Norway the mixed stands had been thinned 1–2 times while there had been no interaction in the monocultures. In Finland considering plot 3 & 4; the mixed stand had been thinned twice while the monoculture had been thinned once. The plots 1 & 2 in Finland were located within the same stand and had been thinned once. Based on the historical data it seems that in the mixed Swedish plots the goal had been to achieve a mixture containing 50% birch, while the silvicultural goals for the Norwegian and Finnish stands were more diffuse. The spruce/birch ratio was very dependent on the silvicultural management and whether birch had been used as shelter wood or as a single storey mixture.

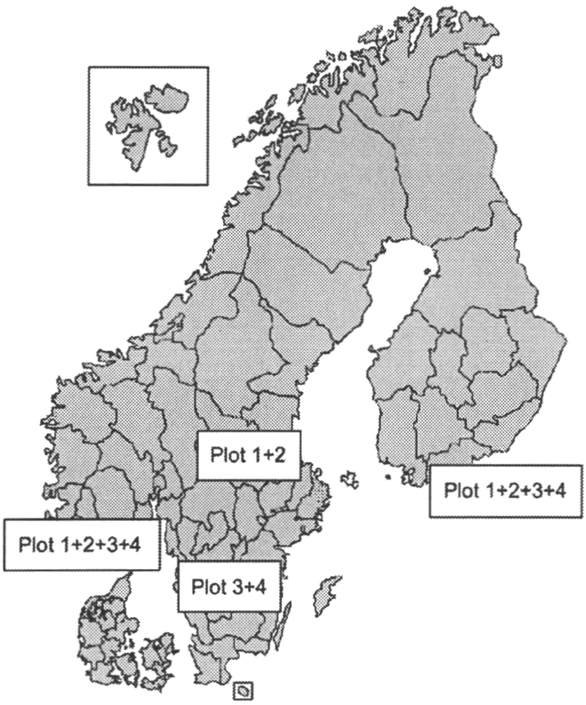

Figure 1. Map showing the location of the stands.

Some of the stand data (Table 1) originate from inventories made several years before the actual sampling, making the comparison with sample tree data difficult. The striking difference in the Swedish plot 3 (the mean diameter of the experimental stand is 20 cm while the mean for the sample trees is 26,7 cm) was due to limitations in the sampling procedure: it was not allowed to remove the desired number of trees within the experimental stand. Instead the sample trees were felled in the border zone around the stand where the regeneration of birch had been poorer, and the diameter growth of the spruce faster. While Table 1 draws a correct picture of the site class and age for this stand, the diameter is not representative for the trees in the border zone.

In each plot six spruce trees were harvested; totally 24 trees from each country. The sample trees were chosen to represent typical growth and development within the stand. In order to obtain sawn timber in structural sizes, no trees with DBH less than 23 cm were selected.

After felling the stems were cross-cut at 20%, 40%, 60% and 80% of total tree height and a disc (approximately 10 cm thick) was cut from the butt end of each stem section. The three sections originating from the lower end of each stem were taken to the sawmill, while the discs were kept frozen until further processing in the laboratory.

Table 1: Physical data of the sampled stands.

Country	Site class/ H_{dom} at 100 years	Treatment	Birch, % of basal area	Age when sampled, years	Age when measured, years	DBH (stand), cm	DBH (samples), cm	Mean height (stand), meter	Origin
Finland, 1*	Medium/G29	With birch	70	83	78	29	27.5	26	Natural regeneration
Finland, 2*	Medium/G29	Monoculture	0	83	78	29	25.9	26	Natural regeneration
Finland, 3	High/G28	With birch	60	95	90	27	28.8	26	Natural regeneration
Finland, 4	High/G30	Monoculture	0	59	54	23	24.2	21	Planted
Norway, 1	Medium/G25	With birch shelterwood	-	72	72	28.3	-	23.5	Natural regeneration
Norway, 2	Medium/G24	Monoculture	-	76	76	24.6	-	22.8	Natural regeneration
Norway, 3	High/G25	With birch	-	68	68	20.3	-	22.4	Natural regeneration
Norway, 4	High/G32	Monoculture	-	51	51	20.2	-	21.1	Natural regeneration
Sweden, 1	Medium/G30	With birch	45	88	77	25.9	28.5	21.8	Natural regeneration
Sweden, 2	Medium/G25	Monoculture	0	98	89	22.4	28.3	22.7	Natural regeneration
Sweden, 3	High/G25	With birch shelterwood (felled in 1985)	65(1985)	65	65	20	26.7	18	Natural regeneration
Sweden, 4	High/G33	Monoculture	0	58	-	-	26.2	-	Planted

- missing value   ** same plot but split in two (with and without birch)*

To supplement the data on diameter increment and wood density, increment cores were taken from trees chosen at random in the close vicinity of each sample tree; 6 or 12 increment cores from each plot. The increment cores were taken form the western side of the trees. By comparing the sample tree data with the data collected from the increment cores it was ensured that the sample trees were unbiased representatives for the stands.

References

Agestam, E. 1985. En produktionsmodell för blandbestånd av tall, gran och björk i Sverige. Sveriges Lantbruksuniversitet, Institutionen för skogsproduktion, Garpenberg. Rapport 15. (In Swedish)

Bergqvist, G. 1998. Wood density traits in Norway spruce understorey: Effects of growth rate and birch shelterwood density. Annales des Sciences Forestieres 55:809-821.

Mielikäinen, K. 1985. Effect of an admixture of birch on the structure and development of Norway spruce stands, Communicationes Instituti Forestalis Fenniae. No. 133, 79 pp.

Tham, Å. 1987. Gran och björk i blanding. Institutionen för skogsproduktion, Rapport 20, Sveriges Lantbruksuniversitet, Garpenberg.

Tham, Å. 1994. Crop plans and yield predictions for Norway spruce (Picea abies (L.) Karst.) and birch (Betula pendula Roth & Betula pubescens Ehrh.) mixtures. Studia Forestalia Suecica, No. 195. SLU, Uppsala. 21 pp.

Diameter increment, wood density and spiral grain

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Abstract

Basic wood quality parameters have been studied in samples of Norway spruce originating from 11 stands in Finland, Norway and Sweden. The stands represent different growing conditions (favourable/medium) and different stand structures (monoculture/single storey mixture/shelterwood). In general, growing in mixture with birch had little effect on wood quality traits of the Norway spruce. On the average, diameter growth had been slightly faster in mixed stands, but large variations were found. Comparing equal rates of diameter increment, the trees grown in mixture exhibited slightly lower wood density than trees grown in monoculture. Similarly, spiral grain orientation was less pronounced in the mixed stands.

Introduction

A major problem in using wood as a building material is its inherent propensity to warping and dimensional changes. These deformations are linked to changing moisture content of the wood in use. The larger part of the warp occurs while drying the green wood during processing, but also smaller deformations caused by moisture fluctuations in use can be annoying. An inquiry among building contractors (Johansson et al. 1994) showed that twist is one of the main causes for rejecting timber.

Drying deformations to some degree depend on wood density, which in Norway spruce is linked to annual ring width (diameter growth) of the trees. The key role of spiral grain as a cause for drying deformations has been shown in theory (Stevens & Johnston 1960) as well as practice (e.g. Cown et al. 1996). The extent an severity of spiral grain is influenced by stand development partly because spiral grain is most prominent in the juvenile wood. Additionally, some studies have shown a connection between grain angle and fast diameter increment (Bergstedt & Jørgensen 1997). The growing of spruce in mixture with other species is expected to affect spiral grain through the different growth conditions present in these stands.

Material and methods

Processing and measurements

The material for this study comprises 72 Norway spruce trees from 11 stands in Finland, Norway and Sweden (page 6). For analysing annual ring width, basic density and spiral grain, approximately 10 cm thick stem discs were cut at stem basis and at 20%, 40%, 60%, and 80% of the total tree height.

From each stem disc a small diametral stick with square cross section (10 mm axially × 10 mm tangentially) was cut for determination of annual ring width. The equipment used for measuring was a Swedish made "Addo" sliding stage micrometer, with a resolution of 0.01 mm. The values were recorded digitally as ASCII files.

After measuring the annual ring width, the sticks were divided into 5-year segments (maximum size 4 cm^3). These segments were used for determination of basic density. The volume of the green wood segments was determined using the water displacement method (Olesen 1971), while oven dry weight was determined after 24 hours of drying at 103 °C.

For measuring spiral grain a method described by Danborg (1994a) was adopted. Larger diametral samples were used for this analysis (6 cm axially × 2 cm tangentially). By consecutively splitting off small segments from both tangential faces of the sample, the grain direction could be marked with a scribe in year ring numbers 2, 4, 6, 8, 12, 16, 20, 24, 32, 40, 48, 56, 64, 72, and 80 counted from the pith. The grain angle was measured on two opposing radii in the same annual ring. Spirality was calculated as the mean of the two measurements (Danborg 1994a), thus eliminating any skewness due to the sample being cut non-parallel to the stem axis. The grain angle was measured with a resolution of 0.1°. Left-hand spirality was denoted positive, while negative values refer to right-hand spiral grain.

Analyses

From earlier investigations (e.g. Olesen 1976; Madsen et al. 1978; Moltesen et al.1985, Lindström 1997) the basic density of Norway spruce wood is known to be negatively correlated with the width of the annual growth rings. The relationship is found to be curvilinear, and Olesen (1976) suggested the following model:

$$\Delta = a + b \,/\, (\Delta r + c) \qquad (1)$$

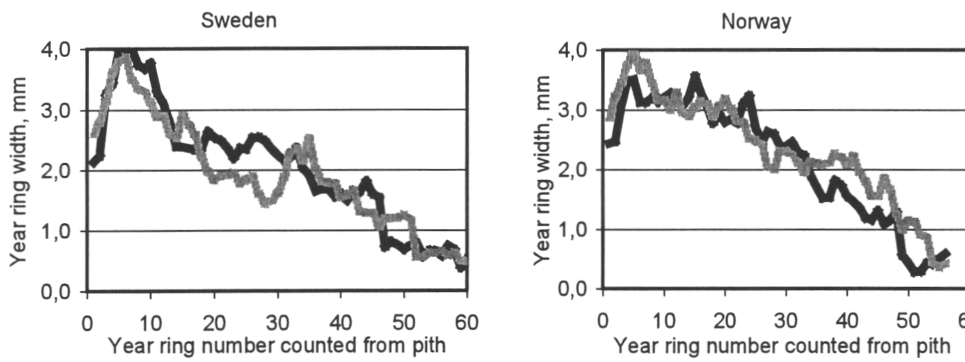
where Δ is basic density, Δr is annual ring width, and a, b, and c are model parameters. As the correlation between b and c is very strong the standard errors of the estimates are generally high. Moreover, nonlinear estimation methods are required. As the fit of the model is not sensitive to the value of c, a fixed value of $c = 2$ was used in the present study to remedy the shortcomings mentioned above. This value has been shown to yield a satisfactory fit in most instances (Danborg 1994b). By using the transformation $x = 1/(2+\Delta r)$ linear estimation methods can be applied.

For the relationship between spiral grain and annual ring width a simple linear model was applied:

$$\theta = d + e \cdot \Delta r \qquad (2)$$

θ being the grain angle, and d, e model parameters. The very large variation of grain angle hardly justifies the use of more sophisticated models. A similar linear model was used for the relationship between grain angle and annual ring number.

All statistical analyses were carried out in SAS® version 6.12, the analyses used being GLM (General Linear Models) with the options LSMEANS /Pdiff (least means squares/the probability value for the null hypothesis) and Scheffe's Test (multiple comparison of variables).



