PROVENANCE VARIATION IN STEM WOOD BASIC DENSITY AND DRY MATTER FOR *PICEA ABIES* GROWN ON FARMLAND IN SOUTHERN SWEDEN

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ABSTRACT

In this study six Swedish, five Polish, two central European and three second generation central European Norway spruce (*Picea abies* (L.) Karst.) provenances grown on a former agricultural site in south-western Sweden were evaluated for basic density, basic density level and dry matter production. The Swedish provenances tended to have high basic density but low volume and dry matter production. The rankings of volume and dry matter were very similar and the variation was mainly explained by geographical zone of origins of provenances. The highest yielding provenances were from Poland but variation within in this group was large especially for basic density. Basic density and annual ring width were not affected by provenances within zones. Provenance was however a significant contributor to the variation in basic density level for which no zonal effect was detected. On fertile land there may be a point in selecting genotypes for which the density is less sensitive to a high growth rate.

Key words: *Picea abies*, basic density, basic density level, provenances, origins, annual ring width

INTRODUCTION

Provenance transfer has proven to be an efficient way to increase growth and yield of Norway spruce (*Picea abies* (L.) Karst.). Transferred provenances may produce 10–30 % more than the local provenance in Sweden (KRUTZSCH 1975a, PERSSON & PERSSON 1992). In Sweden south of lat. 60 °N North-eastern continental populations from Belarus and eastern Poland are recommended (WELLENDORF *et al.* 1986 and PERSSON & PERSSON 1992). Besides high growth capacity, those provenances have late bud flushing and may thus be less susceptible to late spring frosts (KRUTZSCH 1975b, PRESCHER 1982 and SABOR 1989) and have a lower incidence of spike knots and other defects (PERSSON & PERSSON 1992).

Basic density is related to several factors of interest for wood utilisation, e.g. strength of solid wood and pulp yield and quality. In Norway spruce, basic density and growth rate are negatively correlated (ELLIOT 1970, OLESEN 1976, and DANBORG 1994). Negative genetic and phenotypic correlations with basic density to diameter growth rate are also found among genetic entries. In the genus *Picea* this negative relationship is very general on all gentic levels and most pronounced in Norway spruce (review in ROZENBERG & CAHALAN 1997). Provenances with high basic density thus tend to have poor growth (ERICSON 1969 and WORRALL 1975, NEPVEU 1979). Basic density is also strongly genetically correlated to height (HYLEN 1997: $r_g = -0.68$). Of interest is also if different genetic entries yield different basic densities at a given annual ring width, i.e. basic density level, to make it possible to select entries that combine high basic density and growth rate. This has been examined using analysis of covariance by LARSEN *et al.* (1997) and ROZENBERG *et al.* (2001) in order to utilise it in genetic selection. Other strategies to handle the negative correlation in breeding are reviewed by ROZENBERG & CAHALAN (1997).

As an effect of the negative correlation between growth and basic density, yield differences between provenances could be expected to be substantially lower in terms of biomass than in volume. Selection of genetic entries with high growth capacity could have negative impact on basic density, resulting in weak lumber and poor pulp yield. However, earlier studies have shown that provenance variation in basic density of juvenile wood is rather low and do not influence the relative performance of provenances much (ERICSON 1968, BLOUIN *et al.* 1994 and PERSSON & PERSSON 1997). The difference in basic density between north-eastern continental and southern Swedish origins is only a few percent. Studies on older trees showed that provenance differences were greater in the butt log and decreased upwards (Anders Persson, unpublished). Two alternate interpretations of this is that provenance differences are greater in mature wood than in juvenile wood, or that provenance variation decreases once the stand was closed.

Very few unbiased estimates on biomass and volume yield variations between provenances has so far been made. Most genetic tests use single-tree plots, which means that the interaction between trees is not representative.

