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Variation in Stem Properties in a IUFRO 1964/1968 *Picea abies* Provenance Experiment in Southern Sweden

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Abstract

79 provenances from 3 blocks in a 17-year-old IUFRO 1964/1968 *Picea abies* (L.) KARST. provenance trial in southern Sweden were chosen for special measurements. The provenances originated from 11 zones in eastern Europe and southern Scandinavia and belonged all to the most fast-growing half of provenances. Carpathian provenances had the highest stem volume and dry weight and harvest index. Provenances from the Baltic States and Belarus combine high growth, high basic density and low incidence of spike knots. Provenances from southern Scandinavia had rather thin branches and high wood density but very low stem volume. The zonal variation in root anchorage could be attributed to variation in tree size. Partial correlations eliminating effects of zones showed that stems with high volume had poor form, thick branches and low basic density but high harvest index.

Key words: basic density, dry-matter contents, harvest index, *Picea abies,* provenance variation, root anchorage, stem form, wood quality.

FDC: 232.12; 165.5; 811; 174.7 *Picea abies;* (485).

1. Introduction

Studies on genetic variation have much concentrated on survival and growth capacity. However, there may be many other factors important for the value of the wood produced, including factors influencing wood properties and the manifestation of growth capacity in stands. Some potentially important factors are focused in the present study.

Wood density is the major wood property of concern for both pulp wood and lumber, and could be expected to continue as such in future (ZOBEL and VAN BUIJTENEN, 1989). Basic density serves as a wood-quality index as it is highly correlated with pulp yield and wood strength. Low basic density results in high transport costs for a given quantity of biomass, as wood has low dry-matter contents but high moisture contents per volume. Low basic density is also a prerequisite for stem cracks to develop (PERSSON, 1994).

In provenance and progeny testing, growth differences are usually expressed in terms of volumes rather than dry biomass. For *Picea abies* (L.) KARST., basic density is negatively correlated with annual ring width (ELLIOT, 1970; OLESEN, 1976). Negative genetic correlations with basic density to diameter and height have also been found for *Picea abies* ($r_g = -0.56$: BIROT and NEPVEU, 1979). For other species, but far from all, the same pattern is found (see review by ZOBEL and VAN BUIJTENEN, 1989). Consequently, genetic improvement of exclusively for volume growth, or selection of fast-grown provenances, may have negative influence on wood density for *Picea abies*. This also means that a certain gain in volume may not reflect a corresponding gain in dry biomass.

The proportion of the total growth of a tree accounted for by stem growth (harvest index) is an important determinant for acreage productivity (DICKMANN, 1985). If competitive entries are favoured to entries that are able to use limited resources efficiently, yield may be much lower than expected (CANNELL, 1982). This is an obvious risk when using single-tree plots on provenance and progeny testing. Fast-growing provenances of *Picea abies* such as the eastern-continental ones are prone to develop thick branches. As stem growth also is rapid, branch to stem diameter ratio still tends to be low (PERSSON and PERSSON, 1992). Thus, it is not obvious that entries with thick branches also have low harvest index.

The commercial value of the wood produced is influenced by stem form and the occurrence of defects. PERSSON and PERSSON (1992) showed that Eastern-continental *Picea abies* provenances differed from other by having lower incidences of spike knots and double stems. This could be related to their high hardiness to spring frosts (SABOR, 1989; BALUT and SABOR, 1993), owing to late bud flushing (e.g. KRUTZSCH, 1975; PRESCHER, 1982).

The objectives of the present study was to quantify provenance variation in *Picea abies* for properties of potential importance for provenance recommendations – basic density, stem form, harvest index and mechanical stability. Correlations between these properties and stem volume were determined. For basic density, the radial and longitudinal variation was determined and related to diameter increment. The study was concentrated on provenances showing rapid height growth, all originating from eastern and northern Europe.

2. Materials and Methods

The provenance experiment in Abild (lat. 56° 57' N, long. 12° 44' E, alt. 65 m) is situated about 15 km from the Swedish west coast on abandoned farmland (*Fig. 1*). It is part of the IUFRO 1964/1968 provenance series with *Picea abies* and is one of originally 20 experiments planted in 13 countries (KRUTZSCH, 1974, 1992). The experiment was planted April 17 to 26, 1968 at 2 m spacings. The seedlings used were 2+2 bareroot seedlings grown in Schmalenbeck and after transplanting Pein & Pein nursery, both close to Hamburg, Germany (lat. 53° 42').

The set of provenances in the experimental series is very heterogenous, with seed lots being everything from collected from a single tree to commercial collections (KRUTZSCH, 1974). The altogether 1100 seed lots used were almost all collections made at the time of establishment and represent most of the species' European distribution. The provenances were subdivided into 11 blocks. Each block could be regarded as a separate trial, comprising 25 trees of 100 provenances planted with complete randomization in single-tree plots. In each block, provenances were chosen to represent the distribution of the whole set.