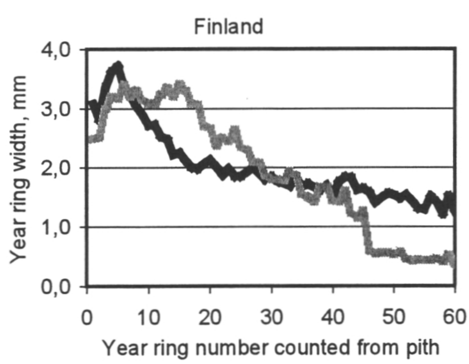


Figure 1. The relationship between cambial age and the annual ring width. Mean values from height at 20% of total stem lenght.

Results

Annual ring width

Due to quite different growth patterns, the annual ring widths are presented countrywise in Fig. 1 and 2. The samples from 20% of total stem length were chosen for showing the relationship between annual ring width and ring number from the pith, as these samples were considered to represent the most valuable part of the stem. In Finland, a very clear suppression of diameter increment in the young mixed stands was noted, followed by a superior diameter growth after freeing the spruce from competing birch trees during the final stage of stand development (Fig. 1). The result has been a very uniform ring width development in the mixed stands from annual ring number 15 outwards. In the other countries the differences were not very clear. A general growth suppression was noted in the mixed stands of Norway from ring number 30 outwards, while no definite trend was apparent in the Swedish stands.

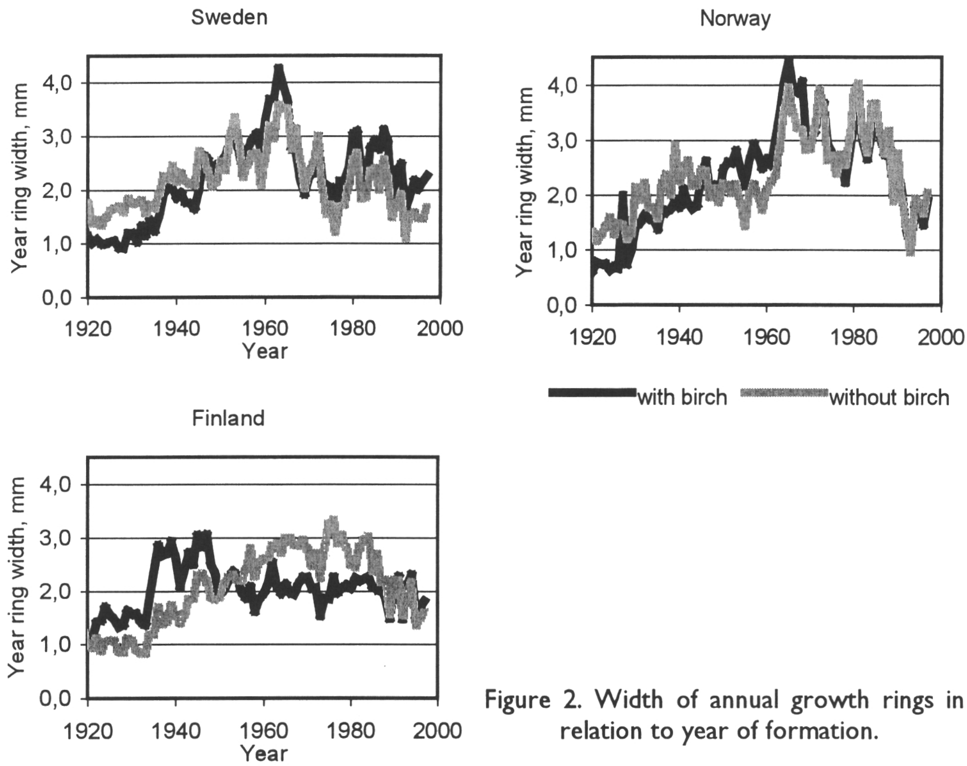


Figure 2. Width of annual growth rings in relation to year of formation.

Table 1. Width of annual growth rings [mm] in increment cores of neighbour trees. Standard deviation in parenthesis.

Country	Growth model	DBH	Juvenile wood	Mature inner wood	Mature outer wood
Sweden	Mixture	282	2.63	2.12	1.60
	N=12	(45)	(0.77)	(0.52)	(0.38)
	Monoculture	279	2.54	1.89	1.40
	N=12	(30)	(0.50)	(0.52)	(0.40)
Finland	Mixture	283	2.14	1.77	1.44
	N=24	(48)	(0.50)	(0.54)	(0.44)
	Monoculture	-	-	-	-
Norway	Mixture	239	2.35	2.39	1.21
	N=24	(36)	(0.58)	(0.49)	(0.54)
	Monoculture	227	2.88	2.15	1.09
	N=24	(36)	(0.69)	(0.45)	(0.34)

The increment cores from neighbour trees showed a more uniform ring width development within the mixed stands in Sweden and Norway, compared to monocultures. No increment cores were available from the Finnish monoculture stands (Table 1).

When relating ring width to calendar year the differences between countries were obvious (Fig. 2). A definite suppression of diameter growth was noted during the initial stages of the mixed stands of Norway and Sweden, reflecting competion from the birch shelter. The opposite effect was found in the Finnish material, presumably because the young spruces were sheltered from frost damage in mixed stands. In general, the annual rings were wider in the mixed stands in Norway and Sweden, while the opposite applied to the Finnish stands. Climatic fluctuations are clearly visible in the growth trend of trees from Norway and Sweden, with remarkably fast growth in the early sixties and narrow growth rings laid down during the drought years of 1975 and -76. Although the same trend is visible in the Finnish material, the growth variation was much smaller in this country. It should be noted that the data behind Fig. 2 are unbalanced, as the growth years early in the century only appeared in the samples from stump height, while wood formed during recent years was found in all samples.

When annual ring width was pictured in relation to distance from the pith (Fig. 3), a homologous development was noted for the mixed and the pure stands, and thus similar technical wood properties might *a priori* be expected.

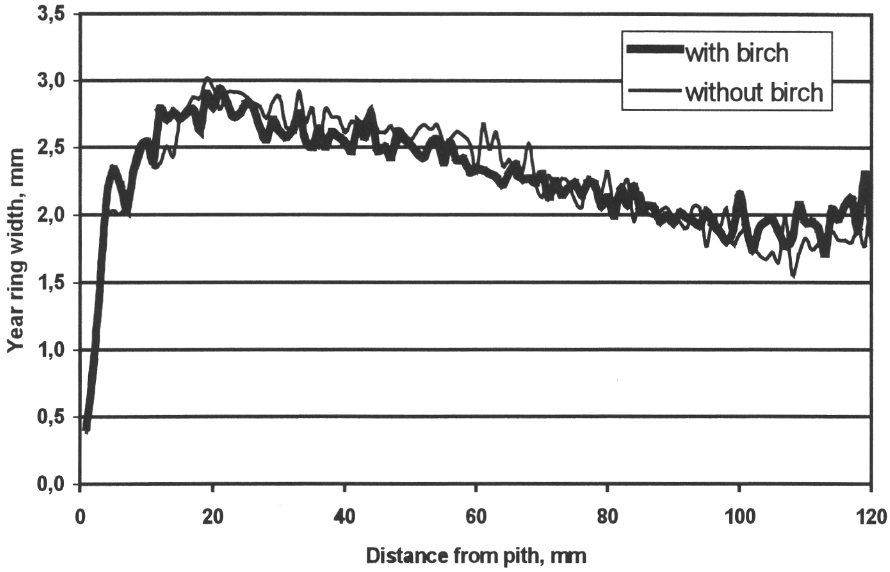


Figure 3. Annual ring width in relation to the distance from pith. Mean values of the study material of 36 stems from monocultures and 36 stems from mixed stands.

Basic density

A significant difference (P>F = 0.001) was found between mixed and pure stands regarding basic density (Table 2). On the average the basic density was 12 kg/m^3 higher in the monoculture than in the mixed stands. This significant difference applied to all three countries in spite of the generally faster diameter growth of the mixed stands in both Norway and Sweden.

The increment cores from neighbour trees in general showed the same pattern, with trees from monoculture exhibiting slightly more dense wood (Table 3), compared to trees from mixed stands. Only the exterior wood from Norwegian trees makes an exception.

A highly significant correlation was found between density and annual ring width (P>F= 0.001) for all sampling heights except 80 % of the tree height. For reasons of simplicity the results are only shown in detail for height 2 (Fig. 4). Least-square approximations of function (1) are included in the figure, illustrating the generally higher density level in the pure stands.

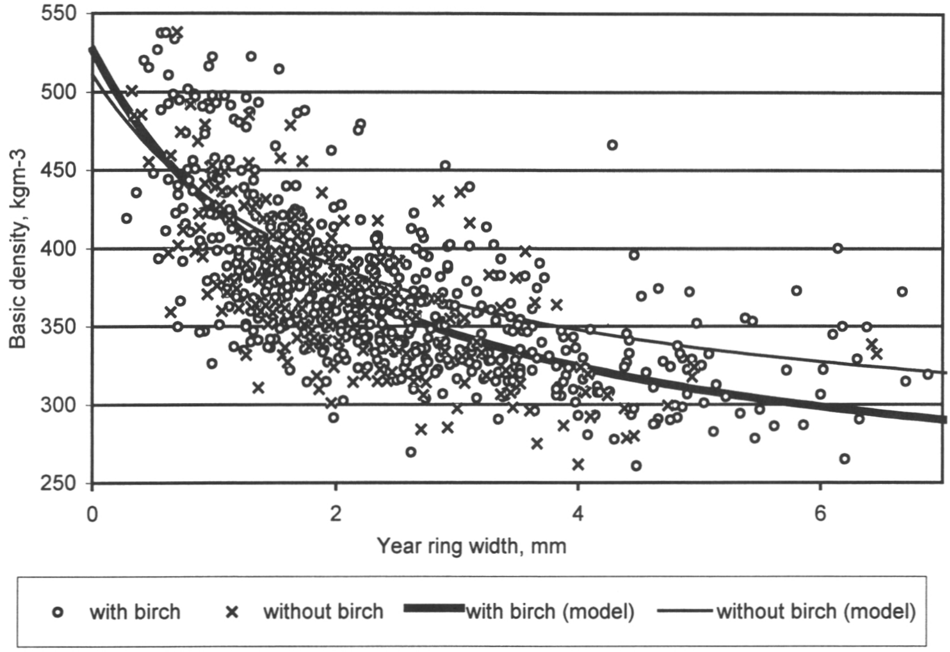


Figure 4. Relationship between annual ring width and basic density for height = 20 % total stem length. All countries included.

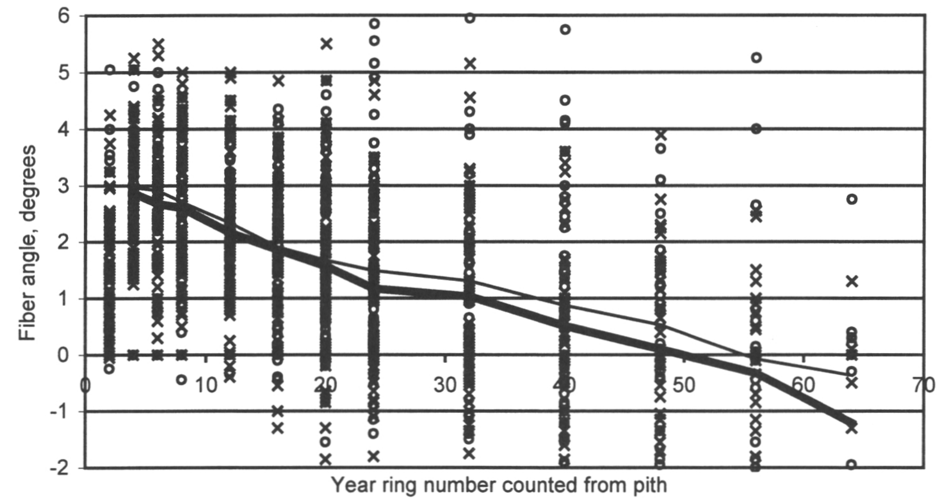


Figure 5. Spiral grain in relation to cambial age. Pooled data from all heights and countries. Ring numbers 72 and 80 are omitted due to few observations.

