Stem Growth and Quality of Six Provenances of *Larix sukaczewii* Dyl. and *Larix sibirica* Ledeb. in a Field Trial Located in North-west Russia

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Abstract

Stem growth and quality of four provenances of *Larix sukaczewii* and two provenances of *Larix sibirica* originating from Russia were estimated in a 9-yr field trial performed in the Komi Republic (north-west Russia) using a fully randomized single-tree plot design with 7 blocks. Overall survival was 78% reflecting the harsh environmental conditions in the region. ANOVA has shown that tree provenance had highly significant ($P<0.05$) effect on height, diameter and volume. There was significant ($P<0.05$) Pearson correlation between tree height at age 5 years and 9 years, indicating age-age correlation at the provenance level. There were strong and significant ($P<0.05$) negative relationships between DBH and stem volume and continentality index of the provenances. The proportion of free-defects stems varied from 46.7 to 65.5% and most common defects were weak crookedness. Better stem growth and quality was observed for northern provenances of *L. sukaczewii.*

Key words: *Larix sibirica*, *Larix sukaczewii*, provenance trial, stem defects, stem growth, survival

Introduction

Larch (*Larix* Miller) is an economically and ecologically important group of tree species, which grow mainly in the boreal forests of the northern hemisphere. Most larch forests in the world, considering both distribution area and wood stock, are in Eurasia (Schmidt 1995). Larch is fast-growing tree species producing high quality timber suitable for outdoor construction due to its high mechanical strength and decay resistance (Polubojarinov et al. 2000). But stem defects, such as stem crookedness, forking, ramicorns may be a problem in larch plantations if unsuitable seed sources are used for planting (Karlman 2010).

In general, larch forests in Russia cover more than 280 million hectares, accounting for 37% of the forested area and 30.7% of the wood stock (Martinsson and Lesinski 2007). The nomenclature of the Eurasian larch species is complex and may vary among authors (Eysteinsson and Skúlason 1995, Abaimov et al. 2002, Lukkarinen et al. 2010, Karlman 2010). According to Farjon (1990), two larch species are recognized in Russia, the Siberian larch (*L. sibirica* Ledeb.) and the Dahurian larch (*L. gmelinii* Rupr.). Dylis (1947) suggested that *L. sukaczewii* Dyl. is a separate species in the European part of Russia, but according to Bobrov (1978), *L. sukaczewii* cannot be distinguished from *L. sibirica* Ledeb. found in the central part of Siberia. Later phylogenetic studies (Bashalkhanov et al. 2003, Khatab et al. 2008, Neyton et al. 2008) confirmed that *L. sukaczewii* is a separate species. Unfortunately, as the results of unfavourable natural conditions (drought, fires, climate change) and industrial development, the distribution area of *L. sukaczewii* in the European part of Russia is now decreasing (Martinsson and Lesinski 2007). Nine thousand years ago larch was also native species in Scandinavian forests but for some unknown reason it disappeared already in prehistoric time (Kullman 1998). For successful larch cultivation, the knowledge of genetic variation in phenology, survival, stem growth and quality are needed.

The series of the field trials with the same material of Russian larches was established in Canada, China, Finland, France, Iceland, Japan, Norway, Russia, Sweden and the United States (Martinsson and Takata 2005). In general, the height growth differences among provenances studied at the age of four and five years were similar in Finnish, Russian and Swedish field trials indicating faster height growth of southern provenances. Differences in survival among the provenances were significant in Kivalo (northern Finland) and Särna (middle Sweden), but insignificant in Punkaharju (southern Finland) and Syktyvkar (north-west Russia) (Lukkarinen et al. 2010, Karlman et al. 2011, Fedorkov 2014). Karlman et al. (2011) also reported about strong and significant negative correlation between survival and continentality index in Swedish tests but opposite results were obtained by Lukkarinen et al. (2010) in Finnish tests. Phenological studies carried out in Punkaharju and Syktyvkar trials revealed that the provenances from cold climates started their growth earlier in the spring, contrary to the provenances from warmer climates (Fedorkov 2012, Lukkarinen et al. 2013). However, accordingly to Lukkarinen et al. (2010) stem damages were common in two Finnish trials (Kivalo and Punkahariu) at the age of four and were attributed to climate, insects, fungi or mammals.

The objectives of this study were to compare stem growth and quality of larch trees under field conditions; evaluate the relationships between growth traits and climatic variable in continental climate of the Komi Republic (north-west Russia) which differ from maritime climate of Fennoscandia. These results would be important for a proper selection of provenances for commercial planting.