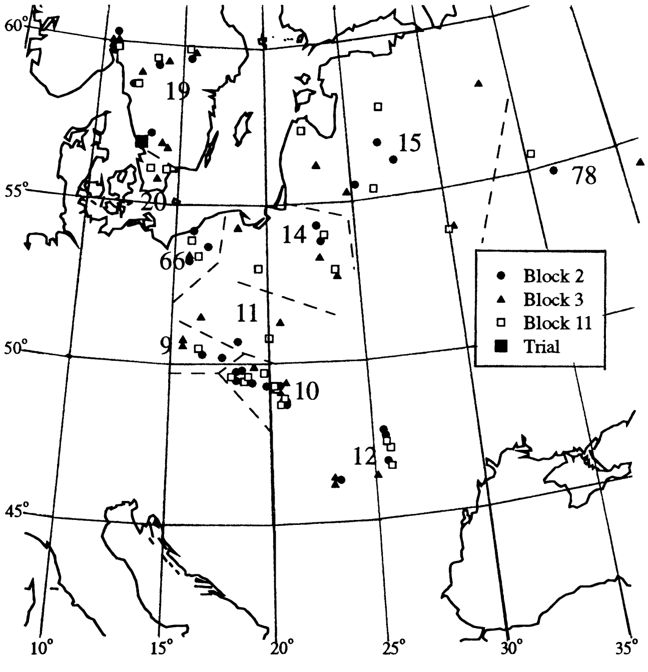

Fig. 1. – Location of the experimental site and the provenances selected. Each provenance was only planted in 1 block.

To illustrate the large-scale variation, the provenances were grouped into zones according to FOTTLAND and SKRØPPA (1989). The zones were the following (*Fig. 1*): 9. Sudeten, Beskids, 10. Tatra, 11. Lowlands of southern Poland, 12. Carpathians, 14. NE Poland, 15. Baltic States, Belarus, Pskov and Novgorod regions of Russia, 19. Southern Sweden (except Scania), Oslo region of Norway, 20. Scania, 66. Polish Pommarania, 78. Upper Volga. In the grouping of FOTTLAND and SKRØPPA (1989) zone 66 belonged to zone 1 which covers north-western continental lowlands and the provenances of zone 78 were not included in any zone.

The present study is based on assessments made at the first thinning in April to August 1984, i.e. at the 17th growing season after planting. The assessments were made on thinned trees in blocks No. 2, 3 and 11. About one third of the provenances in the blocks were chosen (*Fig. 1*), all representing the best half of provenances based on 11-year height (1978). The provenances chosen originate from eastern and northern Europe, whereas western-continental and alpine provenances were all discarded. Trees of the selected provenances were thinned systematically, removing every second. The following assessments were made on the sampled trees: (i) measuring fresh weight of stems and all above-ground parts for calculating harvest index, (ii) stem sectioning for determining volume, (iii) taking increment cores for determining basic density and stem biomass. In block 3 root anchorage was also assessed by static tree pulling using a winch.

Stems were cross calipered on the middle of every one-meter section. The apical residual was calipered on the middle. Stem volume under bark was estimated according to HUBER's formula (e.g. PHILIP, 1993). Stem form was described using the form quotient and artificial form factor, calculated according to:

Form quotient = $D60/D20$,

Form factor = $V_t/(g_{bh}\,H_t)$,

where D20 and D60 are diameters over bark at 20% and 60% of tree height. V_t and H_t are total stem volume under bark and tree height, respectively, and g_{bh} is cross sectional area at breast height.

Increment cores were taken at 25%, 50% and 75% of tree height. Cores were divided in sections of 5 annual rings from bark to pith. Basic density was determined using the mercury-immersion method (ERICSON, 1959). Basic-density level (basic density as function of ring width) was calculated separately for zones and heights within the stem using a model developed by OESEN (1976):

$R = a + b/(RW + c)$,

where R is basic density, RW is ring width, and a, b and c are positive constants. Basic density of a stem cross section was calculated by weighting basic densities of core sections against the area they represented. Mean basic density for the stem was determined by weighting basic density at 25%, 50% and 75% of tree height against the volumes of the 3 sections according to stem sectioning.

Tree pulling to assessing root anchorage was made according to HULTÉN and JANSSON (1978). Trees were pulled down by a wire that was attached to ground at a fixed angle. The horizontal component of the recorded traction force was determined. Torque for pulling trees 5° and 10° was recorded, as well as the force required to pull the tree over.