Table 2. Basic density [kg·m^{-3}] of the sample trees. Arithmetic means of all measurements.

Country	Finland	Norway	Sweden	All countries
with birch	373	380	373	375
monoculture	393***	394***	384***	387***

*** *indicates significant difference between treatments at the 99,9% level.*

Table 3. Basic density [kg·m^{-3}] in increment cores of neighbour trees.

Country	Growth model	DBH	Juvenile wood	Mature inner wood	Mature outer wood
Sweden	Mixture	282	312	388	400
	Monoculture	279	328	393	410
Finland	Mixture	283	322	395	410
	Monoculture	-	-	-	-
Norway	Mixture	239	319	383	433
	Monoculture	227	322	389	429

Including all heights in the annual ring width / density analysis lead to the following parameter estimates for function (1):

Stands with birch:

$\Delta = 245.4 + 530.4 / (\Delta r + 2)$ $\qquad R^2 = 0.3798$

Monoculture:

$\Delta = 271.9 + 468.5 / (\Delta r + 2)$ $\qquad R^2 = 0.3156$

Evaluation of the residuals for the regressions revealed a very homogeneous distribution around zero, supporting the use of function (1) in spite of the moderate R^2 values.

Spiral grain

A linear relationship between cambial age and grain angle is assumed for annual ring number four outwards (Fig. 5). Allowing for plot effects, a significant difference between monocultures and mixed stands was found (P>F = 0.001), with spruces grown in monoculture having on average a larger grain angle (more spiral growth) than spruces grown in mixed stands. However, the difference between geographic locations was also highly significant.

The higher level of spiral grain in the monocultures was found at all sites except Location 5 (Sweden, medium site class). Treating the results from each site separately, the difference was only statistically significant at three of the locations: 1, 4, and 6 (Finland medium site class, Norway high site class, and Sweden high site class). For the pooled material including all heights and locations, the parameter estimates for a linear function were:

Monoculture:	$\theta = 3.00 - 0.0409 \cdot t$	$R^2 = 0.1366$
Mixed stands:	$\theta = 2.72 - 0.0417 \cdot t$	$R^2 = 0.1279$

with t = ring number, counted from the pith. The low R^2-values reflect that the observations were subject to a very large variation (Fig. 5).

A positive and significant correlation between annual ring width and spiral grain was found in mixed stands as well as monocultures. Analysing the linear relationship between annual ring width and spiral grain showed an increasing difference between treatments upwards in the stem. At stump height the trees from mixed stands had more spiral growth, though not significantly different from the monocultures. Further up the stem, trees grown in monoculture had significantly larger grain angles, and this significant difference remained when pooling data from all heights. Establishing linear regressions between ring width and grain angle in the total material lead to the following parameter estimates:

Spruce from mixed stands:	$\theta = 0.455 \cdot \Delta r + 0.61$	(mean value 1.780)
Spruce from monoculture:	$\theta = 0.209 \cdot \Delta r + 1.49$	(mean value 2.037)

Analysing the interaction between the annual ring width and spiral grain shows that the two regression lines have significantly different slopes. However, the partial R^2- value of interaction is only 0.06.

Discussion

During the early years of stand development, the growth of the young spruce is apparently much influenced by the presence of the birch (Fig. 2). Later in the rotation climatic fluctuations are clearly visible in the growth patterns of monocultures and mixed stands alike. Thus, apart from the juvenile phase, the presence of birch seems to neither moderate nor aggravate the influence of climatic fluctuations upon the growth of the spruce. However, since no detailed stand history was available we cannot be absolutely sure, that the trees from monocultures have not grown under shelter in the very early phase.

In general the diameter increment of the spruce is not greatly suppressed by the admixture of birch. In fact, the average growth ring width is slightly larger in the mixed stands than in the monoculture. But as it is clearly demonstrated in the Finnish material, the increment pattern can be changed in mixed stands, moderating the fast juvenile growth and promoting diameter development in the mature phase after removing the birch. Thus, a uniform ring width is achieved (Fig. 1), improving the machining and drying properties of the timber.

The spruce from mixed stands exhibits a density / ring width relationship different from that in monoculture, having on average slightly less dense wood (Fig. 4). As mechanical properties are strongly linked to basic density, the timber from mixed stands might be expected to have slightly inferior strength properties. However, the interaction of different quality parameters is complicated, and the effect of reduced density may be compensated by smaller knots and different radial density distribution. This question will be addressed in a second part of the study.

The positive correlation between spiral grain and diameter increment supports the results of earlier works (e.g. Bergstedt & Jørgensen 1997, Danborg 1994b, Pedini s.a.). A very interesting result is that the spruces grown in mixed stands exhibit less spiral growth than trees grown in monoculture at the same rate of diameter increment (Fig. 4). This adds positively to the merit of mixed stands, as spiral grain causes twisting of the timber during drying, and thus is considered a serious defect by the woodworking industry.

With its limited material drawn rather randomly from widely dispersed and variable populations of Norway spruce, the present study cannot be expected to yield more than rough indication of the possible difference between wood from monocultures and mixed stands. The findings presented above suggest that particularly the question of spiral grain deserves more attention in future studies of spruce grown in mixed stands.

References

Bergstedt, A.; Jørgensen, B.B. 1997. Hugststyrkens indflydelse på vedproduktion og vedkvalitet i rødgran på Lolland. Forskningscentret for Skov & Landskab. Skovbrugsserien nr. 20. 141 pp. (In Danish)

Cown, D.J.; Haslett, A.N.; Kimberley, M.O.; McConchie, D.L. 1996. The influence of wood quality on lumber drying distortion. Annales des Sciences Forestieres 53:1177-1188.

Danborg, F. 1994a. Spiral grain in plantation trees of Picea abies. Canadian Journal of Forest Research 24:1662-1671.

Danborg, F. 1994b. Density variations and demarcation of the juvenile wood in Norway spruce. Danish Forest and Landscape Research Institute, Hørsholm. The Research Series, No. 10. 78 pp.

Frivold, L.H. 1982. Bestandsstruktur og produksjon i blandingsskog av björk (*Betula verrucosa* Ehrh., *B. pubescens* Ehrh.) og gran (*Picea abies* (l.) Karst.) i Sydøst-Norge. Meldinger fra Norges landbrukshøgskole 62(18):1-108. (in Norwegian)

Johansson, G; Kliger, R; Perstorper, M. 1994. Quality of structural timber_product specification system required by end_users. Holz als Roh- und Werkstoff 52(1):42-47.

Lindström, H. 1997. Wood variation in young Norway spruce (*Picea abies* (L.) Karst.) created by differences in growth conditions. Thesis, Swedish University of Agricultural Sciences. Silvestria 21, ISBN 91-576-5305-4. 27 pp. + appendices.

Madsen, T.L.; Moltesen, P.; Olesen, P.O. 1978. Tyndingsstyrkens indflydelse på rødgranens rumtæthed, tørstofproduktion, grentykkelse og grenmængde. Det forstlige forsøgsvæsen i Danmark, 36:181-204. (In Danish)

Moltesen, P.; Madsen, T.L.; Olesen, P.O. 1985. Planteafstandens betydning for rødgranens tørstofsproduktion og vedkvalitet. Det forstlige forsøgsvæsen i Danmark 40:53-76. (In Danish with English summary).

Olesen, P.O. 1971. The water displacement method. Forest tree improvement, Arboretet Hørsholm. 3:3-23.

Olesen, P.O. 1976. The interrelation between basic density and ring width of Norway spruce. Det forstlige Forsøgsvæsen i Danmark 34:341-359.

Pedini, M. (s.a.): "Spiral grain in Sitka spruce", in: "The effect of modern forest practices on the wood quality of fast grown spruce". Royal Vet. & Agric. Univ., Copenhagen, Unit of Forestry. Final report, EC contract no. MA1B-0030-DK (BA).

Stevens, W.C.; Johnston, D.D. 1960. Distortion caused by spiralled grain. Timber Technology 68: 217-218.

A comparison of wood quality between mixed stands and monocultures of Norway spruce

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Introduction

When comparing mixed stands of spruce and birch with monocultures of spruce most studies have focused on the total production (Bergqvist, 1999, Tham, 1988, Mielikäinen, 1985). According to Bergqvist (1999) the presence of a birch shelterwood on sites with a rather low production potential has a significant effect on the understorey stem volume yield, a moderate effect on tree shape and wood density and almost no effect on stand structure, fibre dimensions etc. Shaded trees often have a better slenderness index (h/d) than unshaded. A high slenderness index should lead to smaller taper of the sawlogs which would affect the recovery positively. On the other hand a high slenderness index implies a higher risk for stem damage caused by wet snow. Slodicak et al. (1994) observed reduced resistance to snow- and icebreakage in stands of blue spruce (*Picea glauca*) in mixture with birch compared with pure blue spruce stands.

According to a simulation model of Mielikäinen (1985) the production of sawtimber was higher in a mixed stand with *Betula pendula* than in a pure spruce stand. In mixture with European birch *Betula pubescens* the production would be decreased According to a yield prediction study of Tham (1988) the total yield is greater when a shelter of between 5–800 birches ha^{-1} is left compared to when all broadleaved trees are removed.

The presence of a birch shelter helps to protect the young plants from frost (Tham, 1994) Birch also improves the soil conditions. According to Tham (1988) the soil activity is promoted by higher pH in the litter and a higher temperature on the ground due to more light reaching the ground. In studies of Norway spruce in mixture with birch an increase in carbon mineralisation and microbial biomass have been shown as well as higher decomposition rate, higher concentrations of Ca and Mg and a higher pH-value (Saetre et al. 1999, Brandtberg et al. 2000, Saetre, 1998). The presence of birch leaf litter influences the soil fauna composition as well as the composition of the ground vegetation (Saetre et al. 1999 Saetre et al. 1997).

Wood quality has been considered when studying Scots pine in mixture with birch. These studies have often focused on the branch diameter of Scots pine (Kellomäki et al. 1988, Hägg 1988). According to both authors the birch stems enhance the quality of the pine. Kellomäki et al. (1992) states that the branch diameter of young pines is strongly dependent upon the number of stems per hectare rather than mixture of species. Self regenerated birch increases the number of stems per hectare and with denser stands the self pruning is enhanced.

According to Oyen, (2000) knots are one of the main defects in softwood from northern countries. Since knots and branches are essential for the tree I would not consider all knots as defects, rather as properties of wood. However size, type, position and the number of knots are essential when grading logs and sawn wood. Thinning affects knot size and length through removal of competition. Higher site index and better climate results in larger knots, greater number of knots per whorl and longer sound-knot lengths (Moberg, 1999). The closure of the stand also affects the size of branches due to competition.

The shape of logs and boards, growth rate and the presence of defects such as compression wood, stem damages and cracks are also considered when grading (Anon. 1998, Anon. 1994). Twist in sawn wood is mainly caused by spiral grain (Forsberg, 1999). According to Pape (1999) several authors have found a positive correlation between spirality of grain and growth rate. Pape (1999) found in his own studies a slight increase in spiral grain directly after thinning. A thinned stand is also more vulnerable to stem damages such as top failures directly after thinning. There is a close correlation between stem damages, stem form and compression wood, since compression wood is the regulatory tissue. When a tree loses the terminal leader a side branch takes over the apical function. During this process compression wood is formed on the lower side of the branch, reorientating the branch to a vertical position (Timell 1986) Bow and spring is often influenced by the pronounced longitudinal shrinkage of compression wood and juvenile wood (Ormarsson, 1999, Warensjö & Lundgren 1995). According to Koski (1994) the frequency of defects, such as spike knots and crooked stems, is under stronger genetic than silvicultural control.

