Comparison of Height Growth of Two *Picea abies* Provenances from Estonia and Belarus

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Abstract

This study was carried out to compare the growth of Norway spruce provenance from Estonia (Järvselja) with the growth of provenance from Belarus (Vitebsk Braslav). There was a significant difference between tree height growth of Estonian and Belarus provenance. The average height of Norway spruce of Belarus provenance exceeded the Estonian provenance in average 22.8 cm, 34.7 cm and 48.0 cm, respectively at age 9, 10 and 11 years. Along with the generalized additive mixed model the annual height growth was 3.22 cm greater for Belarus provenance compared to Estonian provenance. Based on the results of this study the northern regions of Belarus are suitable for Norway spruce seed transfer to Estonia.

Key words: Belarus, height growth, *Picea abies*, provenance

Introduction

Norway spruce (*Picea abies* (L.) Karst.) is *economically* a valuable tree species in boreal and temperate regions. Its timber is valuable for the local forest industry. To increase the productivity of Norway spruce stands it is important to select proper regeneration and soil preparation method (Miina and Saksa 2013) and to pay more attention on the planting material used in forest regeneration (Kļaviņa et al. 2013). Using high quality seedlings for forest regeneration helps to increase the growth rate and to maximise wood production of the established stand. Regeneration works can be performed with the trees of local provenance or with the trees of transferred provenances, which are expected to give higher productivity (Hannerz and Westin 2005). Several Norway spruce provenance trials have been established and are given high priority in Baltic states, where the species is planted on a large scale (Gailis 1993, Danusevičius 1996, Baliuckas et al. 2004).

Norway spruce (*Picea abies* (L.) Karst.) is genetically diverse (Goncharenko et al. 2005, Areškevičienė et al. 2005) and morphologically variable coniferous tree species (Metslaid et al. 2005, 2007), and plastic species when transferred to other geographical regions. It has been concluded that in certain regions a southwards transfer leads to a loss while a northwards transfer favours its growth (König 2005). Several Scandinavian trials have shown that Norway spruce provenances from the southern regions often grow faster than the local provenances (Liesebach et al. 2001, Langvall 2011). When transferred northwards Norway spruce provenances start growth later in spring, which reduces the risk for late spring and early summer frost damage in plantations and in open areas, and cease growth later in autumn, which results in increased productivity compared with the local provenances (Morgenstern 1996, Danusevičius and Gabrilavičius 2001).

However, the gain in productivity achieved by the use of north-transferred provenances is accompanied by delays in shoot growth cessation and increased risk of autumn frost damage (Morgenstern 1996, Hannerz and Westin 2005). Late frosts cause a loss of buds or young shoots and also stem defects, which result in quality losses (König 2005). Hannerz (1994) reported that Norway spruce seedlings from central Sweden had to sustain almost twice as many frost occasions than seedlings from Belarus, when planted in central and southern Sweden.

In Estonia, provenance trials of Norway spruce have been established since 1970 (Etverk 1990). The main aim was to identify provenances that would be suitable to introduce and to use in Estonian conditions, and to investigate breeding material of different origin. In the beginning of the 2000s 4-year-old seedlings that were grown from seeds of Belarus origin were imported on a large scale from Swedish nurseries.

The main objective of this study was to compare the growth of Norway spruce provenance from Estonia (Järvselja) with that from Belarus (Vitebsk Braslav). We studied a Norway spruce provenance trial that included seedlings of the local Estonian provenance and provenance from Belarus. We hypothesized that the north-transferred Belarus provenance show greater height growth compared to the local Estonian provenance.

Materials and Methods

Järvselja, situated in the south-eastern part of Estonia in Tartu county near Lake Peipus, belongs to a hemiboreal zone with a moderately cool and moist climate. The average annual temperature is 4 6 ºC. The annual precipitation is between 500 mm and 750 mm, of which about 40 80 mm falls as snow. The active period of vegetation growth (daily air temperature above 5 ºC) mostly lasts between 170 and 180 days per year.

On May 2, 2002 sample plot with a total size of 0.9 ha was established in Järvselja Training and Experimental Forest Center of Estonian University of Life Sciences (compartment JS273). The experiment was established on a clearfelled area cut in winter 2001/2002. The size of the clear-cut was 2.1 ha. The site type is *Myrtillus* (by Lõhmus 2004) and the site index of previous stand was bonitet class 3, which corresponds to sites of average fertility in Estonia. The main canopy (determined by basal area) consisted of 65% Norway spruce (*Picea abies* (L.) Karst.), 30% silver birch (*Betula pendula* Roth) and 5% Scots pine (*Pinus sylvestris* L.). The volume of the stand before clear-cutting was 287 m^3 ha^{-1}.