Materials and Methods

Field trial and material

The study was performed in a field trial located near the town of Syktyvkar in the Komi Republic (NW Russia) (61°39'N, 50°41'E, alt. 160 m a.s.l) and seed collection of four provenances of *Larix sukaczewii* Dyl. and two provenances of *Larix sibirica* Ledeb., accomplished as described in the Russian-Scandinavian Larch Project of 1994–2000 (Abaimov et al. 2002) (Figure 1, Table 1). Seeds were sown in containers (7×7 cells/container, cell size of 128 cm^3) in May 2006 and grown in a plastic greenhouse without supplemental heat or light. At the beginning of August 2006, seedlings were moved to the open air before planting. The two-year-old seedlings were planted in September 2007, with a spacing of 3×1 m using a fully randomized single-tree plot design with 7 blocks (20–25 seedlings from each provenance per block). The 1,068 seedlings were planted in a clear-cut area with Albic Podzol soil prepared by using a plough.

Measurements

All trees in the plantation were assessed after nine growing seasons in the field in autumn 2016. The trees were categorized in two classes: trees with no stem defects and trees with stem defects (crookedness, forking and ramicorn branches). Stem crookedness was visually graded in two classes: class 1 = stems with a weakly crooked bole and class 2 = stems with a severely crooked bole. Forked trees are those with two stems having about equal stem diameters. Ramicorn branches are large, steep-angled branches that occur when terminal shoot temporarily loses apical dominance to a lateral branch (Magalska and Howe 2014). Type of defects was recorded. Dead trees were also recorded to be used for determination of survival at the age of nine in the field.

Trees without defects were callipered at breast height which was defined as 1.3 m (DBH, 1 mm accuracy) and tree height was recorded in meter (0.1 m accuracy) using a measure stick. The stem volume (on bark) was calculated using Kalinin's (1965) equations.

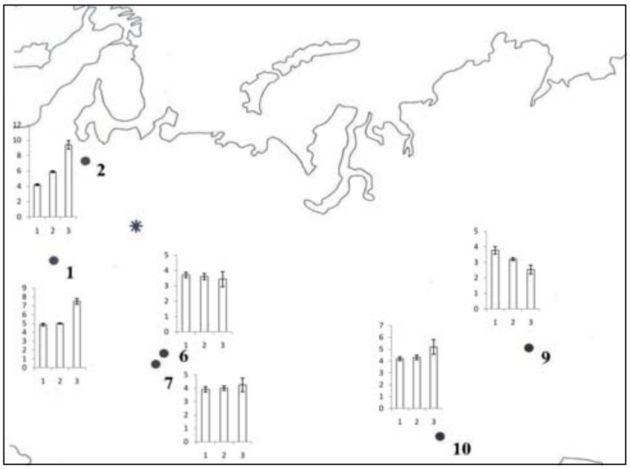

Figure 1. Location of field trial (*) and provenances studied (•). Average tree height (m), DBH (cm), stem volume (dm^3) and standard errors of provenances studied are given as column 1, 2 and 3, respectively

Table 1. Identification, ecological characteristics and survival of the Larch provenances studied

Provenance*	Geographical location and elevation			Annual mean	Continentality	Degree	Field
	Lat. (N°)	Long. (E°)	Alt. (m)	temperature (°C)	index**	days +5°	survival (%)
Larix sukaczewii Dyl.							
1 Nizhnij Novgorod	57° 30'	45° 10'	145	3.1	44	1446	78
2 Plesetsk	63° 05'	40° 21'	100	1.1	40	1037	82
6 Perm	55° 43'	60° 27'	480	2.2	49	1441	75
7 Ufa	54° 58'	60° 07'	380	1.9	52	1480	72
Larix sibirica Ledeb.							
9 Boguchany	58° 39'	97° 30'	158	-2.6	64	1204	80
10 Novokuznetsk	53° 48'	88° 00'	400	1.9	54	1753	81

*According to Abaimov et al. (2002)

For trees with height < 5.0 m (Eq. 1):

$$V = 0.0000481 \times d^2 \times h + d^2 \quad (1)$$

For trees with height > 5.0 m (Eq. 2):

$$V = 0.0000198 \times d^2 \times h^2 + 0.000016 \times d^2 \times h + 0.000186 \times d^2 / 0.635 \times h + 1.65 \quad (2)$$

where V is the stem volume (m³), h is the height (m), and d is DBH (cm). The volumes were then converted to dm³.