Possible negative effects of low basic density could be expected to be most prominent on very fertile sites, such as on abandoned farmland. NORÉN (1996) showed that basic density at a given ring width was not lower on farmland than on equally fertile forest land, but still very low. Since basic density is a major concern when considering the suitability of growing Norway spruce on abandoned farmland, choosing seed sources that are prone to develop low density may not be advisable. This is particularly true in cases where there are other factors that may contribute to low basic density, such as northern latitude (SARANPÄÄ 1993 and BJÖRKLUND 1984), high site quality and moist soil (OLESEN 1976, MADSEN *et al.* 1978 and MOLTESEN *et al.* 1985) or wide spacings (JOHANSSON 1993). Dominant trees may also be more prone to develop low basic density (JOHANSSON 1993, PAPE 1999).

The objectives of this study were to state whether there is a provenance variation in the diameter growth and basic density wood and biomass yield for Norway spruce grown on farmland in southern Sweden. The provenance variation in basic density level was also to be evaluated. The study was made in a provenance test belonging to a large experimental series laid out as a balanced lattice design established with 25-tree plots. This make yield studies possible and it is possible to discuss the representativity of the results.

MATERIAL AND METHODS

Site, seed source and experimental design

A provenance trial with Norway spruce situated on flat agricultural land in Östad, south-western Sweden (latitude 57° 56', longitude 5° 40', altitude 60 m) was used. The trial belongs to an experimental series established in 1969 with originally 23 provenance test

Table 1. Origin of provenances.

Reg No	Geographic location	Latitude, °N	Longitude, °E	Altitude, m
Sweden				
S 12	Fredros, Gunnarskog, County of Värmland	59°55'	12°37'	250
P 61	Fjällstjärn, County of Älvsborg	58°57'	12°19'	110
Bg 82	Härryda, County of Bohuslän	56°42'	12°18'	120
F 162	Unnaryd, County of Jönköping	56°58'	13°35'	165
G 121	Vevik V. Torsås County of Kronoberg	56°40'	14°38'	150
N 124	Dalagärde, Nösslinge, County of Halland	57°13'	12°38'	130
Western Continental Second Generation in Sweden				
E 175	Omberg, V. Tollstad, County of Östergötland	58°18'	14°40'	190
N 123	Nordanå, Våxtorp, County of Halland	56°22'	13°10'	80
M 329	Boserup, Risekatslösa, County of Scania	56°02'	12°56'	50
Western Continental				
Ty 108	Westerhof, Harz	51°45'	10°08'	170
Ty 109	Bayrischer Wald, Böhmerwald	49°00'	13°15'	1100
Poland				
Po 46	Zwierzyniec, Białowieza	52°40'	25°15'	160
Po 77	Bialystok, Białystok	52°40'	23°50'	120
Po 78	Przerwanki, Olsztyn	54°09'	22°08'	100
Po 1	Istebna, Kraków	49°35'	18°50'	700
Po 79	Zakopane, Kraków	49°18'	19°57'	850

sites of which two were written off, two were established in northern Sweden and 19 in Sweden south of latitude 60°N (WERNER & KARLSSON 1982). The trial comprised 16 provenances - six Swedish, three second generation western continental grown in southern Sweden, two western continental, three Polish north-eastern continental and two were from the Beskids Mts. in southern Poland (Table 1.) The seed was collected in 1964–1965 and sown in the spring of 1965. The seedlings were transplanted in 1967 and planted on the site in 1969. A 16 treatment balanced lattice design was used (COCHRAN & COX 1957), with eight blocks each consisting of sixteen 5 × 5 seedling plots to which the provenances were randomly assigned. The spacing was 2 × 2 m. The trial was thinned in 1993 leaving approximately 1500 stems· ha^{-1}.

Sampling and measurements

In 1981 all trees were measured for height and in 1991 all trees were callipered at breast height and a sample of trees were measured for height make it possible to estimate mean height and dominant height per plot. In the calculation of volume and dry matter yield, trees which had died before 1991 were ignored. Trees which had died between 1991 and 1995, or were thinned in 1993 were assigned heights and diameters according to a regression model derived from diameter and height data from 1995. Diameter and height increments up until 1993 were assumed to be half of the increments for the whole period and were modelled using diameter in 1991 as the independent variable. Separate models for different provenances did not improve the estimates why one single diameter model and one single height model was employed. Tree volumes were obtained using the models developed by NÄSLUND (1947).