The experiment was designed to compare the growth of Norway spruce seedlings, which seeds were originated from Belarus (Vitebsk Braslav) and grown in Swedish nursery with growth of seedlings of the local Estonian (Järvselja) origin (Table 1). The experiment was established with three replicates, altogether six sample squares. In each sample square 4-year-old Norway spruce seedlings were planted in nine rows (10 seedlings in each row). The distance between rows was 1.8 m and the distance between seedlings in rows was 2 m. The length of sample squares was 21 m and width 17 m, so the area of the sample squares was 357 m^2. Initial distribution of seedlings' height is shown in Figure 1.

Table 1. Geographic origin of the seed sources

Provenance	Latitude N	Longitude E	Elevation m a.s.l.	Type of basic material
Vitebsk Braslav, Belarus	55°40'	27°05'	200	Seed collection area
Järvselja, Estonia	58°17'	27°17'	50	Seed collection area

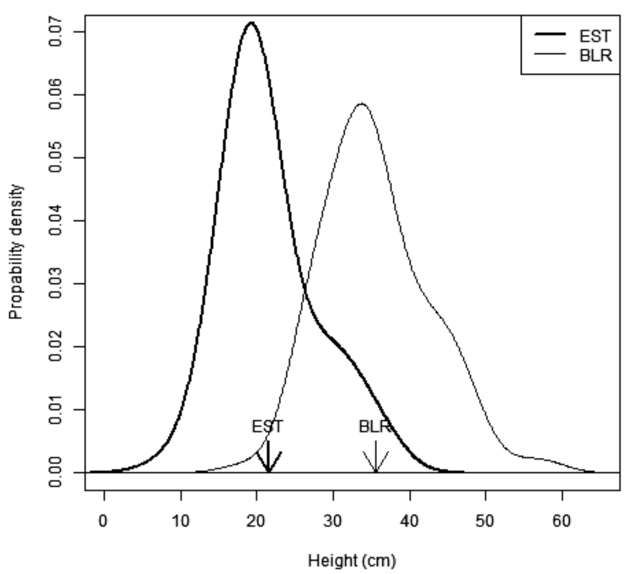

Figure 1. Probability density functions of initial seedling height by provenance (EST – Estonia, BLR – Belarus). Mean seedling heights are indicated with arrows

One year after the planting height and last year's height growth of all trees in the experiment was measured with measuring rod. Further, the heights and height growth of all trees in the experiment were measured in 2006, 2007 and 2008. Summary statistics of tree height by provenance and measurement year is presented in Table 2. Figure 2 shows tree mean height with standard error by provenance and biological age.

Table 2. Summary statistics of tree height by provenance and measurement year

Provenance	Year	Mean ± SE	Min	Max	SD
Järvselja, Estonia	2002*	21.6 ± 0.55	7	38	6.1
	2006	114.3 ± 3.00	25	280	43.0
	2007	151.2 ± 3.73	42	343	53.4
	2008	193.9 ± 4.67	58	400	66.9
Vitebsk Braslav, Belarus	2002*	35.5 ± 0.63	18	58	7.0
	2006	137.1 ± 3.46	25	294	49.5
	2007	186.0 ± 4.65	28	385	66.6
	2008	241.9 ± 5.78	42	470	82.8

*Initial seedling height

Effect of provenance and calendar year on spruce height (h) was studied using a linear mixed model:

$$h_{ijkl} = \beta_0 + \beta_i + \beta_j + \alpha_{k(i)} + \alpha_{l(k(i))} + \varepsilon_{ijkl} \quad (1)$$

where: β_0 is the fixed intercept (height of seedlings of Estonian provenance in 2006); β_i is main effect of provenance (Estonia or Belarus); β_j is main effect of year (2006, 2007 or 2008); $\alpha_{k(i)}$ is a random effect of