Additional data on branch thickness and frequencies of trees with double stems, double leaders, spike knots and stem cracks were available from assessments of all trees made in autumn 1983, 16 years from planting (PERSSON and PERSSON, 1992; PERSSON, 1994). For stem cracks only data from block 3 was used as the frequencies in the other 2 blocks were very low. Data on volume per stem under bark was also taken from these assessments to study the representativity of the later sampled trees. Stem volume was calculated from height, DBH and height to the live crown according to functions of BRANDEL (1990, function 390-02) and ANDERSSON (1954).

To decrease deviations from normal distribution, survival, form quotient, harvest index and frequencies of cracked stems, double stems, stems with double leaders and stems with spike knots were transformed by arcsine of the square root. Form factor and branch thickness data were converted to $\log_e$ values. In order to make data from different blocks comparable the following transformation was made:

$$y'_{ij} = \bar{\bar{y}}_{..}\, y_{ij} \;/\; \bar{y}_{i.}$$

where

y'_{ij} = transformed value for a performance variable,

y_{ij} = assessed value,

$\bar{y}_{i.}$ = block mean of sampled trees,

$\bar{\bar{y}}_{..}$ = mean of block means.

For analysis of variance the following model was used:

$$y'_{klm} = \mu + \tau_k + \beta_{l(k)} + \epsilon_{(kl)m}$$

where μ is general mean, τ_k is effect of zones (fixed), $\beta_{l(k)}$ is effect of provenances within zones (random), and $\varepsilon_{(kl)m}$ is random error. Analyses on survival and frequencies of cracked stems, double stems, double leaders and spike knots, respectively, were based on provenance means which means that provenance effects could not be studied. Total above ground stem weight was included as covariate in analysis of root anchorage to evaluate if there was any genetic variation not attributable to tree size. Pairwise comparisons of variation between zones was studied using TUKEY-KRAMER tests (DAY and QUINN, 1989).

Partial correlations were calculated, and effects of zones were eliminated by treating zones as indicator variables in a regression model. In partial correlations where stem volume was not involved, effects of stem volume was also eliminated.

Statistical analyses were performed with SAS programme package (Anon., 1987) on a personal computer.

3. Results

The trees analysed for this study represent a sample from the experimental site. *Table 1* shows how function-estimated stem volume under bark of the sampled trees deviated from provenance means and zonal means per block and over the whole experiment. The deviations are summarized per zone. The sampled trees were slightly shorter than average trees of the provenances and zones involved. The deviation was greatest for zones represented by fewer trees. Height at sectioning 1984 was generally lower than assessed previous year (*Table 1*) as it was measured from stump level. Height difference was greatest for zone 11.

F-ratios and significances from analysis of variance are given in *table 2*. No significant variation was found between provenances within zone for any of the studied variables.

Table 1. – Function-estimated stem volume under bark of sampled trees in block 2, 3, and 11 (V) relative to means of all trees of the provenances (V_P), zones in blocks 2, 3, 11 (V_Z), and zones in all 11 blocks (Z_{ZT}). Volumes calculated with functions (V) and by sectioning (V_S) were also compared. All figures are expressed as percentages.

Zone	No. trees	$100\Sigma\left(1-\frac{V}{V_P}\right)$	$100\Sigma\left(1-\frac{V}{V_Z}\right)$	$100\Sigma\left(1-\frac{V}{V_{ZT}}\right)$	$100\Sigma\left(1-\frac{V}{V_S}\right)$
1	53	4.3	-13.0	-18.6	2.0
9	132	-4.2	-4.1	-7.1	5.7
10	178	-4.0	-4.3	-2.3	8.3
11	39	10.4	10.6	15.8	9.4
12	84	0.6	-0.5	3.4	1.2
14	73	8.7	10.0	10.5	9.2
15	104	-3.4	-3.8	-0.3	9.9
78	31	-0.3	-0.3	4.8	7.6
19	145	9.8	9.6	-9.6	5.9
20	33	-13.7	-13.7	-1.9	-1.3
Σ	872	0.7	-0.4	0.8	6.4

Between zones there was significant variation for stem volume, basic density, stem dry weight amd harvest index. No significant variation could be stated for stem form or the variables where the calculations were based on provenance means (frequencies of spike knots and cracked stems).

Variation between zones is shown in *figure 2* and significances of pairwise TUKEY-KRAMER tests are shown in *table 2*. Zone 12, Carpathians, had the highest stem volume. Harvest index was superior, owing to high stem growth and moderately thick branches. Basic density for zone 12 and other southern zones tended to be low. Still, stem dry weight exceeded all other zones. The amount of cracked stems tended to be high. The local zone, 19, had poor growth but showed a tendency to high basic density and good stem form. Zone 15, Baltic States, Belarus and adjacent parts of Russia, was second to the Carpathians in volume and stem dry weight but tended to have better density and a lower incidence of spike knots and stem cracks.