A sample of increment cores for density assessment was taken in the spring of 1996 when also diameters and heights were measured. Three sample trees were chosen from each plot; one large, one medium sized and one small tree. Increment cores were taken from bark to pith at breast height (1.3 m.) at the western side of the trees.

Annual ring widths were measured on the cores, after which the cores were cut into segments of three annual rings from the cambium towards the pith. Basic densities of the segments were determined using the water displacement method (OLLSEN 1971).

Analyses

To evaluate large-scale variation, the provenances were grouped into zones according to origin. Owing to the limited number of provenances, the extensive zonal division suggested by FOTTLAND & SKRØPPA (1989) was not adopted. Instead a grouping of origins into just three zones was made: 1. Sweden, 2. Western continental (including second generation continentals grown in Sweden for one generation), and 3. Poland.

The basic density level model, the dependence of basic density on annual ring width, developed for Norway spruce by OLESEN (1976), has been used by several researchers to compare various treatment effects on density for a given ring width (PAPE 1999, JOHANSSON 1993, DANBORG 1994, and BROLIN & NORÉN 1993). The basic density level model was used to study the relationship between basic density (R) and ring width (RW) variation which is represented by the intercept in the model:

$$R = a + \frac{b}{RW + c}$$

where the intercept a expresses earlywood (minimum) density, b represents the difference between latewood and earlywood density, and c is set to 2 as suggested by DANBORG (1994). The model was fitted separately to each tree in order to avoid nonindependent observations and enable simultaneous analysis of different ring numbers from pith. The estimated parameters, a and b, were compared in a univariate analysis of variance using the model (1).

Densities of the stem crosscuts were estimated weighing the segment densities according to area. Whole stem-densities were then calculated from breast height values according to a formula described for Norway spruce in Finland (HAKKILA 1966). Similar parameter estimates has been obtained when fitting the equation to highly productive Swedish stands (PAPE 1999) why the original estimates were assumed to be reasonably valid also for this material. Stem volume and dry matter yields were estimated for each plot/block –provenance representation using all callipered trees on the plot including trees felled in thinnings and trees that had died. Biomass yield was determined as the product between stem volumes and densities.

The variations of basic density and ring width, as well as the parameters a and b in the basic density level equation were analysed using the following model:

$$Y_{ijklm} = m + j_i + t_j + b_k + d_{l(k)} + jd_{il(k)} + td_{jl(k)} + e_{(ijkl)m} \quad [1]$$

where Y_{ijklm} is the dependent variable, basic density or ring width, m is the overall mean j_i is block (fixed effect), t_j is tree size class (fixed effect), b_k is zone (fixed), $d_{l(k)}$ is provenance within zone (random) and $e_{(ijklm)n}$ is random error. To analyse variation between segments a repeated measures analysis of variance was performed using segment number from pith as a repeated measure. SAS statistical program package, ver. 6.11, PROC GLM was used in the analysis (ANONYMOUS 1996).

Tree volume and dry matter values were summed up for each block and provenance combination thus forming one value per plot. A univariate analysis of variance of the stem dry matter and volume was performed using the model:

$$Y_{klm} = m + j_i + b_k + d_{l(k)} + e_{(kl)m} \quad [2]$$

RESULTS

Density and annual ring width

The range in area weighted density between different provenances was ca 20 kgm^{-3} (Table 2). Swedish provenances tended to have higher densities than Western continental, whereas the density of the Polish provenances was low but varied much. In the mature wood the range was ca 40 kgm^{-3} and the largest variation was found within the Western continental group. The repeated measures test of density is shown in Table 2a. No interaction effects were significant why the model (1) was run without interaction factors. The corresponding analysis of ring width is shown in Table 2b. The trend is similar for both variables; the effects of block and zone are significant whereas the model fails to detect any effect on the provenance level. The development of basic density and annual ring width by zone is shown in Figure 3.