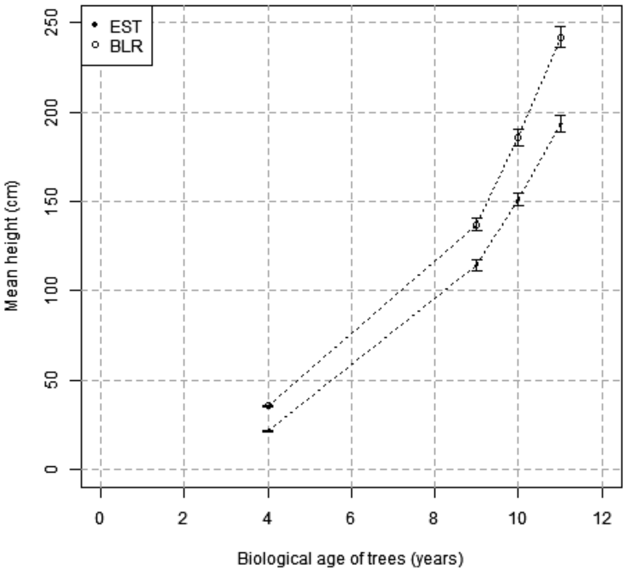

Figure 2. Norway spruce mean height with standard error by provenance and biological age

block nested within provenance, and $\alpha_{l(k(i))}$ is a random effect of tree nested within block having normal distribution with mean zero and variances $\sigma^2_{k(i)}$ and $\sigma^2_{l(k(i))}$, respectively.

The error term, ε_{ijkl}, is assumed to have a normal distribution with mean zero and variance, σ^2_{ijkl}.

Annual height growth (*ih*) of trees was modelled with generalized additive mixed model (GAMM) (Wood 2006) as follows:

$$ih_{ijkl} = \beta_0 + \beta_i + \beta_j + f(h_l) + \alpha_{k(i)} + \alpha_{l(k(i))} + \varepsilon_{ijkl} \quad (2)$$

where: β_0 is the fixed intercept; β_i is effect of provenance; β_j is effect of year; $f(h_l)$ is nonlinear modifier as a function of tree height, h_l; $\alpha_{k(i)}$ is a random effect of block nested within provenance, and $\alpha_{l(k(i))}$ is a random effect of tree nested within block having normal distribution with mean zero and variances $\sigma^2_{k(i)}$ and $\sigma^2_{l(k(i))}$.

The error term, ε_{ijkl}, is assumed to have a normal distribution with mean zero and variance, σ^2_{ijkl}.

Statistical calculations were carried out using packages nlme and mgcv with R software (R Core Team 2014).

Results

The average height of Norway spruce of Belarus provenance exceeded the Estonian provenance in average 22.8 cm, 34.7 cm and 48.0 cm, respectively in 2006, 2007 and 2008 (Table 2, Figure 3). However, the linear mixed model (Equation 1) found the difference between tree height of Estonian and Belarus provenance insignificant (P = 0.17). Statistical characteristics of the linear mixed model (Equation 1) of tree height are presented in Table 2. Figure 3 shows Norway spruce mean height by block and measurement year. The Estonian provenance had lower height values in all blocks in the same year except block 1, where the Estonian provenance showed similar height values with two Belarus blocks, which had lower height values.

Results of the annual height growth model (Equation 2) are presented in Table 4 and Figure 4. The height growth model describes 70 % of the height growth variance. According to the model the annual

Table 3. Statistical characteristics of the linear mixed model (Equation 1) of tree height, h_{ijkl} *(m)*

Coefficient	Estimate	SE	*t*-value	*p*-value
Fixed effects				
Intercept β_0	111.5	13.7	8.14	<0.0001
Country β_i (BLR)	32.0	19.3	1.66	0.1728
Year β_j(2007)	42.9	1.36	31.5	<0.0001
Year β_j(2008)	92.2	1.36	67.7	<0.0001
Variance components:				
$\sigma^2_{k(i)}$	511	22.6		
$\sigma^2_{l(k(i))}$	3150	56.1		
σ^2_{ijkl}	380	19.5		
Observations	1230			