Radial variation of basic density is shown in *figure 3* for 4 zones. Values on 5-ring segments from bark to pith were transformed to pith to bark curves to show effects of maturity of the cambium. As the most interior segments consisted of 1 to 4 rings, the curves are smoothed. Basic density was highest close to pith and decreased towards the bark. The peak at pith was most pronounced in the lower part of the tree. There were no major rank shifts between zones radially. For zone 12 the inferiority in the density tended to increase towards bark. There seems also to be zonal variation in basic density at a given ring width. The patterns were less clear in the upper part of the tree.

There was significant variation between zones in torque needed to pull trees through 5° or 10°, but zonal variation in the maximal torque needed to pull the tree over was not significant (*Table 3*). There was no significant provenance variation within zones. When above tree fresh weight was introduced as a covariate, zonal variation lost all significance. This suggests that the variation in root anchorage only was determined by zonal variation in tree size.

When effects of zones were eliminated, stem volume was positively correlated with branch thickness and harvest index but negatively correlated with basic density (*Table 4*). Large stems had poor stem form. Partial correlations where effects of zones and stem volume were eliminated showed that trees with thick branches had poor stem form and low harvest index. Harvest index and basic density showed no partial correlation.

Table 2. – Nested ANOVAs of effects of zones and provenances within zones, and pairwise comparisons of zones using TUKEY-KRAMER tests. Block effects were eliminated. Properties analysed were sectioned volume per stem under bark, volume weighted basic density, dry weight of stem wood under bark, form quotient under bark (D60/D20), form factor releated to cross sectional area at breast height, harvest index of aboveground parts on a fresh weight basis, diameter of the thickest branch over bark 1 m to 2 m above ground, and percentages of trees with spike knots or stem cracks. Significant differences between zones are shown by letters: zones having the same letter are not significantly different. Analysis of spike knots and cracked stems were based on provenance means. For other properties individual tree values were used. Stem cracks were only analysed in block 3.

Property	No. stems	F-ratio and significance		Zonal differences									
		Zone	P(Z)[1]	66	9	10	11	12	14	15	78	19	20
Volume stem^{-1}	872	4.52***	0.39^{NS}	AB	ABC	ABC	BC	A	ABC	ABC	ABC	C	ABC
Form quotient	814	1.39^{NS}	1.10^{NS}	A	A	A	A	A	A	A	A	A	A
Form factor bh	814	1.25^{NS}	1.05^{NS}	A	A	A	A	A	A	A	A	A	A
Basic density	840	2.73**	1.02^{NS}	A	AB	B	AB	B	AB	AB	AB	A	AB
Stem dry weight	840	4.40***	1.19^{NS}	A	AB	AB	B	A	AB	AB	AB	B	AB
Harvest index	846	6.04***	1.04^{NS}	ABC	AB	ABC	ABC	A	CD	BCD	D	ABCD	ABC
Branch thickness	871	2.04 *	1.07^{NS}	A	AB	AB	AB	AB	AB	AB	AB	B	AB
Stems with spike knots, %	95†	0.64^{NS}	-†	A	A	A	A	A	A	A	A	A	A
Cracked stems, %	33†‡	0.65^{NS}	-†	A	A	A	A	A	A	A	A	A	A

[1]) = Provenances within zones
†) = Analysis based on provenance means, provenance effects could not be evaluated
‡) = Only data from block 3 analysed