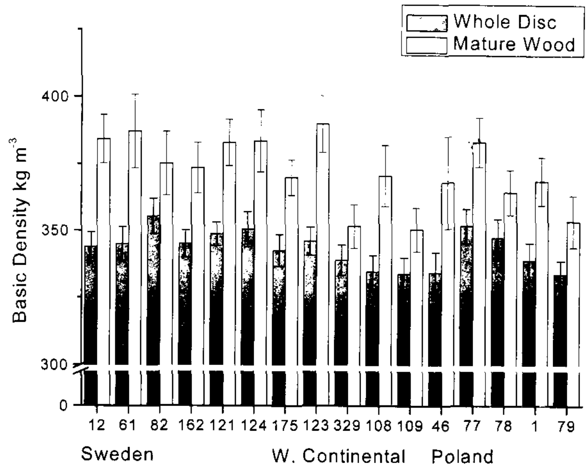

Figure 1. Area weighted basic density, means per provenance, standard errors are shown. Empty bar – mature wood, dark bar – whole disc.

Table 2. Area weighted basic density (kgm^{-3}) and ring width (mm), means per provenance, standard errors inside brackets (N = 24)

Provenance	Whole disc				Mature wood (Ring no from pith≥ 18)			
	Basic density		Ring width		Basic density		Ring width	
Sweden								
S 12	343.9	(5.40)	3.47	(0.12)	384.3	(9.01)	2.17	(0.13)
P 61	345.0	(6.35)	3.53	(0.19)	387.2	(13.74)	1.98	(0.16)
Bg 82	355.4	(6.59)	3.27	(0.12)	375.1	(11.95)	2.14	(0.14)
F 162	345.1	(5.13)	3.49	(0.12)	373.5	(9.47)	2.09	(0.14)
G 121	348.7	(4.42)	3.58	(0.18)	383.0	(8.65)	2.56	(0.19)
N 124	350.5	(6.59)	3.28	(0.13)	383.6	(11.61)	2.15	(0.14)
Western Continental								
E 175	342.5	(5.95)	3.55	(0.13)	369.9	(6.66)	2.41	(0.11)
N 123	346.0	(5.27)	3.42	(0.16)	389.9	(10.61)	2.17	(0.14)
M 329	338.9	(5.71)	3.81	(0.19)	351.6	(8.20)	2.89	(0.26)
Ty 108	334.5	(6.10)	3.51	(0.14)	370.6	(11.44)	2.39	(0.21)
Ty 109	333.7	(6.19)	3.70	(0.16)	350.4	(8.19)	2.64	(0.19)
Poland								
Po 46	334.2	(7.69)	3.64	(0.15)	368.0	(17.30)	2.54	(0.17)
Po 77	351.7	(6.43)	3.41	(0.14)	383.1	(9.22)	2.19	(0.12)
Po 78	347.2	(7.07)	3.44	(0.16)	364.3	(8.44)	2.52	(0.20)
Po 1	333.6	(5.08)	3.70	(0.14)	353.4	(9.71)	2.46	(0.14)
Po 79	338.7	(6.67)	3.56	(0.14)	368.5	(9.00)	2.41	(0.21)

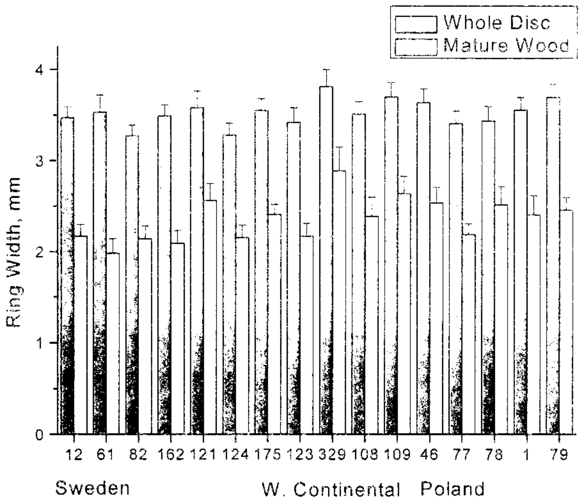

Figure 2. Annual ring width, means per provenance, standard errors are shown. Empty bar – mature wood, dark bar – whole disc.