Statistical analysis

Statistical analysis of growth traits (height, DBH and stem volume) was performed on a provenance mean (per block) basis as independent units. These characteristics exhibited normal distribution according to the Kolmogorov-Smirnov test. For quality traits (proportion of trees with/without defects) the frequencies for each provenance were calculated. Taking into account the complicated nomenclature of Eurasian larch species, statistical analysis was performed for all provenances together. The statistical significance of provenance and block effects on growth traits were studied using ANOVA. The linear model equation was defined as (Eq. 3):

$$y_{ik} = \mu + P_i + B_j + e_{ij}, \quad (3)$$

where y_{ij} is the trait value for plot means of the ith provenance in the jth block, μ is the overall mean, P_i is the fixed effect of provenance, $i = 1\ldots6$, B_j is the fixed effect of block, $j = 1\ldots7$, and e_{ij} is the experimental error.

Because assumption of normality in distribution of proportions of trees with/without defects was violated, comparisons were performed using nonparametric Kruskal-Wallis test. Pearson correlations were used to study the relationships among the measured variables. Continentality index values for the same provenances were calculated by Lukkarinen et al. (2009) and Karlman et al. (2011) using Conrad's (1946) formula (Eq. 4):

$$C = \frac{1.74A}{\sin(\varphi + 10°)} - 14 \quad (4)$$

where A is the annual monthly temperature range (the difference between the warmest and coldest month) and φ is the latitude.

Simple regressions were employed to explain the relationships between the traits studied and continentality index of provenances. The Statistica 6.0 statistical package was used for all statistical analyses (SAS/STAT User's Guide 1999).

Results

The overall estimated survival in September 2016 was 78%, and varied between 72% and 82% according to provenance, reflecting initial adaptedness to the environmental conditions (Table 1). The effect of provenance was significant ($P < 0.05$) for height, DBH and volume (Table 2). The average height was 4.11±0.17 m and varied between 4.87±0.15 m for Nizhnij Novgorod (No. 1) and 3.71±0.17 m for Perm (No. 6). The average diameter was 4.3±0.4 cm and varied between 5.9±0.1 cm for Plesetsk (No. 2) and 3.2±0.1 cm for Boguchany (No. 9). The average volume was 5.38±1.06 dm³ and varied between 9.40±0.56 dm³ for Plesetsk (No. 2) and 2.53±0.28 dm³ for Boguchany (No. 9) (Table 3). The block effect was insignificant ($P > 0.05$) for all parameters studied (Figure 1).

Table 2. Results of ANOVA: the significance of effects of provenance and block on tree height, stem diameter and volume

Variable	df*	MS**	F-value	p-value
Height				
Provenance	5	1.268	5.600	<0.001
Block	6	0.175	0.772	0.598
Error	30	0.227	-	-
DBH				
Provenance	5	6.711	41.777	<0.001
Block	6	0.102	0.635	0.701
Error	30	0.161	-	-
Volume				
Provenance	5	47.220	27.933	<0.001
Block	6	1.133	0.671	0.674
Error	30	1.691	-	-

*degrees of freedom; **mean sum of squares

The more continental provenances had worse stem growth, while the effect of continentality was insignificant ($P>0.05$) for tree height and share of stems without defects (Figure 2). Pearson correlation coefficient between tree height at the age of five (Fedorkov 2014) and nine years was strong and significant ($r= 0.85$, $P < 0.05$) indicating age-age correlation at the provenance level.

The share of stems without defects varied from .46.7 (Nizhnij Novgorod) to 65.5% (Plesetsk) but differences were statistically insignificant (Kruskal-Wallis test, $\chi^2= 6.00$, $P > 0.05$). The most common defects were crookedness: proportion of weakly crooked stems was 78% and severe crooked stems less than 18 % in average (Table 3).

Table 3. The percentage of defect-free trees and trees with different types of defects for provenances studied

Seed source (provenance)	Defect-free stems	Forks*	Ramicorns*	Crookedness* weak	Crookedness* severe
1 Nizhnij Novgorod	46.7	9.3	2.1	74.0	14.6
2 Plesetsk	65.5	-	1.2	87.8	11.6
6 Perm	62.0	11.1	-	55.6	33.3
7 Ufa	59.4	13.3	0.8	85.9	-
9 Boguchany	50.0	-	0.4	74.5	25.1
10 Novokuznetsk	60.0	1.3	0.5	91.2	7.0