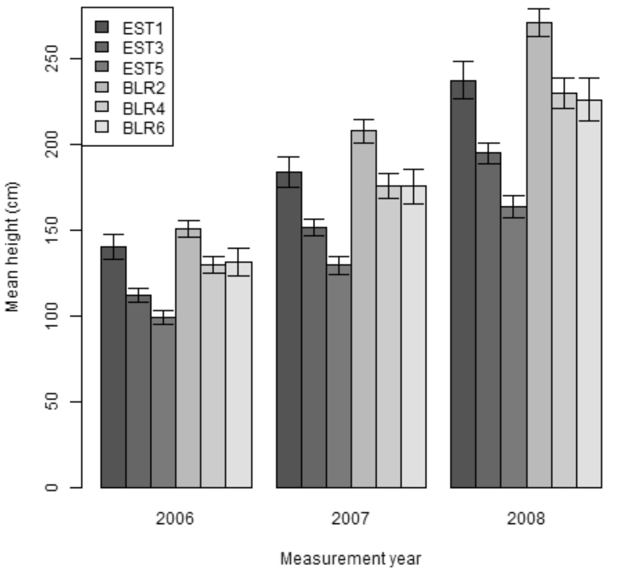

Figure 3. Norway spruce mean height with standard error by block and measurement year

height growth of trees predicted for same height was 3.22 cm greater for the Belarus provenance compared to the Estonian one.

Table 4. Statistical characteristics of generalized additive mixed model (Equation 2) of annual height growth, *ih (m)*

Coefficient	Estimate	SE	*t*-value	*p*-value
Fixed effects				
Intercept β_0	46.90	0.79	59.4	<0.0001
Country β_i(BLR)	3.22	1.01	3.20	<0.0328
Year β_j(2008)	-4.79	0.61	-7.83	<0.0001
$f(h_k)$	13.57	3.24	4.177	<0.0001
Variance components				
$\sigma^2_{k(i)}$	7.6e-07	8.7e-04		
$\sigma^2_{l(k(i))}$	66.72	8.17		
σ^2_{ijkl}	52.74	7.26		
Observations	820			

Table 5. Survival of Norway spruce provenances by blocks in observed period

Provenance	Number of seedlings in the year 2008	Initial number of seedlings in the establishment year	Survival, %
I Järvselja, Estonia	57	90	63
II Vitebsk Braslav, Belarus	74	90	82
III Järvselja, Estonia	87	90	97
IV Vitebsk Braslav, Belarus	86	90	96
V Järvselja, Estonia	84	90	93
VI Vitebsk Braslav, Belarus	68	90	76

Discussion and Conclusions

In present study the Belarus provenance showed greater height growth values compared with the local Estonian one. The northwards transferred Belarus provenance had higher height values in all sample squares except square 1, where the Estonian prove-

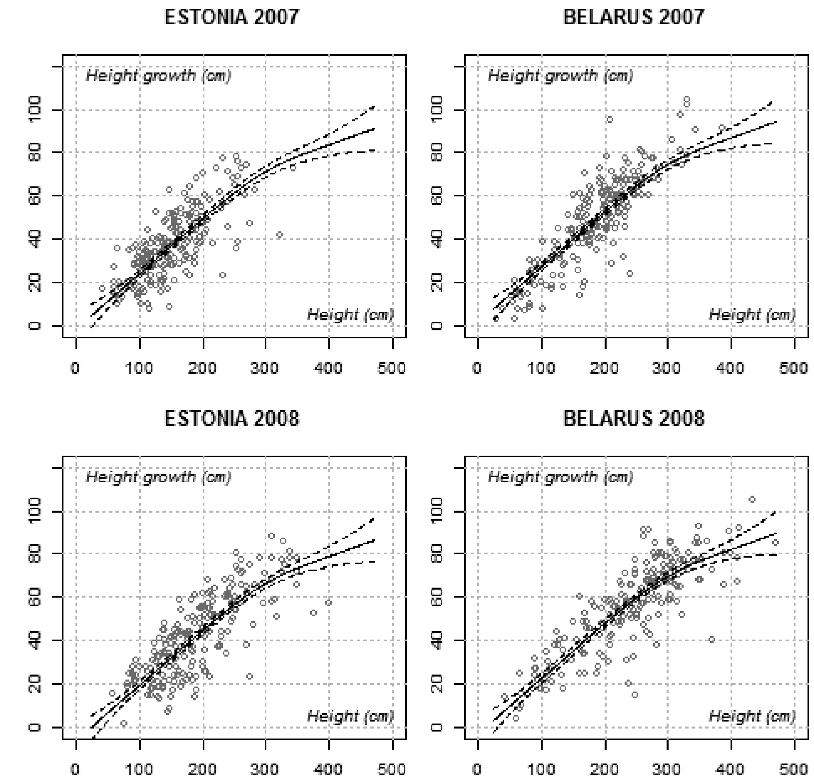

Figure 4. Scatter plot of Norway spruce height growth by provenance and measurement year with predicted trend using the generalized additive mixed model (Equation 2)

Table 5 shows the tree survival by blocks during the period 2002 2008. The highest survival was in the third block of Estonian provenance and the lowest in the first block of Estonian provenance. The Belarus provenances showed variable results in survival, some consistent, some inconsistent between blocks.

nance showed similar height values with two Belarus sample squares, which had lower height values. These results correspond well with the earlier findings, where the northward transferred Belarus provenances of Norway spruce showed better performance compared with the local provenances (Krutzsch 1974, Persson and Persson 1997, Hannerz and Westin 2005).