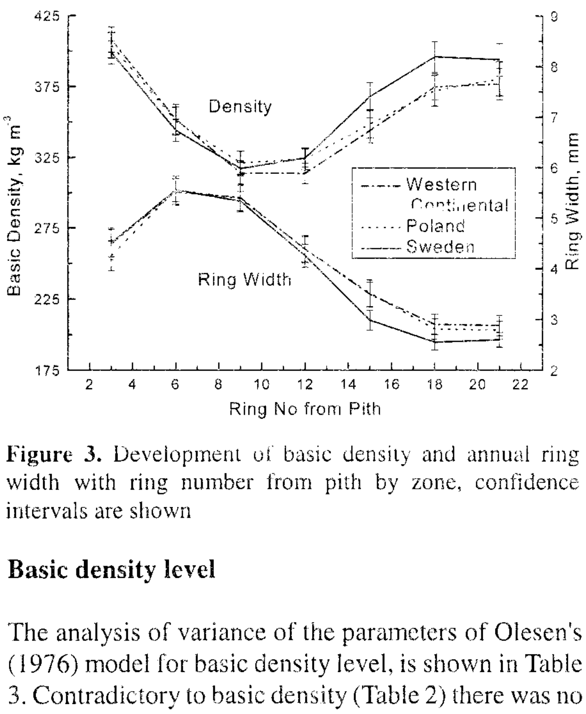

Figure 3. Development of basic density and annual ring width with ring number from pith by zone, confidence intervals are shown

Basic density level

The analysis of variance of the parameters of Olesen's (1976) model for basic density level, is shown in Table 3. Contradictory to basic density (Table 2) there was no significant zonal variation but significant provenance variation within zones. The R-squares of the model varied between 1 and 94 % with the bulk of the values around 40 %. The residuals of the models were studied and no correlation to ring number from pith or other discrepancies were detected. The basic density levels, for the different provenances are shown in Figure 4.

Volume and dry matter

The analysis of variance (Table 4a and b) showed significant variation between blocks as well as between zones, but no significant variation between provenances within zones was proven. For both the western continental and the Polish zones, all provenances except one had higher volume and biomass yield than any of the Swedish provenances. The ranking of provenances was very similar for volume and stem biomass yield (Figures 5 and 6).

DISCUSSION

Abandoned farmland is usually more fertile than farmland, but often frost prone. The seedlings and trees should be able to utilise the good growing conditions without risking to suffer from frost injury. It is therefore essential to choose suitable genetic entries or provenances. Compared to other trials in the series, the tree growth was fast and there was a rather high frequency of trees injured by frost (WERNER & KARLSSON 1982). As a provenance test the trial is very decisive. The experiment is laid out on both sides of a small stream and there are moist patches which are probably very frost prone. Growth tended to be somewhat lower in blocks close to the stream but there were no apparent trends in mortality between the blocks. The block effect was large for basic density and ring width and moderate for basic density level and for volume and dry matter yield.

The trees were sampled according to their social position (small medium large) within the stand. This sampling is not ideal for analysing variations in growth rate (annual ring width).