*the percentages were calculated as share of stems with defects

Discussion and Conclusions

Survival is a complex character reflecting combined effects of all events causing injuries and die-back in tree populations. Overall survival dropped 4% during last four

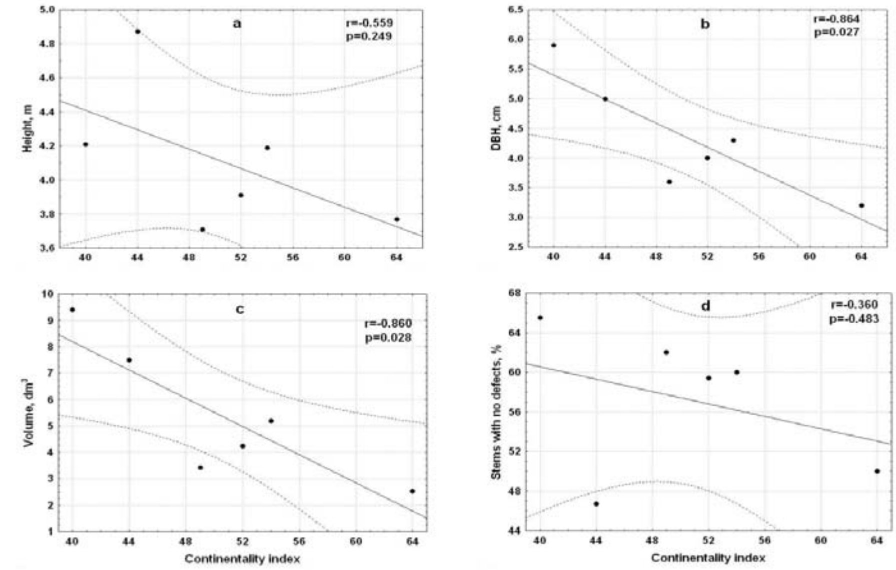

Figure 2. Relationships between traits values (•) and continentality index of provenances studied: a) tree height, b) DBH, c) stem volume and proportion of stems with no defects. Dotted lines represent 95% confidence intervals

years after previous evaluation which was carried out in 2012 (Fedorkov 2014) and it seems that dropping in survival was most pronounced in southern provenances. Higher survival of the northern provenance of *L. sukaczewii* (Plesetsk) and the continental provenances of *L. sibirica* (Boguchany and Novokuznetsk) observed in this study is in agreement with results obtained by Lukkarinen et al. (2010) in Finland and Karlman et al. (2011) in Sweden in field trials established using similar materials.

Better stem growth of the provenances of *L. sukaczewii* (Plesetsk and Nizhnij Novgorod) revealed in this study is in accordance with results obtained in larch plantations located in Fennoscandia (Martinsson and Lesinski 2007). These provenances have also demonstrated the best height growth at the age of five years (Fedorkov 2014). Negative correlations between stem growth (DBH and volume) and continentality index means poor growth when provenances were transferred from strongly continental areas and these results agree with findings in both Finnish (Lukkarinen et al. 2010) and Swedish (Karlman et al. 2011) field trials. A correlation coefficient between tree height and continentality index was modest and negative but statistically insignificant ($P>0.05$) (Figure 2), maybe owing to small number of provenances studied.

Faster stem growth of Plesetsk provenance is in line with results presented by Rehfeldt et al. (2003) with respect to provenance for three larch species (*L. sukaczewi*, *L .sibirica*, and *L. gmelinii*) from throughout the fSU indicated that growth and survival of most populations are enhanced when populations are transferred to warmer climates.

The main reason of larch stem crookedness is leader shoot damage by autumn frosts (Sigurdsson 2013). It is also known that there is a positive correlation between frost resistance and growth on the one hand and stem form in young larch seedlings on the other hand (Eystensson and Skślason 1995). In this study the lowest share of defect-free stems was observed in Nizhnij Novgorod provenance, which demonstrated late growth cessation in autumn. Contrary to this, the highest proportion of defect-free stems was observed in Plesetsk provenance, which characterized by early growth cessation in autumn (Fedorkov 2012). According to Kalinin (1965) weak crookedness shall more or less disappear when tree became older.

In conclusion, the results of this study, when taken together with data from trials in other geographic regions, can be used to compare stem growth and quality for different climate regions, and may be able to provide information on the climatic adaptation of larch species and provenances. The suitability of larch species and provenances from different regions to be used in forest cultivation in north-west Russia depends on population origin. However, the survival, stem growth and quality of these populations must be followed for longer periods in field trials before any conclusions can be drawn about their utility to applied forestry.

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