Material and methods

This study is part of a larger study dealing with differences in properties of Norway spruce from monocultures and mixed stands in Sweden, Finland and Norway. The material and the background of the study is thoroughly described (see page 5) The aim of the present study was to compare the wood quality in monocultures of Norway spruce with mixed stands of Norway spruce and birch. The comparison was made on both logs and sawn wood.

Grading of logs and boards

The logs were graded according to the Swedish grading rules for saw timber (Anon. 1998). Wood defects such as compression wood, spike knots, stem damages etc. were registered. The distance from the large end of the log to the location of the defect was also measured. After grading the logs were sawn. The sawing pattern was 2 x log. Dimensions and sawing patterns are shown in Fig. 1. While sawing the logs were positioned with the eastern side up. This was done in order to split the log into one board representing the northern side and one the southern side.

The boards were dried in a compartment kiln to a moisture content of 12%. After drying the boards were graded according to the "Blue book" (Anon. 1994). All defects such as spike knots, top failures, stem damage, compression wood, cross grain, wane, warp etc. were registered. The distances from board end to the failures were measured and registered.

Analyses

Statistical analyses were carried out in Minitab version 12.2. Procedures GLM (Tukey) and one-way analysis was used.

When evaluating the whole trial a factorial design was used. The model used was:

$$Y_{ijk} = \mu + a_i + \beta_j + d_{ij} + C_k + C_{ik} + C_{jk} + e_{ijk}$$

i = Type of stand (mixed/monoculture)
j = Site Index (moderate/high)
k = Country

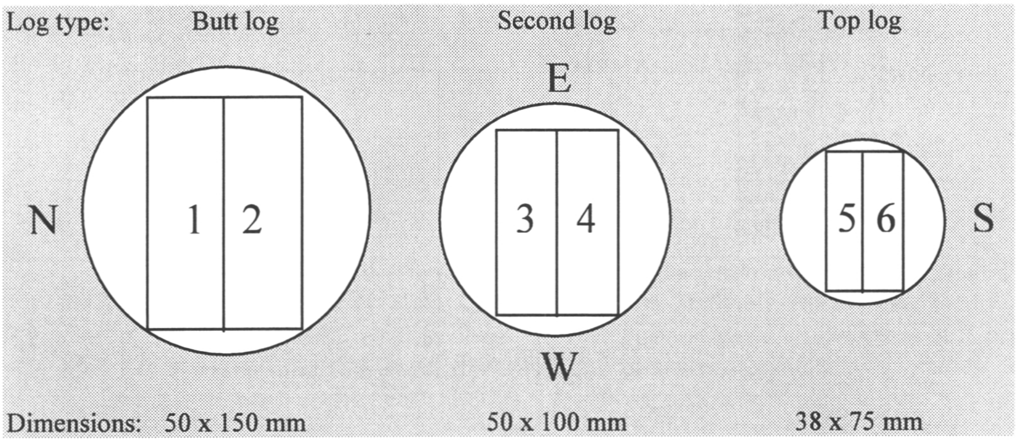

Figure 1. Sawing pattern according to cardinal direction and dimensions of centre boards.

Results

Grade of logs

The outcome of the grading is presented in Fig. 1. Best grade in this grading system is grade 1. Only two of the boards were graded as class 1. However this grade occurs rather seldom and this result resembles the outcome from an ordinary grading operation. To fulfil grade 1 certain requirements must be met regarding number and size of green and dry knots. 46% of the logs were graded class 2. The criterion to fulfil grade 2 is that there has to be at least one green knot within the first 15 dm from the large end of the log. Butt logs are not allowed in this grade. About half of the logs were classified as grade 3. Three logs from Norway were graded grade 4 due to crooks and compression wood. There were no significant differences between the different sites.

Grade of boards

Totally 432 boards were graded according to the blue book (Anon. 1994). The outcome of the grading is presented in Fig. 2 and Table 1. In Fig. 2 all boards/types of stand and countries are summarized.

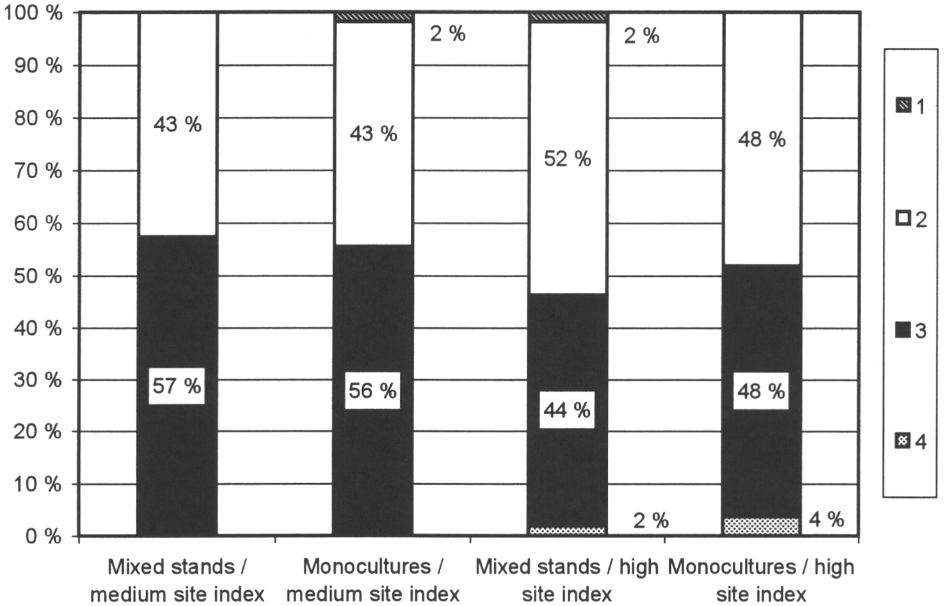

Figure 2. The percentage of logs/grade (1—4) from different sites (all countries included). The best grade is 1.

There were no differences between the outcome of grade A boards from the mixed stands located on different site indexes. If the outcome from the monocultures is compared there are a rather large difference, 81% compared to 60%. However this difference is not significant. There is also no significant difference if we compare the outcome of grade A boards from all the mixed stands with all the boards from monocultures.

In Table 1 the number of class A boards from each type of stand/country and log type are presented. There are no significant differences between mixed stands and monocultures. For top logs from the Swedish stands there are significant differences between stands representing moderate and high Site Index (p=0.014). The Swedish boards from the second logs show the same pattern. However this difference is not significant due to higher standard deviation (p=0.063). There is a significant difference between the countries (p=0.015). Almost all boards from Finland were graded class A (94%) compared with 78% of the Swedish boards and only 43% of the Norwegian boards. For top logs the difference was even larger. Here, only 21% of the Norwegian boards were graded class A compared with 85% of the Finnish and 71% of the Swedish.

Table 1. Number of class A boards graded according to the blue book (Anon. 1994).

	Medium Site Index		High Site Index		Sum
	Mixed stand	Mono-culture	Mixed stand	Mono-culture	
Boards from buttlog					
Sweden	11	12	11	10	44
Finland	12	12	12	12	48
Norway	4	7	10	7	28
Sum	27	31	33	29	120
Boards from Second log					
Sweden	11	12	7	4	34
Finland	11	12	12	12	47
Norway	4	8	7	5	24
Sum	26	32	26	21	105
Boards from top log					
Sweden	12	11	6	5	34
Finland	11	11	12	7	41
Norway	1	3	3	3	10
Sum	24	25	21	15	85

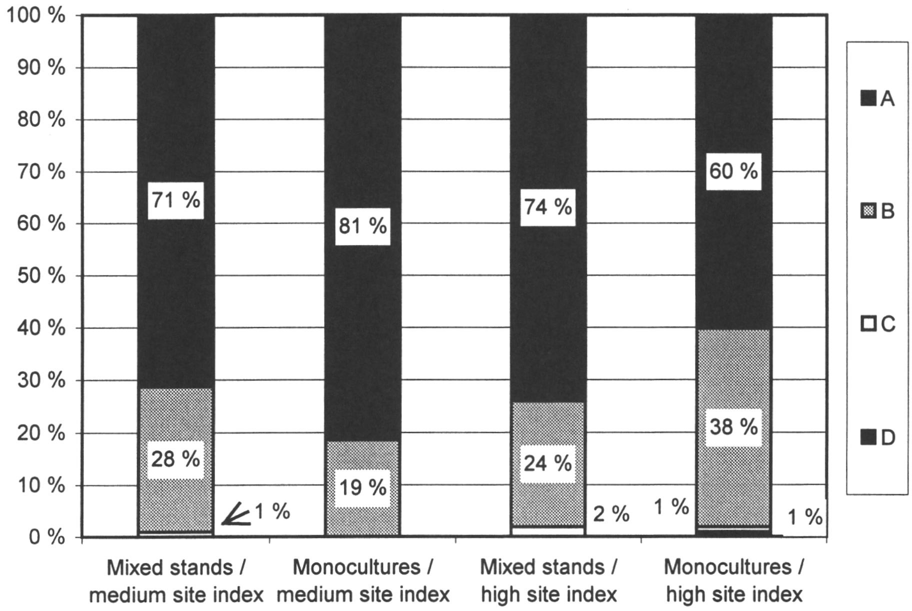

Figure 3. The percentage of centre boards representing quality classes (A-D) according to the blue book (Anon. 1994) from the different sites (all countries included).

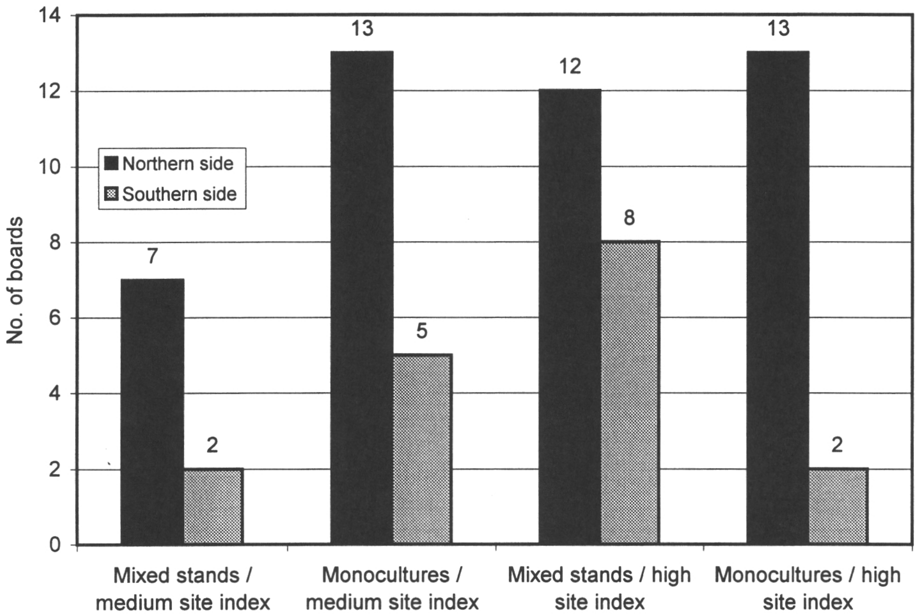

Figure 4. The total number of class-A boards/ log side from the sites located in Norway.

The Norwegian boards also differ in another way. The two boards from the same log often have different quality. There are almost three times as many class A boards from the northern side as the southern side (Fig. 3). The difference is significant (p=0.014). This difference can not be observed in the Swedish and the Finnish material.

Defects on sawn wood

Defects such as compression wood, spike knots, warp, number and type of knots determines the grade of the boards. In Fig. 4 the incidence of defects is presented. The most common defect in this material was stem damage. About 20% of the boards had this defect. The mixed stands on a high site index had less stem damage than the other stands. Due to large variation between stands and countries this difference was not significant. The Finnish stands had less share of boards with stem damage, 11% compared with 24% of the Swedish and 26% of the Norwegian. There were also differences regarding the position of the stem damage. The Finnish boards with stem damage often came from the butt log, the Swedish came from the second log and the Norwegian came from the top log.