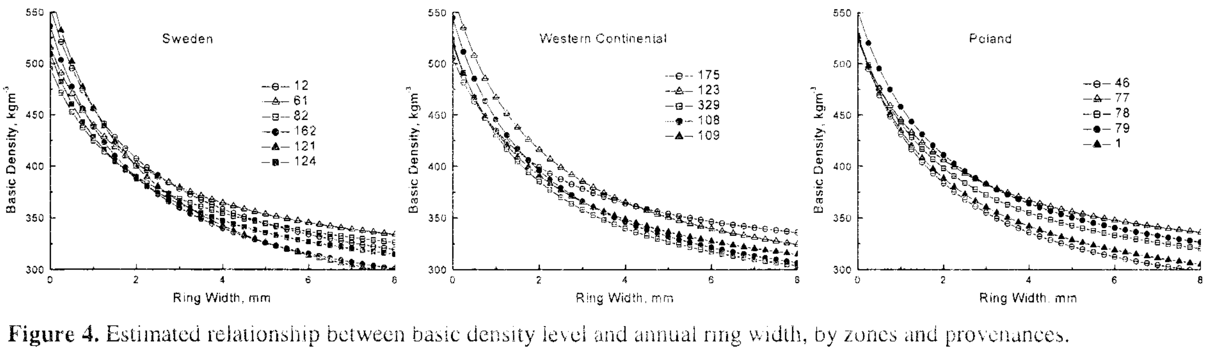

Figure 4. Estimated relationship between basic density level and annual ring width, by zones and provenances.

Table 3. Repeated measures analysis of variance of basic density and annual ring width.

Source	a, Basic density (kgm^{-3})			b, Annual ring width (mm)		
	df	MS	F-value	df	MS	F-value
Zone	2	23890	5.15**	2	11.26	8.30***
Block	7	15252	3.29**	7	10.29	7.59***
Tree Size Class	2	200954	43.3***	2	333.34	245.***
Provenance (Zone)	13	3930	0.85^{NS}	13	2.11	1.56^{NS}
Error	304	4641		306	1.36	

Table 4. Basic density level, analysis of variance of intercept a, and parameter, b.

Source	a, parameter a, intercept			b, parameter b		
	df	MS	F-value	df	MS	F-value
Zone	2	134	0.04^{NS}	2	30030	0.33^{NS}
Tree Size Class	2	2209	0.58^{NS}	2	10585	0.12^{NS}
Block	7	9325	2.46*	7	191787	2.09*
Provenance (Zone)	13	10218	2.70**	13	252142	2.75**
Provenance (Zone)*Size	30	5362	1.42^{NS}	30	116436	1.27^{NS}
Provenance (Zone)*Block	105	5282	1.39*	105	140297	1.53**
Error	219	3786		219	91732	

Table 5. Analysis of variance of stem volume and stem dry matter.

Source	df	a, Stem volume (m^3)		b, Stem dry matter (kg)	
		MS	F-value	MS	F-value
Zone	2	1609.30	2.56**	163.67	4.76*
Block	7	642.85	2.22*	81.35	2.37*
Provenance (Zone)	13	366.86	1.27^{NS}	42.35	1.23^{NS}
Error	105	289.67		34.37	

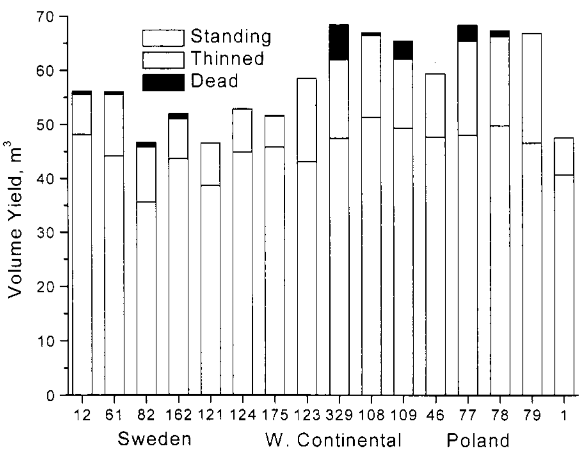

Figure 5. Stem volume production by provenance.