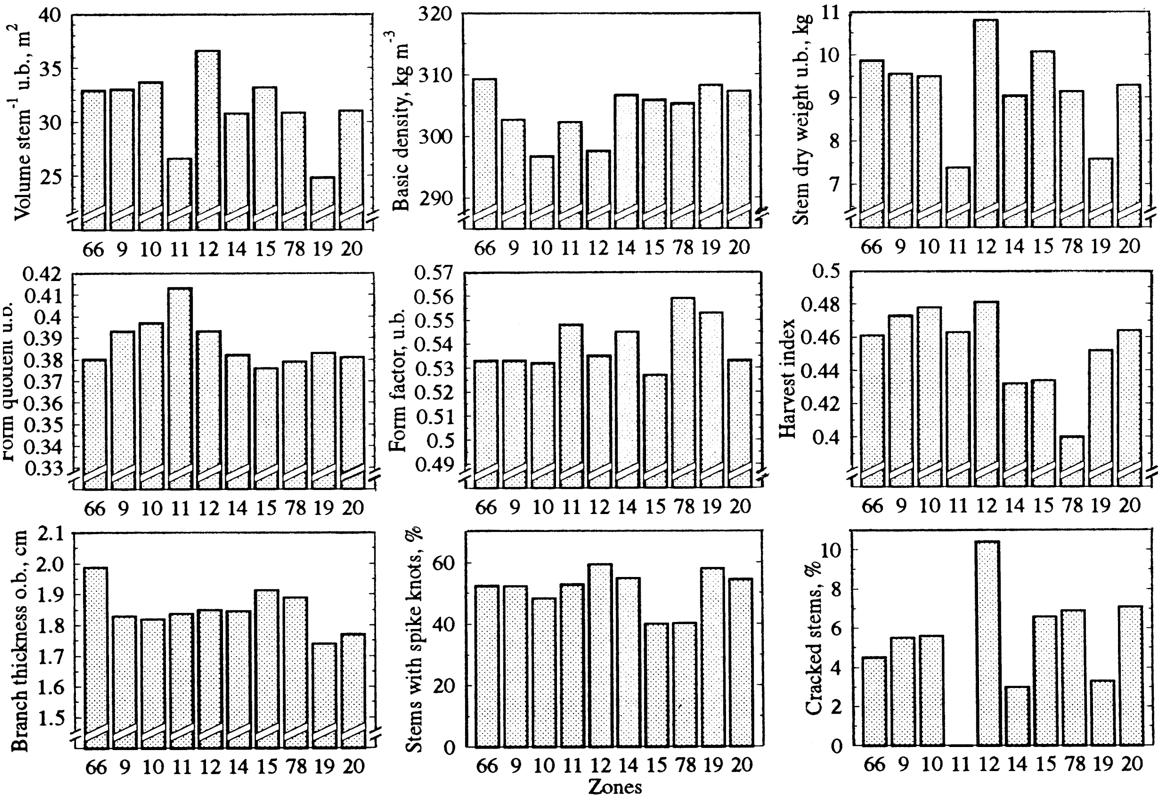

Fig. 2. – Mean performance of zones. Values were adjusted for block means before forming zonal means over blocks. Means of survival, cracked stems, double stems, double leaders and spike knots were based on provenance means, for other traits data on individual trees was used.