The second most common defect was compression wood. About 16% of the boards had this defect. There were no significant differences between the different stands. The Swedish material from the medium site index stands had more boards with compression wood than the monocultures. There were no significant differences between the countries.

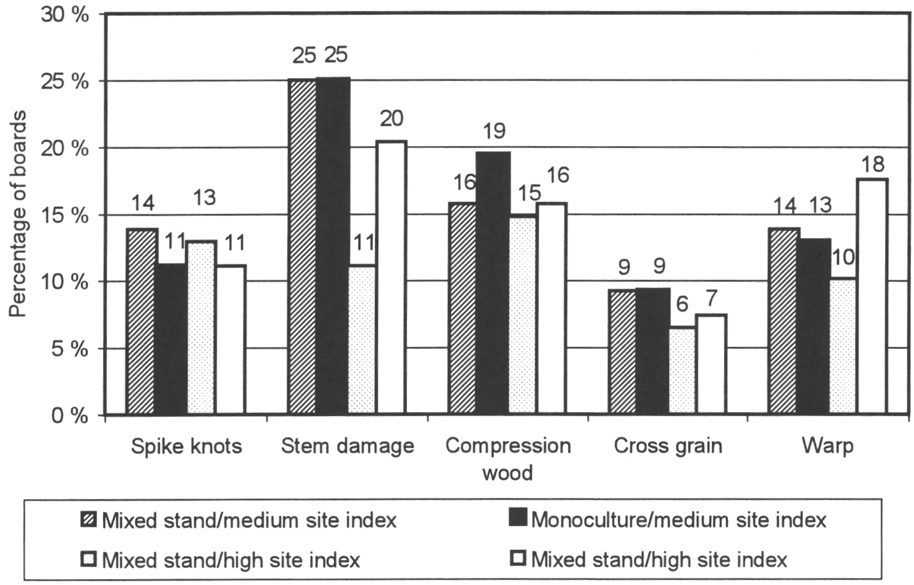

Figure 5. Percentage of boards with wood defects representing the different sites (all countries included).

Warp and spike knots occurred at approximately 12% of the boards. There were no significant differences between stands regarding warp. The Swedish stand representing a monoculture on high site index had twice as many boards with warp compared with all the other stands in Sweden as well as all the other Norwegian and Finnish stands.

In the Swedish stands spike knots occurred more often on boards from the top logs than from other logs. There were also more boards with spike knots from the top logs from the mixed stands. This difference was not significant (p=0.095).

Discussion

The results from the log grading showed no significant differences between the mixed stands and the monocultures. When the logs where sawn some differences became evident. The outcome of class A-boards from the monocultures was lower on the highly productive sites than from the moderately productive sites. This is probably a result of the silvicultural treatment and the faster growth leading to larger knots and (see Moberg 1999). The differences were most pronounced in boards from top logs from the Swedish and the Finnish sites and boards from second logs from the Swedish sites. Additionally, the Swedish boards from top logs had more defects which probably also caused downgrading. The significant difference in number of class A-boards between countries is probably a result of different site factors and silvicultural treatments. It is important to consider the different thinning regimes on the different sites. When a stand is thinned trees with spike knots and poor stem shape are often removed. Those trees also often contain compression wood. Probably those trees where already removed on the highly productive sites in Sweden and in all the Finnish stands. However, a newly thinned stand is more prone to develop stem defects like top failures caused by wind and snow. The difference in quality between different cardinal directions, azimuthal variation, have earlier been reported by Moberg (1999). He found that knots facing towards the south were larger probably due to light intensity and the rate of net photosyntesis. Since knot size is crucial when grading boards this may be one explanation to the significantly fewer class A-boards on the southern side in the Norwegian stands.

In general there are no significant differences between the different stands in this study apart from the variation between countries. One reason for this could be that the mixture with birch does not affect the sawtimber quality of spruce. From a theoretical point of view this seems unlikely. The effect of shelterwood and competition on wood properties has been shown by several authors (Bergqvist, 1999, Pape, 1999, Hägg, 1989). Thus we must conclude that the experimental design was inappropriate for the problem studied. The limited amount of trees studied at each experimental site could be a reason. Another reason could be that these stands are not representative. The variation between stands in the four countries is large probably due to the difference in silvicultural treatment. Perhaps we would also have observed more differences in the material if the boards had been classified into more distinct classes. In the blue book (Anon. 1994) the grade A is separated into four different grades ranging from A1 to A4. If our material had been classified into these classes the differences might have been significant. On the other hand they would have been even more difficult to evaluate.

Acknowledgement

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References

Anon. 1998. Kompendium i virkesmätning, del IV, Mätning av barrsågtimmer, Instruktions-handledning, Virkesmätningsrådet, Märsta.

Anon. 1994. Nordiskt Trä. Sorteringsregler för sågat virke av furu och gran. Föreningen svenska sågverksmän, Markaryd.

Bergqvist, G. 1999. Stand and Wood Properties of Boreal Norway Spruce Growing under Birch Shelter, Doctoral thesis, Acta Universitatis Agriculturae, Silvestria No. 108. ISSN: 1401-6230.

Brandtberg, PO., Lundkvist, H. & Bengtsson, J. 2000. Changes in forest-floor chemistry caused by a birch admixture in Norway spruce stands. Forest Ecology and Management, 2000, 130: 1-3, 253-264.

Forsberg, D. 1999. Warp, in particular Twist of Sawn Wood of Norway Spruce (*Picea abies* (L.) *Karst*, Doctoral thesis, Acta Universitatis Agriculturae, Silvestria No. 119. ISSN: 1401-6230.

Hägg, A. 1989. The influence of birch upon the branch diameter and the self pruning of pine trees in mixed stands. The Swedish University of Agricultural Sciences, Dept. of Forest Products, Report No. 208, 35pp. ISSN:0348-4599.

Kellomäki, S., Lämsä, P., Oker-Blom, P. & Uusvaara, O. 1992. Management of Scots pine for high quality timber. Silva Carelica 23: 1-133.

Koski, V., in Korpilahti, E., (ed.), 1994. How genotype and silviculture interact in forming timber properties. Silva-Fennica. 28: 4, 275-282.

Mielikäinen, K. 1985. Effect of an admixture of birch on the structure and development of Norway spruce stands, Communicationes Instituti Forestalis Fenniae. No. 133, 79pp.

Moberg, L. 1999. Models of Knot Properties for Norway Spruce and Scots Pine. Doctoral thesis, Acta Universitatis Agriculturae, Silvestria No. 121. ISSN: 1401-6230.

Oyen, O. 1999. Wood quality in old stands of Norway spruce (*Picea abies* (L.) *Karst*), thesis Department of Forest Sciences, Agricultural University of Norway, As, Norway.

Pape, R. 1999. Effects of Thinning on Wood Properties of Norway Spruce on Highly Productive sites. Doctoral thesis, Acta Universitatis Agriculturae, Silvestria No. 88. ISSN: 1401-6230.

Saetre, P. 1998. Decomposition, microbial community structure, and earthworm effects along a birch-spruce soil gradient. Ecology, 1998, 79: 3, 834-846.

Saetre, P., Brandtberg, PO., Lundkvist, H. & Bengtsson, J., 1999. Soil organisms and carbon, nitrogen and phosphorus mineralisation in Norway spruce and mixed Norway spruce - birch stands. Biology and Fertility of Soils. 1999, 28: 4, 382-388.

Saetre, P., Saetre, LS., Brandtberg, PO., Lundkvist, H. & Bengtsson, J., 1997. Ground vegetation composition and heterogenity in pure Norway spruce and mixed Norway spruce - birch stands. Canadian Journal of Forest Research. 1997, 27: 12, 2034-2042.

Slodicak, M. & Soucek, J. 1994. The effect of thinnings from above and from below on development of mixed forest stands of birch and blue spruce in the Krusne hory Mts. Lesnictvi Forestry. 1994, 40: 10, 438-445.

Tham, A. 1988. Yield prediction after heavy thinning of birch in mixed stands of Norway spruce (*Picea abies* (L.) *Karst.*) and birch (*Betula pendula* Roth & *Betula pubescens* Ehrh. Dissertation, The Swedish University of Agricultural Sciences, Dept. of Forest Yield Research, Report No. 23, 36pp. (ISSN 0348-7636).

Timell, T. 1986. Compression wood in gymnosperms, Vol 1-3, Springer-Verlag, Berlin, Heidelberg, New York, Tokyo.

Strength of Norway spruce from both mixed stands and monocultures

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Abstract

Bending strength (MOR) and modulus of elasticity (MOE) of wood taken from Norway spruce (*Picea abies* [L.] Karst.) in mixed spruce stands and in monocultures was investigated. Samples were taken from the outer sawn boards (mature wood). The average MOE was 12.6 GPa and the average MOR was 82.3 MPa which agrees with earlier Norway spruce results. Bending strength increased with increasing density (regression formula: $y = 0,2381x - 27,51$, $R^2 = 0.79$) and decreased with increasing growth ring width. The density of samples from different sites was similar and thus the strength properties were similar. The average weight density (ρ_{12}) of the study material was 462 kgm^{-3} (± 46 kgm^{-3}) and the average basic density was 380 kgm^{-3}. The average growth ring width was 2.3 mm.

Introduction

Bending strength (MOR) and elasticity (MOE) are commonly used to describe the mechanical performance of wood and wood products. Structural uses of wood are diverse and thus the ability of wood to carry applied loads and forces is of great importance. Elasticity is significant because it determines the ability of wood to resist deformation under load. A stiff board with high MOE is able to resist high loads without deformation.

Most of the mechanical properties of wood improve with density. The correlation has been found to be weaker for MOE than MOR (e.g. Okstad and Kårstad 1985, Flaete and Kucera 1999). Juvenile wood of Norway spruce has a low density and thus a lower MOE than mature wood (Steffen et al. 1997). Density decreases with increasing ring width and wood with narrow rings, and with a high percentage of latewood shows better strength than fast grown wood (e.g. Verkasalo 1992).

The aim of this study was to investigate the strength properties of clear wood samples of Norway spruce (*Picea abies* [L.] Karst.) trees grown in a monoculture and in a mixed stand of spruce. Sample trees were taken from medium and high site quality. The purpose was also to find out the relationship between mechanical (MOE and MOR) and physical properties (density and growth ring width).

Material and methods

Norway spruce logs were sawn to obtain clear wood samples (see description of test sawing). After sawing, altogether ten boards were selected from butt (4), centre (3) and top (3) portions of each stem. A total number of 432 boards with straight grain were further selected to prepare clear wood samples (without any knots and defects) for bending tests. Boards were sawn and carefully planed into 20 x 20 x 300 mm dimensions and kept under a constant environment (+20 °C, 65 % RH).

Longitudinal modulus of elasticity (MOE) was determined by the four-point bending test (ISO STANDARD 3349, International Organisation... 1975, Kucera 1992). Load was applied on the specimen in the tangential direction. The test was carried out with a modified Lloyd universal testing machine (England). The strain was recorded with a digital length gauge system (Heidenhain, Germany).

Dimensions of the samples were measured with a digital caliper and the weight of the sample was determined at 12 % RH in order to obtain weight density values (ρ_{12}) before testing. After the bending test, a small sample was further cut from each stick for determining basic density and growth ring width. The basic density of this sample was determined as the weight after drying (103 °C) until constant weight divided by the green volume, which was measured by the water displacement method (Olesen, 1971). Growth ring width and percentage of latewood were measured under a microscope.

Results and discussion

Variation in MOE and MOR

The average MOE of Norway spruce was 12.6 GPa. However, variation was fairly large, ±2.0 GPa (Table 1). According to Flaete and Kucera (1999) the average MOE of *Picea abies* from different provenances in Norway was 10.4 GPa and it varied between 5.6 GPa to 18.3 GPa. The slightly lower MOE in their study was due to a lower average weight density (ρ_{12}= ca. 393 kgm^{-3}) than in this study (462 kgm^{-3}). Okstad and Kårstad reported an average MOE of 9.7 GPa for *Picea abies* grown in northern Norway and the average density (ρ_{12}) of their study material was 410 kgm^{-3}.