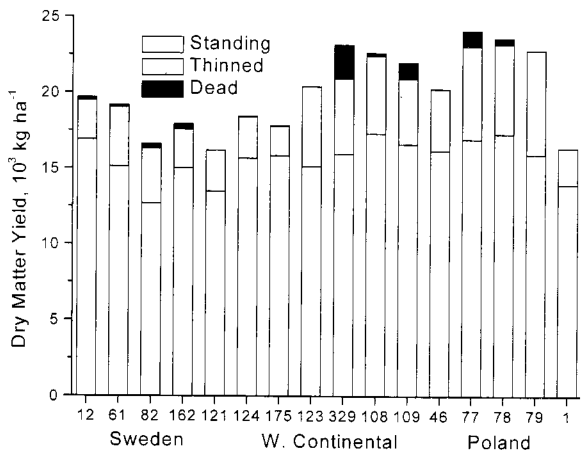

Figure 6. Production of dry matter by provenance

The main findings that zones influence the basic density and volume growth but that effects of provenances within zones are harder to detect (Table 2). agrees well with previous findings for Norway spruce in Sweden (PERSSON & PERSSON 1997) and Quebec, Canada (BLOUIN *et al,* 1994). In a trial in Norway comprising two sites, provenance was significantly influencing basic density on one site but not on the other (HYLEN, 1996). Significant differences between the density of provenances has been found by BUJOLD *et al.* (1996) and NEPVEU (1984). Most researchers seems to agree that the variation between genotypes is far greater than differences between provenances (e.g. BLOUIN *et al,* 1994 and NEPVEU 1984). The high standard errors in Figure 1 might support this conclusion.

In general, Swedish provenances had high density but low volume and dry matter production, the western continental and the Polish had low density and high volume and dry matter yield. The variation between provenances within each zone varied more particularly regarding density. For basic density level, generalisations about the zonal variation is more difficult to make as the density level varied widely within the geographical zones.

For southern Sweden, north-eastern continental provenance are recommended and plus-tree selections are also made within those provenances. In the present study, the provenances Po 46, Po 77 and Po 78 are of north-eastern continental origin. The two latter are have the highest volume yield of all provenances and among the highest basic densities. Thus, there seems to be no obvious risk for deteriorating basic density by selecting such origins instead of local ones. The same conclusion was stated by PERSSON & PERSSON (1997). There may be phenological explanations to this apparently correlation-breaking behaviour, linked to the late bud flushing of eastern-continental origins. However, there are very contradictory results concerning the relationship between flushing and basic density.

Another interesting aspect concerning the eastern continental origins is that they tend to have less variation in basic density between juvenile and mature wood than other zones (Figure 3).

The Polish provenance Po 1 from Istebna has a lower volume production compared with the other Polish provenances. In the whole series this provenance has lower mean height and higher frequency of fost damage and spike knots than other eastern continental provenances (WERNER & KARLSSON 1992). Also in Östad the Istebna provenance was the most injured and also had the lowest height 12 years after planting . In contrast, the provenances from north-eastern Poland were the least frost injured and had the fastest seedling height growth. In an older provenance series the Istebna provenance performed well at less frost prone site close to Stockholm (lat. 59°) but was not hardy enough at lat. 64° (KRUTZSCH 1975b). The Istebna provenance is one of the most southerly ones in the trials and compared to Po 79 from Zakopane and Ty 109 it originates from lower altitude. Provenances from southern Poland are not recommended for the area where Östad is situated.

This study goes up to the 21st annual ring from the pith and hence concerns mainly juvenile wood. Rankings and general comparative results should however be valid as there is a correlation between juvenile and mature wood for Norway spruce (e.g. BLOUIN *et al.* 1994 and ROZENBERG & CAHALAN 1997). The variation between trees in mature wood can however be expected to be somewhat greater (ZOBEL & VAN BUIJTENEN 1989).

In contrast to basic density and annual ring width there was significant variation between provenance within zone on the intercept basic density level whereas no variation between zones was significant. The intercept a in the basic density level equation can be regarded as the density of an indefinitely wide annual ring. It may be interpreted as minimum density or earlywood basic density (OLESEN 1976). Provenances with high basic density level may therefore have more homogeneous density than provenances with lower values of a. Moreover, a seed source with lower value of b may be less sensitive to higher growth rates as far as density is concerned. For selection purposes it may be worth checking the basic density level ranking of the different provenances in conjunction with selection for e.g. volume production, particularly for sites were high growth rates are expected.

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