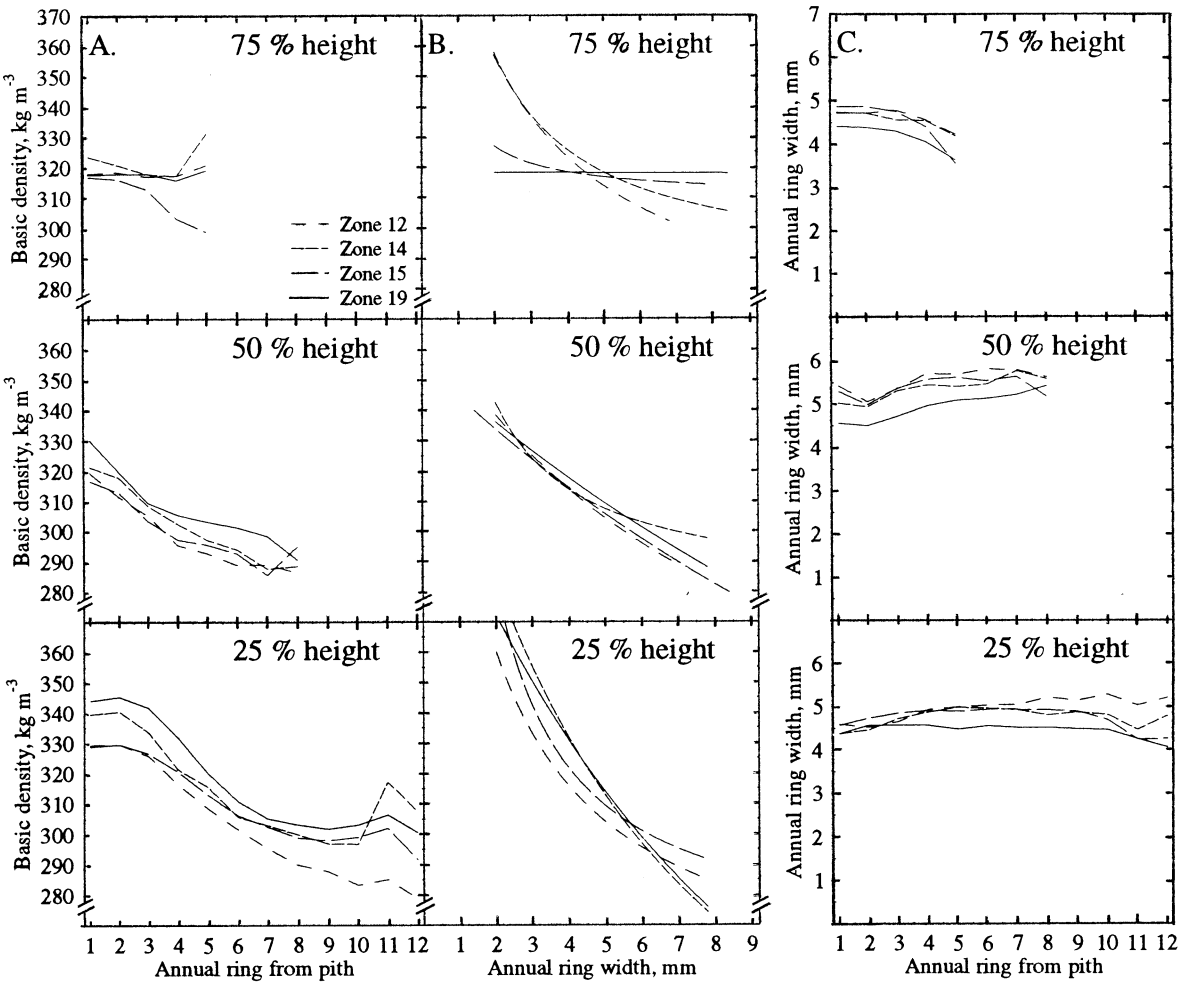

Fig. 3. – Longitudinal variation in basic density and annual ring width of zones N. 12, 14, 15 and 19. A. Variation of basic density radially from pith, B. basic density levels at various ring widths, C. radial variation in ring width.

4. Discussion

4.1 Validity and reliability of results

The Abild experiment is situated in a transition zone between coastal climate and the local-continental conditions at the central plateau of southern Sweden. Being situated on abandoned farm land, site quality is high. In part of the trial, including block 11, conditions are somewhat poorer. In block 11 mean height was 1 m shorter than in block 2 and 3, 16 years from planting (PERSSON and PERSSON, 1992). The experimental site has been exposed to severe spring frosts that predominately affected the early-flushing provenances. Autumn frosts have also affected, particularly in the year of planting when 80% of the seedlings were visibly damaged and almost 10%

Table 3. – F-ratios from analysed of variance and covariance of the torque for pulling trees 5° and 10° and maximal torque. In A. no covariate was uses, in B. total fresh weight of aboveground parts of the tree was covariate. 379 trees in block 3 were studied.

Torque	Zone	Provenance (Zone)	Total weight
A.			
T_{5°	1.96*	1.56^{NS}	-
T_{10°	2.23*	1.51^{NS}	-
T_{Max}	1.86^{NS}	1.44^{NS}	-
B.			
T_{5°	1.35^{NS}	0.74^{NS}	878***
T_{10°	1.08^{NS}	0.83^{NS}	749***
T_{Max}	0.93^{NS}	0.84^{NS}	733***

Table 4. – Partial correlations with volume stem^{-1} where effects of zones are eliminated and partial correlations of other variables eliminating effects of zones and volume stem^{-1}.

	Form quotient	Form factor	Branch thickness	Basic density	Harvest index
Volume stem^{-1}	-0.41^{A}	-0.42^{A}	0.40^{A}	-0.50^{A}	0.43^{A}
Form quotient		0.11	-0.19	-0.01^{NS}	0.24
Form factor			-0.20	0.16	-0.23
Branch thickness				-0.02^{NS}	-0.26
Basic density					-0.02^{NS}

$^{A)}$ = effects of stem volume not eliminated

$^{NS)}$ = not significant at the 5% level (all other correlations were significant at the 0,1% level) seemed to be dead (KRUTZSCH, 1974), although most of them survived and recovered (PERSSON and PERSSON, 1992).

Conditions on the site are representative of fertile sites in great parts of southern Sweden. Similar conditions could also be found in southern Norway and the Baltic States, as well as south of the Baltic although photoperiod would be quite different.

The experimental design with blocks having no common markers is a source of bias when comparing provenances in different blocks, particularly as growing conditions vary considerably within the trial. Block variance was reduced by transformation, but provenance-block interaction cannot be distinguished from random error variance. As pointed out by PERSSON and PERSSON (1992) this means that variation between adjacent provenances planted in different blocks is exaggerated, clinal patterns are less clear and zonal variation is less significant.

The trees sampled in our study represented just 4.5% of the number of trees, taken from 37% of the available provenances. The sampled trees seem to be representative since their mean volumes did not deviate much from provenance and zonal means (*Table 1*). The low number of trees per provenance does not permit any reliable conclusions of the magnitude of variation between provenances within zones. Still, the number of trees per zone was reasonable high, on average 88 stems (*Table 1*). That significant variation between zones was found only for a few properties was not primarily owing to a too small sample size, rather an effect of the experimental design and the limiting of the study to zones with high growth capacity. As shown in analyses of various traits in the whole experiment, only few incidences of significant variation was found in pairwise tests of the zones concerned and only small variation was found between provenances within zones (PERSSON and PERSSON, 1992).