Table 1. Density, growth ring width, modulus of elasticity (MOE) and bending strength of Norway spruce of a total of 432 samples from 72 stems.

	X	Min	Max	s
Density (ρ_{12}), kgm-3	462	328	611	46
Growth ring width, mm	2.3	1.1	5.4	0.8
Latewood, %	15.2	3.3	39.6	6.7
MOR, MPa	82.3	36.7	119.0	12.5
MOE, GPa	12.6	6.8	17.9	2.0

The average MOR of Norway spruce was 82,3 MPa. However, variation was also fairly large, ±12,5 MPa (Table 1). Flaete and Kucera (1999) reported a much lower average MOR of 65.8 MPa and an average density (ρ_{12}) of ca. 400 kgm^{-3}. The average MOE of *Picea abies* grown in northern Norway was similar (67.7 GPa) and the average density (ρ_{12}) was 410 kgm^{-3} (Okstad and Kårstad 1985).

Dependence of MOE and MOR on wood density and growth ring width

The average weight density (ρ_{12}) of the material was 462 kgm^{-3} and the average basic density was 380 kgm^{-3}. These values correspond well with earlier studies of Norway spruce (e.g. Hakkila 1968). The average growth ring width of the study material was 2.3 mm and it varied between 1.1–5.5 mm (Fig. 1).

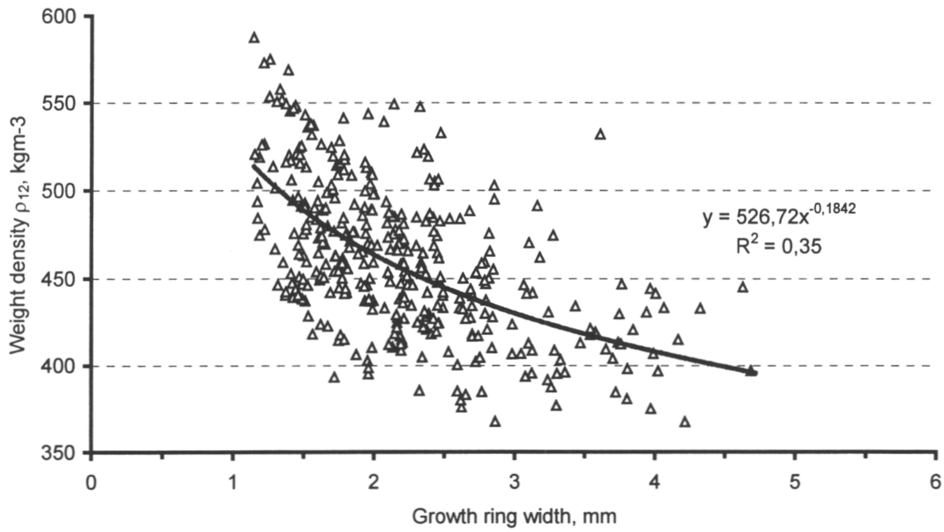

Figure 1. The relationship between the density and growth ring width. N= 432.

According to the measurements of the stem disks (see Bergstedt et al. in this book) the average growth ring width of the study material was 2.1 mm and the difference between medium and high site index was negligible.

Density decreased with increasing ring width. However, the correlation was not very strong (Fig. 1). Flaete and Kucera (1999) have reported a similar relationship between growth ring width and weight density in Norway spruce.

MOR increased linearly with increasing density ($y = 0,2381x - 27,51$, $R^2 = 0.79$, Fig. 2)). Okstad and Kårstad (1985) reported an exponential regression model ($y = -54.24 + 0.416x - 0.000288x^2$, $R^2 = 0.84$) to describe the relationship between MOR and density. Their model gives a MOE of 76.5 MPa with the average weight density (ρ_{12}) of 462 kgm^{-3}, which is slightly less than the average of this study (82.3 MPa). Seeling also (1999) reported a linear regression model ($y = 0,2546x - 30,236$; $R^2 = 0,75$), which gives a MOE of 87.4 MPa with the average weight density (ρ_{12}) of 462 kgm^{-3}.

MOE was dependent on wood density using the linear regression model ($y = 0,0305x - 1,4385$) but the correlation was weaker than that for MOR ($R^2 = 0.48$, Fig. 3). Okstad and Kårstad also reported a linear regression model ($y = 1.308 + 0.02673x$; $R^2 = 0.69$) which gives a MOE of 13.7 GPa using the average density of this study ($\rho_{12} = 462$ kgm^{-3}). In contrast to MOR, their model gives a slightly higher MOE than the average of this study material (12.6 GPa).

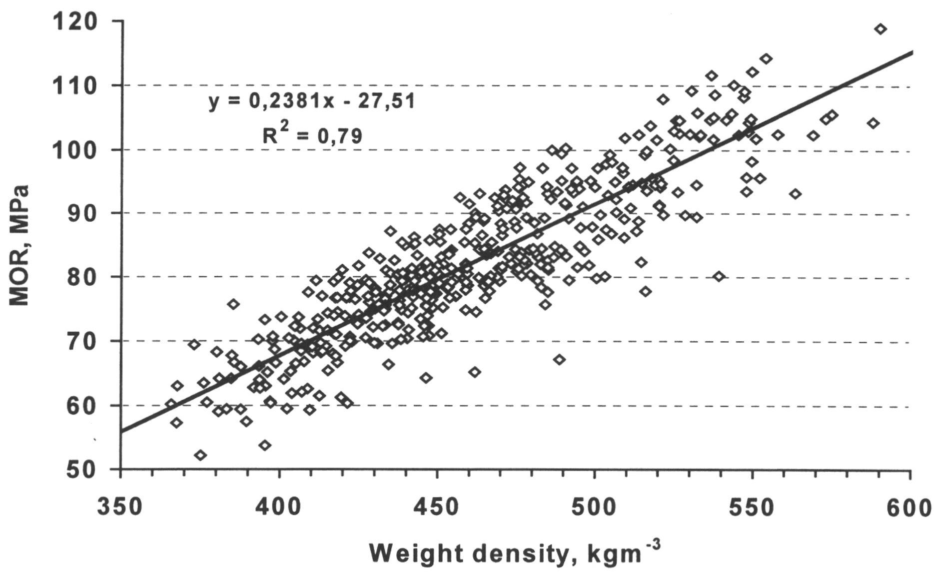

Figure 2. The relationship between MOR and density. N= 432.

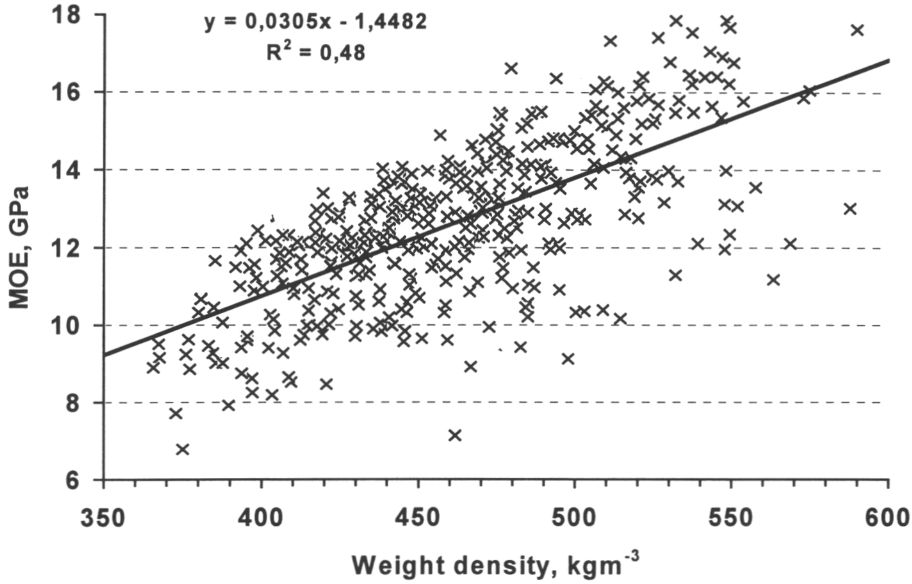

Figure 3. The relationship between MOE and density. N=432.

Growth ring width explained approximitely 40 % of the variation in MOR (linear regression, data not shown). When the latewood width was included in the regression model, the R^2 did not increase remarkably. When the latewood percentage increased from 5 % to 30 % MOR increased approximitely 30 MPa (from ca. 60 MPa to 90 MPa) according to a non-linear relationship (y = 98.52 + (-264.72/ (x+3.25)); Olesen 1976, 1977).

Strength of Norway spruce from different stands

No clear differences were found between the samples from different stands (Fig. 4). This was due to a rather uniform density distribution (ρ_{12}) of the samples (Fig. 4). Only logs from a monoculture with a moderate site index showed slightly higher density and strength (Fig. 4). However, the difference was not statistically significant. No clear differences were found between the bottom, centre or top of logs.

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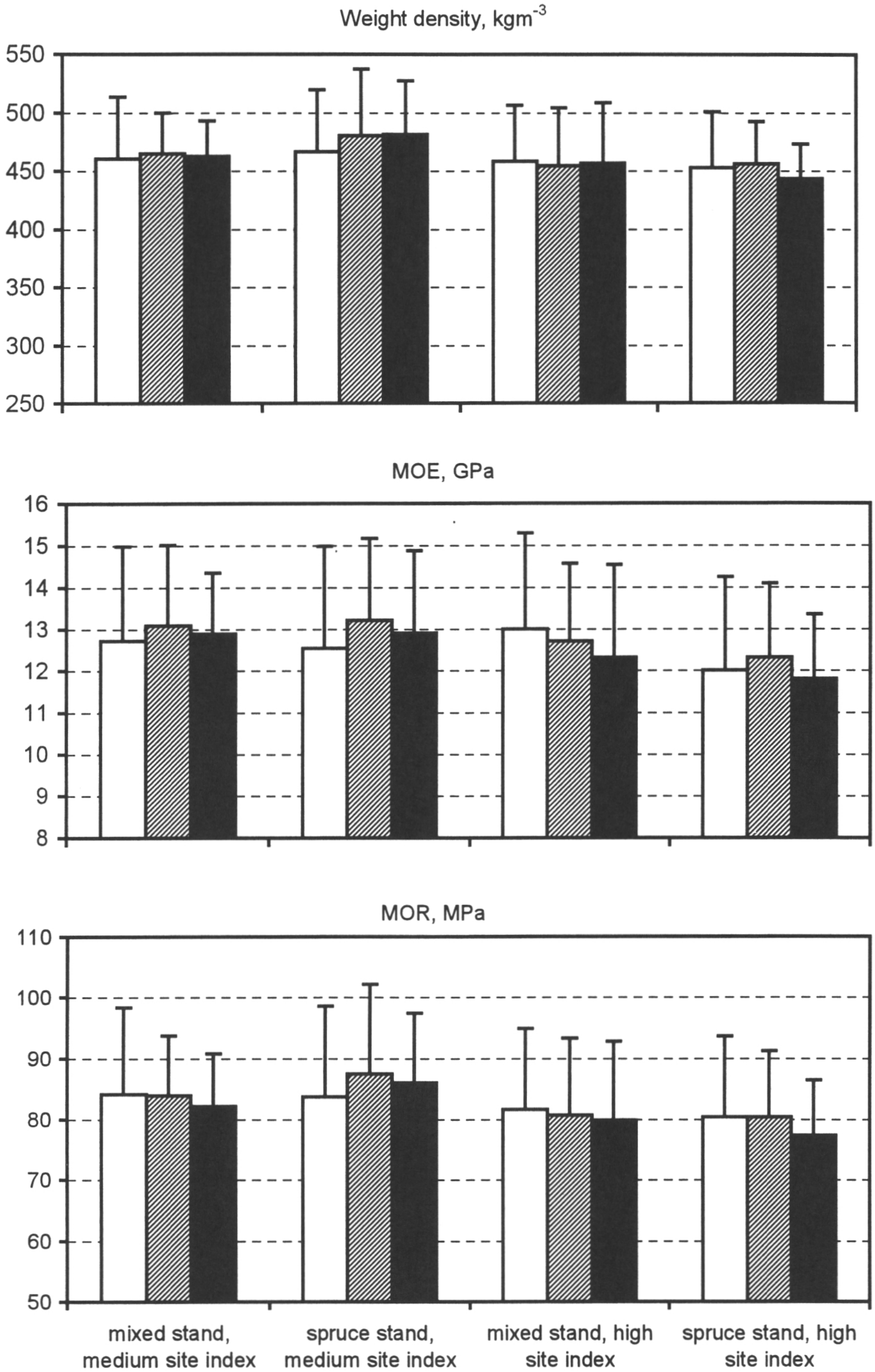

Figure 4. The variation of weight density (ρ_{12}), MOE and MOR of test samples from the four different sites, based on 432 clear mature wood samples sawn from the bottom logs (open bars), centre logs (diagonal bars) and top logs (black bars).