The elongation of terminal shoots for the southern populations of Norway spruce lasts longer during the growing season than for the northern populations (Skrøppa and Magnussen 1993). Norway spruce provenances with a long shoot elongation period and a late cessation of growth have shown the best height (Skrøppa and Magnussen 1993, Danusevičius and Gabrilavičius 2001) and diameter growth (Danusevičius and Gabrilavičius 2002). This might be true also in our study, where Belarus provenance showed higher height and height growth values compared with the Estonian provenance. However, the early shoot elongation incorporates a risk for spring frost damage (Westin et al. 2000b).

Hardening in the autumn is primarily affected by temperature and photoperiod (Skrøppa and Magnussen 1993, Hannerz 1994, Langvall 2011). Hannerz and Westin (2005) found that the northward transferred provenances harden later in autumn than the local provenances. Similarly, Beuker et al. (1998) and Westin et al. (2000a) found that in autumn the southern provenances hardened later than the northern populations. Northward transfer of provenances from Belarus may involve increased risk of autumn frost damage (Hannerz and Westin 2005).

The risk of spring and autumn frost damage in Norway spruce is related to the timing of bud burst and growth cessation (Hannerz et al. 1999). Late flushing, as observed for Belarus provenances (Dormling 1982, Persson and Persson 1997, Danusevičius and Persson 1998), may help to reduce the damage of spring frosts and early summer frosts (Hannerz 1994, Danusevičius and Persson 1998). However, the late flushing provenances are not more tolerant to frosts occurring after the onset of shoot elongation (Persson and Persson 1997). The increase in productivity achieved by the use of the north-transferred provenances is accompanied with the delay in shoot growth cessation, which is induced by short days (Hannerz 1994), and the increased risk of autumn frost damage (Hannerz et al. 1999). Therefore, the challenge is to select the provenances that have superior growth and well-timed elongation period (Skrøppa and Magnussen 1993). In nurseries, one possibility is to treat the seedlings of southern origin with shorter night length treatments to increase their frost hardiness (Konttinen et al. 2007).

If the seedling growth starts too early in spring or ceases too late in autumn the seedling is subject to increased frost risk, whereas a late growth start and early growth cessation results in reduced growth (Hannerz 1994), which might be the case for the Estonian provenance. The Belarus provenance, which seems to have late flushing, long shoot elongation period, late growth cessation and high frost tolerance, may therefore have advantage in terms of height growth if compared with the Estonian provenance. Provenances with late growth cessation can probably exploit the growing season more fully due to the longer growth duration, but at the same time higher growth rate might be even more important factor (Hannerz and Westin 2005). The better growth of the Belarus provenance compared to the local provenance can be due to longer growth period, faster growth rate or combination of these factors (Skrøppa and Magnussen 1993). Danusevičius and Persson (1998) reported that the Belarus provenances, which had the latest bud flushing and set and were little damaged by spring frost, had the highest growth capacity.

Predicted climate change scenarios show that there will be an increased risk of damage due to frost events in spring and early summer and the risk would be lower while using the seedlings of the north-transferred Belarus provenance (Langvall 2011). Rammig et al. (2010) concluded based on their modeling results that due to climate change in the long run there will be less frost events (e.g. in northern Sweden) and increased productivity of Norway spruce because of longer growing seasons and increased atmospheric CO_2 concentrations.

In conclusion, the Belarus provenance showed higher height and height growth values compared with the local Estonian one. The average height of Norway spruce of Belarus provenance exceeded the Estonian one in average 22.8 cm, 34.7 cm and 48.0 cm, respectively at age of 9, 10 and 11 years. The annual height growth was 3.22 cm greater for the Belarus provenance compared to the Estonian one. Based on the results of this study the northern regions of Belarus are suitable for Norway spruce seed transfer to Estonia.

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