4.2 Phenology

Late bud flushing means that damage of spring frosts could be avoided. In the Polish IUFRO 1964/1968 provenance experiment Krynica (lat. 49° 28', alt. 705 m to 795 m), the incidence of spring frost tolerance was clearly linked to timing of flushing (SABOR, 1989; BALUT and SABOR, 1993). However, late-flushing provenances are not more tolerant to frosts occuring after the onset of shoot elongation; they often have rather rapid growth once they started to elongate their shoots (KRUTZSCH, 1975; PRESCHER, 1982). In a nursery trial outside Uppsala, Sweden (lat. 59° 30') consisting of the seedlots of the IUFRO 1964/1968 provenance test, KRUTZSCH (1975) found that the latest flushing provenances originated from zones 12, 14 and 15. The same pattern was found in another Swedish nursery trial (PRESCHER, 1982), as well in many other studies (for review see SCHMIDT-VOGT, 1977). Provenances from Belarus were particularly late-flushing. As result the frequency of spike knots and other defects that could be associated with frost damage was low as shown by PERSSON and PERSSON (1992).

Winter hardening, as measured as timing of bud set, shows a latitudinal cline (KRUTZSCH, 1986, 1988). Compared with provenances from southern Sweden, Estonian provenances tend to be earlier, provenances from Belarus and Latvia are on average slightly later, whereas Slovakian and Romanian provenances were much later. At 2 Norwegian sites belonging to the IUFRO 1964/1968 series widespread winter injuries were observed that were attributed to poor winter hardening. The injuries followed the same pattern as the timing of bud set in KRUTZSCH's study, with Romanian provenances being most damaged (SKRØPPA and DIETRICHSON, 1986).

4.3 Basic density

The general tendency found in our study, that basic density was lowest for Romanian and Slowakian provenances, higher for north-east continental sources, and highest for provenances from southern Sweden, corresponds well with findings of ERICSON (1968) in Sweden and BLOUIN et al. (1994) in Quebec. Besides zonal variation, there was a strong negative partial correlation with stem volume (*Table 4*). Compared with the provenance variation for growth and yield properties, the variation in basic density was much lower. Thus, variation in stem dry weight corresponds well with the variation of stem volume and the ranking of zones were essentially similar for the 2 properties. Earlier studies agree that provenance variation in basic density is low. Some studies failed to find any variation at all (e.g. KNUDSEN, 1958). Conversly, other studies have found northern sources to have the lowest basic density (ERICSON, 1969; WORRALL, 1975). This contradicts our and other results showing a negative relationship between growth and basic density.

Basic density is determined by the proportion of cellwalls in the wood since the basic density of cellwalls is found to be essentially constant (TRENDELENBURG, 1939; SAARMAN, 1992). High correlation between basic density and cellwall thickness is also found (NICHOLLS, 1984; QUIRK, 1984). As cellwall thickness is higher in latewood than in earlywood, latewood content is important. Latewood is formed after termination of shoot growth (LARSON, 1969). According to WORRALL (1970), height growth is positively correlated with earlywood width but not correlated with latewood width. Latewood formation is more influenced by timing of radial growth cessation. Studies on *Picea abies* have shown that trees, clones and provenances with early bud flushing have low latewood contents and low basic density (MERGEN et al., 1964; WORRALL, 1970, 1975). Phenological variation accounted for up to 42% of the variation in basic density. Other studies found the opposite relationship between earliness and basic density (LACAZE and POLGE, 1970; THIERCELIN, 1970), or failed to find any clear correlation (BIROT and NEPVEU, 1979; NEPVEU and BIROT, 1979). The results seem to depend on which entries were studied. In the referred studies, there tended to be a negative relationship between basic density and growth capacity, regardless the time of flushing of the entries. Timing of flushing and growth cessation vary rather independently between entries. Whereas bud flushing is controlled by temperature, growth cessation is also controlled by photoperiod (e.g. HÄKKINEN and HARI, 1982; KOSKI and SIEVÄNEN, 1985; HÄNNINEN et al., 1990). Consequently, the same set of genetic entries could perform differently at different photoperiodic and temperature conditions.

In our study basic density was studied at a low age and the wood was entirely juvenile. According to DANBORG (1994), juvenile wood is produced in the first 10 annual rings. Basic density shows a decreasing trend in the juvenile zone, but there is great variation in basic density between years mainly due to weather conditions. *Figure 3* seems to confirm such a development. The smoothed appearance is caused by conversion of 5-ring segments from bark to pith to curves from pith to bark. To make early testing of basic density meaningful, high juvenile-mature correlations are needed. Density of zone 12 tends to decrease towards bark, but whether this implies a further deviation in the mature wood is not at all certain. In a 70-years old *Picea abies* provenance experiment, 64% of the whole tree basic density could be determined by the density in ring 1 to 15 and 53% by density in ring 1 to 9 (BLOUIN et al., 1994). High genetic correlation between densities of inner and outer wood was also found in grafts of *Picea abies* ($r_g = 0.90$: Birot and Nepveu, 1979). For other species high genetic correlations are shown between juvenile and mature wood of progenies (*Pinus taeda* $r_g = 0.9$: Loo et al., 1984; Williams and Megraw, 1994; *Pseudotsuga menziesii* $r_g > 0.8$: Vargas-Hernandez and Adams, 1992).