References

Flaete, P-O. & Kucera, B. (1999) Virkesegenskaper til mellomeuropeiske og norske granprovenienser plantet i Ostfold. Rapport Skogforskningen, NISK 1/99: 1—30.

Hakkila, P. 1968. Geographical variation of some properties of pine and spruce pulpwood in Finland. Comm Inst For Fenn 66.8: 1—60.

International Organisation for Standardization (ISO): 3349 Determination of modulus of elasticity in static bending.

Kucera, B. 1992. Skandinaviske normer for testing av små feilfrie prover av heltre. Skogforsk, Norwegian Forest Research Institute, Ås. 104 p.

Kufner, M. 1985. Verteilung von Eigenschaftswerten in einem Fichten-Stammabschnitt. Holz als Roh- und Werkstoff 43: 123—129.

Kärkkäinen, M. & Dumell, O. 1983. Kuusipuun taivutuslujuuden riippuvuus tiheydestä ja vuosiluston leveydestä Etelä- ja Pohjois-Suomessa. Silva Fennica 17(2): 125—135.

Kärkkäinen, M. & Hakala, H. 1983. Kuusitukin koon vaikutus sivulautojen taivutus- ja puristuslujuuteen. Silva Fennica 17(2): 137—142.

Okstad, T. & Kårstad, H. 1985. Mekaniske egenskpaer hos små, feilfrie prover av granvirke (*Picea abies* L. Karst.) fra Nord-Norge. (The mechanical properties of spruce wood (*Picea abies* L. Karst.) in Northern Norway). Meddelelser fra Norsk Institutt for Skogforskning 38.38. 47 s.

Olesen, P. O. 1971. The water displacement method. A fast and accurate method for determing the green volume of wood samples. For. Tree Impr. 3: 1—57.

Olesen, P. O. 1976. The interrelation between basic density and ring width of Norway spruce. Det Forstl. Forsogsv. Danm. 34:340—359.

Olesen, P. O. 1977. The variation of basic density level and tracheid width within the juvenile and mature wood of Norway spruce. For. Tree Impr. 12: 1—21.

Seeling, U. 1999. Einfluss von Richtgewebe ("Druckholz") auf Festigkeit und Elastizität des Fichtenholzes. Holz als Roh- und Werkstoff 57;81—91.

Steffen, A., Johansson, C. J. & Wormuth, E.-W. 1997. Study of the relationship between flatwise and edgewise moduli of elasticity of sawn timber as a mens to improve mechanical strength grading technology. Holz als Roh- und Werkstoff 55: 245—253.

Verkasalo, Erkki (1992) Relationships of the modulus of elasticity and the structure of Finnish Scots pine wood. Silva Fennica 26 (3): 155—168.

Strength and related properties of Norway spruce timber in structural sizes

Comparison of spruce grown in mixtures with birch and in monocultures

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Introduction

Bending strength and stiffness are important properties for structural load carrying timber and are affected by several other wood properties. Juvenile wood has lower bending strength and stiffness compared to mature wood (Kliger et al. 1995). Dhubain et al. (1988) found reduced modulus of elasticity (MOE) in compression wood. Modulus of rupture (MOR), however, was not affected by compression wood content, but the timber tended to rupture brashly without warning. Grain angle has been found to be negatively correlated with bending strength and stiffness (e.g. Eikenes 1991). Timber with broad annual rings from fast-grown Norway spruce has been reported to have lower average strength and stiffness compared to timber from slow-grown spruce (Kliger et al. 1995). Wood density is considered a relatively good indicator of many technical properties of wood (Kollmann & Cote 1984). High density implies a high proportion of cell wall per unit of volume, and the strength and stiffness of wood increase with increasing density. Generally, there is a negative correlation between annual ring width and density in Norway spruce (e.g. Klem 1942, Olesen 1976). However, this relationship can vary considerably due to variations in tracheid dimensions, which are highly related to cambial age and climatic conditions. Knots are possibly the single most important strength- and stiffness-reducing defects in timber because of grain distortion around the knot and geometrical reduction of the cross section caused by the knot (Kollmann & Cote 1984, Hoffmeyer 1987).

The aforementioned wood properties are in various degree growth related, and can to some extent be controlled through silviculture. Increasing the density of the initial spacing reduces the annual ring width and the branch diameter, and increases the wood density (Høibø 1991, Johansson 1997, Vestøl 1998).

Mixed stands contain two or more tree species, and are often stratified. Stratified stands with trees in the upper and lower strata are commonly referred to as shelterwoods. Lower annual ring width, smaller branches and reduced amount of defects have been reported in young stands of Norway spruce planted under a birch shelter compared with spruce grown in monoculture (Klang & Ekö 1999). Hence, it should be expected that a birch shelter improves the strength properties of spruce timber. However little effect of birch shelter on wood density of Norway spruce has been reported (Bergqvist 1999).

The objective of this study was to investigate effects of birch grown in mixture with Norway spruce on strength properties of structural timber of spruce, MOR and MOE, and strength- and growth related properties of structural timber were of specific interest. Additionally, the study aims at investigating relationships between the different properties measured.

Material and methods

The material comprised 432 beams taken from 72 trees, out of which 36 trees originated from monocultures and 36 trees from mixed stands. A comprehensive overview of the experimental design is presented in earlier parts of the report.

Preparation of wood samples

Three logs from each tree, cut at fixed relative tree height, were sawn into structural beams.

Dimensions of beams and their vertical positions in the trees:

0–20% of tree height: 48 mm x 143 mm
20–40% of tree height: 48 mm x 95 mm
40–60% of tree height: 36 mm x 71 mm

From each log two beams were included in the study. One beam was sawn from the north and the other from the south side of the pith.

After sawing, the timber was kiln dried, planed and conditioned in standard environment according to EN 408 (CEN 1995b) to 12% wood moisture content (percent of dry mass).

The beams were cut into standard lengths (19 x depth of beam) according to EN 408.

Tests and measurements

Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from data obtained by edgewise two-point static bending on a universal test rig (Instron 1185).

Calculation of MOE was done according to the standards ISO 3349 (ISO 1975d) and EN 408. MOE values were corrected when deviating from 12% wood moisture content, based on ISO 3349 (ISO 1975d).

MOR was calculated following procedures in ISO 3133 (ISO 1975c) and EN 408. MOR in beams with moisture content differing from 12% was adjusted according to correlations previously found for spruce (Hoffmeyer 1979, 1980, Høibø & Eikenes 1991). MOR values were corrected to 150 mm dimension height according to EN 384 (CEN 1995a).

One cross sectional sample disc was cut from clear wood close to the fracture from MOR testing. This disc was used for calculation of density, annual ring width and wood moisture content at the time of testing.

Wood moisture content at the time of testing was determined on each beam as prescribed in EN 408 and ISO 3130 (ISO 1975a). Density was determined according to ISO 3131 (ISO 1975b). Annual ring width used in the calculations was the mean value of all the annual rings outside a 25-mm ring surrounding the pith.

Diameter of the biggest knot in each beam was measured in mm perpendicular to the longitudinal direction of the beam. It was measured in the area where fracture was expected to occur.

Grain angle was measured close to the centre of each beam on the bark-side broad face. It was measured along a distance of 100 mm between two whorls with a resolution of 0.1 degree.

There are two missing values in the data set. One of the beams was discarded because of extremely low MOE and MOR as a result of compression wood. The other beam was lost before testing.

Statistical analyses

The statistical tests were performed by using two-sample t-test in the statistical software package JMP (SAS Institute Inc. 1995). The significance level used in all tests was 0.05.

For the properties measured, considerable correlation was found between the beams obtained from the same tree. To eliminate the effect of this correlation, each tree was represented by one observation for each of the properties only. This observation was calculated by weighting the samples from each tree according to their beam volume.

Simple linear regressions were performed to study relationships between various wood properties.

Results

Annual ring width, density, diameter of thickest knot and grain angle

Annual ring width, density, diameter of thickest knot and grain angle of the 430 beams are summarised in Table 1 by their mean, range and standard deviation.

Annual ring width

Mean annual ring width for all beams was 2.8 mm, ranging from 1.4 mm to 6.8 mm. Although there was some variation between sites, the annual ring width of beams was not significantly different when comparing timber from mixed stands and monocultures.

Density, ρ_{12}

Mean density at 12% wood moisture content was 429 kg/m^3, ranging from 342 kg/m^3 to 545 kg/m^3. The beams from monoculture sites had slightly higher density than the beams from mixed sites, but this difference was not statistically significant.

Relationship between density and annual ring width

The linear relationship between density and annual ring width was modelled by simple regression (Fig. 1). The fit was poor, and did not improve noticeably by fitting non-linear models.

Table 1. Annual ring width, density, diameter of thickest knot, grain angle of beams from mixed stands (n = 215) and beams from monocultures (n = 215).

	Treatment	Mean	Min	Max	St.dev.
Annual ring width	Mixed	2.8	1.5	6.8	0.9
(mm)	Monoculture	2.9	1.4	5.5	0.8
Density, ρ_{12}	Mixed	425	347	534	34
(kg/m^3)	Monoculture	433	342	545	39
Diameter of thickest	Mixed	24	9	45	6
knot (mm)	Monoculture	24	11	60	7
Grain angle (degrees)	Mixed	1.7	0	4.6	0.9
	Monoculture	1.7	0	4.6	1.0

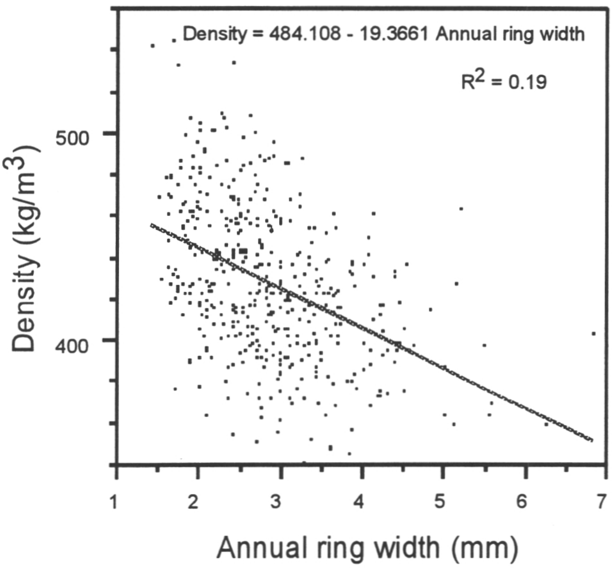

Figure 1. Relationship between density and annual ring width (n=430).

Diameter of thickest knot

The overall average diameter of the largest knot in the zone of each beam where fracture was assumed to propagate was 24 mm, varying from 9 mm to 60 mm. No significant difference between beams from mixed stands and monocultures was found.

Grain angle

Mean grain angle was 1.7 degrees, ranging from 0 to 4.6 degrees. Grain angle showed the same pattern in beams from all sites.

3.2 Strength properties

Modulus of elasticity (MOE)

Mean MOE was 8.7 GPa, ranging from 2.8 GPa to 15.7 GPa. Table 2 shows that MOE varies between sites, but there are no differences or patterns that can be contributed to origin from monocultures or mixed stands.

Simple linear regression models between MOE and various wood properties are shown in Table 3.

Table 2. Means, range and standard deviation of the modulus of elasticity, MOE (GPa).

Site	Treatment	Mean	Min.	Max.	Std. dev.
Finland1	Mixed	8.9	5.4	13.2	2.1
Finland2	Monoculture	9.3	6.2	13.3	1.6
Finland3	Mixed	10.0	6.8	14.2	1.6
Finland4	Monoculture	7.7	4.9	10.3	1.4
Norway1	Mixed	8.0	3.6	10.6	1.7
Norway2	Monoculture	9.2	2.8	15.7	2.5
Norway3	Mixed	8.3	4.7	13.1	2.1
Norway4	Monoculture	7.8	2.8	15.2	2.0
Sweden1	Mixed	9.3	7.4	12.4	1.2
Sweden2	Monoculture	9.1	5.1	13.5	1.9
Sweden3	Mixed	8.3	4.9	13.2	1.9
Sweden4	Monoculture	9.0	5.1	14.2	2.1
All countries	Mixed	8.8	3.6	14.2	1.9
All countries	Monoculture	8.7	2.8	15.7	2.0

Table 3. Simple regression models of the relationship between MOE and various wood properties.

Estimated function	x_i	RMSE	Prob>F	R^2
$E_{12}(GPa) = 12.5 + 1.32\ x_i$	Annual ring width (mm)	1.63	<0.0001	0.31
$E_{12}(GPa) = -1.9 + 0.02\ x$	Density, ρ_{12} (kg/m^3)	1.74	<0.0001	0.21
$E_{12}(GPa) = 11.8 - 0.13\ x_i$	Max knot diameter (mm)	1.78	<0.0001	0.18
$E_{12}(GPa) = 9.2 - 0.28\ x_i$	Grain angle (degrees)	1.95	<0.0047	0.02

Table 4. Modulus of rupture, $MOR_{(150)}$ (MPa).

Site	Treatment	Mean	Min.	Max.	Std. dev.
Finland1	Mixed	43.1	20.7	60.6	10.7
Finland2	Monoculture	49.4	28.8	79.4	12.5
Finland3	Mixed	54.4	31.0	71.1	10.6
Finland4	Monoculture	40.2	23.6	55.2	8.5
Norway1	Mixed	41.7	18.1	63.6	11.4
Norway2	Monoculture	46.5	14.9	94.4	17.9
Norway3	Mixed	44.1	25.4	79.4	13.0
Norway4	Monoculture	40.9	22.3	75.0	11.7
Sweden1	Mixed	48.8	30.2	73.1	10.3
Sweden2	Monoculture	51.6	23.6	75.5	12.7
Sweden3	Mixed	41.5	18.3	67.1	10.0
Sweden4	Monoculture	47.4	18.3	71.0	12.1
All countries	Mixed	45.6	18.1	79.4	11.9
All countries	Monoculture	46.0	14.9	94.4	13.4

Table 5. Simple regression models of the relationship between MOR and various wood properties.

Estimated function	x_i	RMSE	Prob>F	R2
$\sigma_{12(150)}(MPa) = 66.9 - 7.41\ x_i$	Annual ring width (mm)	11.05	<0.0001	0.24
$\sigma_{12(150)}(MPa) = -12.9 + 0.14\ x_i$	Density, ρ_{12} (kg/m^3)	11.60	<0.0001	0.16
$\sigma_{12(150)}(MPa) = 65.9 - 0.85\ x_i$	Max knot diameter (mm)	11.40	<0.0001	0.19
$\sigma_{12(150)}(MPa) = 50.2 - 2.53\ x_i$	Grain angle	12.43	<0.0001	0.04

Modulus of rupture (MOR) corrected to 150 mm dimension height

Mean $MOR_{(150)}$ was 45.8 MPa, ranging from 14.9 MPa to 94.4 MPa. Measurements of $MOR_{(150)}$ are summarised in Table 4. The differences in means reported in table 4 are not significantly different when comparing beams from monocultures and beams from mixed stands.

Simple linear regression models between $MOR_{(150)}$ and various wood properties are shown in Table 5.

Relationship between $MOR_{(150)}$ and MOE

The linear relationship between $MOR_{(150)}$ and MOE was modelled by simple regression (Fig. 2). MOE was superior as regressor compared with the other measured wood properties for describing the variation of MOR.

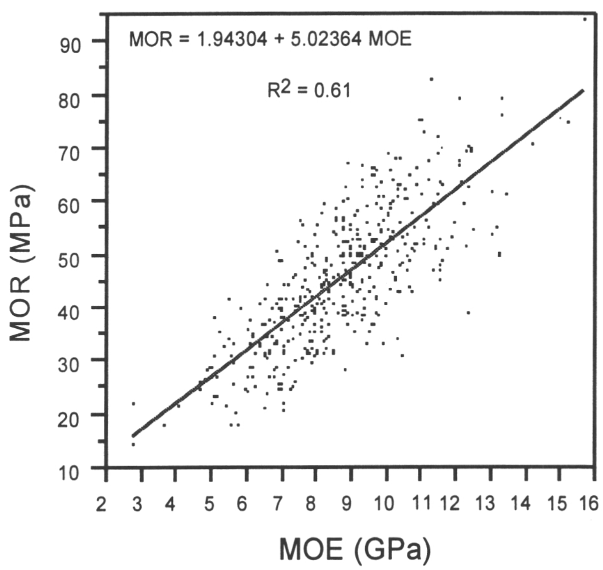

Figure 2. Relationship between modulus of rupture (MOR) and modulus of elasticity (MOE) (n=430).

Discussion

The material in the present study had high bending strength, comparable with what has been reported for slow grown spruce (Eikenes et al. 1995, Kliger et al. 1998). The modulus of elasticity was lower than expected and in the magnitude of what has been found for fast grown spruce (e.g. Flæte & Kucera 1999).

The relationship between studied strength properties and growth related wood properties showed a traditional pattern: Bending strength and modulus of elasticity were negatively correlated with annual ring width, knot diameter and grain angle, and positively correlated with wood density. All the applied regression models resulted in significant relationships; the explanatory power of these models was however, low.

When modelling MOR using MOE as the independent variable, the model accounted for 61% of the variation. This is at the same level as previously reported for spruce (Kliger et al. 1998).

The similar strength properties of beams from monocultures and mixed stands indicate that the presence of birch had little influence on the investigated properties. It is noteworthy to mention that mixed stands of birch and spruce are not a homogeneous category. The wide range of competitive conditions in mixed stands of birch and spruce makes it important to emphasise that the results cannot be generalised. However, the results reported are consistent with prior research of strength related wood properties of spruce grown under birch shelter (Bergqvist 1999).

References

Bergqvist, G. 1999. Stand and wood properties of boreal Norway spruce growing under birch shelter. Doctoral thesis. Acta Universitatis Agriculturae Sueciae. Silvestria 108.

CEN 1995a. Structural timber - Determination of characteristic values of mechanical properties and density. EN 384. European Committee for Standardization, Brussels. 13 pp.

CEN 1995b. Timber structures. Structural timber and glued laminated timber. Determination of some physical and mechanical properties. EN 408. European Committee for Standardization, Brussels. 12 pp.

Dhubhain, A.N., Evertsen, J.A. & Gardiner, J.J. 1988. The influence of compression wood on the strength properties of Sitka spruce. Forest Products Journal 38(9): 67-69.

Eikenes, B. 1991. Properties of Norway spruce (Picea abies (L.) Karst.) from Western Norway tested on timber in structural sizes. Meddelelser fra Norsk institutt for skogforskning 44. 1-78. (In Norwegian)

Eikenes, B., Kucera, B., Fjærtoft, F., Storheim, O.N. & Vestøl, G.I. 1995. Wood quality from uneven-aged forests. Norwegian Forest Research Institute, Report no 24/95: 1-30. (In Norwegian)

Flæte, P.O. & Kucera, B. 1999. Wood properties of Central European and Norwegian spruce provenances planted in Østfold. Norwegian Forest Research Institute, Report no 1/99: 1-31. (In Norwegian)

Hoffmeyer, P. 1979. Vandindholdets betydning for konstruktionstræs styrke og elasticitetsegenskaper. Nordisk Trætidsskrift 6: 191-203. (In Danish)

Hoffmeyer, P. 1980. The moisture-mechanical property relationship as dependent on wood quality. Technical report 84. Building Materials Laboratory, Technical University of Denmark. 1-31.

Hoffmeyer, P. 1987. The role of grain angle, knots, tension wood, compression wood, and other anomalies on the mechanical properties of wood. Technical report 183. Building Materials Laboratory, Technical University of Denmark. 1-75.

Høibø, O.A. 1991. The quality of wood of Norway spruce (*Picea abies* (L.) Karst.) planted with different spacing. Agricultural University of Norway. Doctor scientiarum thesis 1991: 13. (In Norwegian)

Høibø, O.A. & Eikenes, B. 1991. Properties of Norway spruce (Picea abies (L.) Karst.) planted with wide spacing. Agricultural University of Norway, Department of Forest Sciences. 33 pp. (In Norwegian)

ISO 1975a. Wood – Determination of moisture content for physical and mechanical tests. ISO 3130. International Organisation for Standardisation. 2pp.

ISO 1975b. Wood – Determination of density for physical and mechanical tests. ISO 3131. International Organisation for Standardisation. 2pp.

ISO 1975c. Wood – Determination of ultimate strength in static bending. ISO 3133. International Organisation for Standardisation. 2pp.

ISO 1975d. Wood – Determination of modulus of elasticity in static bending. ISO 3349. International Organisation for Standardisation. 3pp.

Johansson, K. 1997. Effect of early competition on wood properties of Norway spruce, Doctoral thesis. Acta Universitatis Agriculturae Sueciae. Silvestria 19.

Klang, F. & Ekö, P.-M. 1999. Tree properties and yield of *Picea abies* planted in shelterwoods. Scandinavian Journal of Forest Research 14: 262-269.

Klem, G.G. 1942. Planteavstandens innflytelse på granvedens og sulfitcellulosens kvalitet. Meddelelser fra Det norske Skogforsøksvesen 8: 258-293. (In Norwegian)

Kliger, I.R., Perstorper M. & Johansson G. 1998. Bending properties of Norway spruce timber. Comparison between fast- and slow-grown stands and influence of radial position of sawn timber. Annales des Sciences Forestieres 55: 349-358.

Kliger, I.R., Perstorper, M., Johansson, G. & Pellicane, P.J. 1995. Quality of timber products from Norway spruce. Part 3: Influence of spatial position and growth characteristics on bending stiffness and strength. Wood Science and Technology 29: 397-410.

Kollmann, F.P. & Cote, Jr, W.A. 1984. Principles of wood science and technology I, Solid Wood. Springer Verlag, 592 pp.

Olesen, P.O. 1976. The interrelation between basic density and ring width of Norway spruce. Det Forstlige Forsøgsvæsen i Danmark 34: 339-360.

SAS Institute Inc. 1995. Statistics and graphics guide. Version 3.1 of JMP. SAS Institute Inc., Carey, NC, USA. 593 pp.

Vestøl, G.I. 1998. Single-tree models of knot properties in Norway spruce (Picea abies (L.) Karst.) Agricultural University of Norway. Doctor scientarum thesis 1998: 34.

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