4.4 Stem cracks

Although no significant variation in stem crackings was found, there is a clear tendency toward higher degree of crackings in zones with rapid growth (*Fig. 2; Table 2*). The same tendency was found in earlier studies of the IUFRO 1964/1968 series (Dietrichson et al., 1985; Persson, 1994).

4.5 Harvest index, stem form and root anchorage

Harvest index was at the same level in comparable of Norway spruce of the same age (Pulkkinen et al., 1989); as age and competition increase, harvest index also tends to increase.

There seems to be no direct relationship between harvest index and stem growth at the zonal level (*Fig. 2*): Zone 12 had high and zone 15 comparably low harvest index, both having high stem volumes. This could indicate that zone 12 would be more superior in yield when grown in a homogenous stand than indicated from the zonal variation in stem volume found in our study. On the other hand, there was a positive correlation between harvest index and stem volume (*Table 4*). Fast-grown stems tend to develop thick branches and stems with thich branches tend to have low harvest index when size effects are eliminated (*Table 4*). The negative effects of thick branches seem to be compensated for by rapid growth. When measuring harvest index, the branch diameter/stem diameter ratio tends to be low for zones with thick stems (*Fig. 2*; Persson and Persson, 1992). It would have been more relevant to compare harvest index of entries at the same size, rather than at the same age.

It is not easily understood why harvest index has a positive partial correlation with form quotient but negative correlation with form factor (*Table 4*). On interpretation is that trees with low harvest index tend to be more tapered at the butts. Great taper variation in the lower part of the tree is probably the reason for the remarkably low partial correlation between form quotient and form factor (*Table 4*). It is not likely that the correlations at this young age will be persistent over the rotation since stem form will change substantially.

Root anchorage shows no significant zonal effects which could not be related to tree size (*Table 3*). Thus, spruce from zones with rapid growth are not more prone to be wind-thrown than other zones. Nielsen (1992) speculated than breeding for higher growth would lower root/shoot ratio and decrease wind stability. However, a comparizon of fine-branched pendula spruces and normal spruces (Pöykkö and Pulkkinen, 1990) found great differences in harvest index but no variation in root/shoot ratio.

4.6 Conclusions and recommendations

For basic density, stem properties and root anchorage the variation between zones was of lower magnitude than for stem volume. This implies that these properties are of secondary importance when choosing provenances. If the same conclusion is valid for breeding cannot be stated from our study. However, the correlations found indicate that breeding exclusively for growth may have detrimental effects on wood density, stem form and branch thickness, whereas harvest index may be improved (*Table 4*).

In some respect our results should have an impact on what provenance to choose. The low harvest index of north-eastern continental provenances (zone 14, 15, 78) could indicate that they will produce less wood than expected when grown in closed stands. Carpathian provenances (zone 12) may be avoided on fertile ground owing to low basic density. Particularly on abandoned farmland, low wood density is a severe problem. Lowering would be detrimental.

Earlier studies (e.g. Persson and Persson, 1992) have identified three alternative areas of origin for planting *Picea abies* in southern Scandinavia: south-eastern continental, north-eastern continental, and autochtonous provenances. In our study they are represented by zone 12, 15 and 19, respectively. From the Abild experiment the following characteristics of the zones are given. Zone 12 had excellent stem volume. The disadvantages of zone 12 were relatively poor basic density and a predisposition for stem cracking and spike knots. Zone 15 had higher basic density but also high volume growth. However, both stem volume and stem dry biomass was lower than for zone 12, a tendency which over the rotation could be reinforced by low harvest index. The low incidence of spike knots indicates that susceptibility to frost is low. The autochtonus zone 19 showed high basic density and a tendency to fine branches and good stem form. However, growth capacity was much inferior to the continental origins. Judged entirely from the results in the Abild trial, zone 12 is a competitive alternative. This is further confirmed in other adjacent trials (Ståhl, 1986; Wellendorf et al., 1986). In a compilation of the IUFRO 1964/1968 series, zone 12 was found to perform well in very diverse climatic conditions (Skrøppa et al., 1993). However, we recommend caution in a more widespread use of provenances from that zone, based on the findings of Skrøppa and Dietrichson (1986) and Ravensbeck (1991). The first study, commented on in 4.2, showed severe winter injuries in southern Norway on Carpathian provenances (zone 12) because of poor winter hardening. Ravensbeck found that in Denmark, where needle loss had been serious, Carpathian provenances were most damaged. These findings indicate that zone 12 would be a risk alternative in a northern maritime climate whereas the potential gain is limited. With an unpredictable climatic change to come, there are all reasons to avoid use of seed sources that are close to the limit of their adaptive range.

5. References

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