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Aleksey Fedorkov

Vitality and height growth of two *Larix* species and provenances in a field trial located in north-west Russia

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Highlights

- Differences in tree vitality among provenances were insignificant ($p > 0.05$) at an early age.
- The provenance effect was significant ($p < 0.05$) for total height.
- These findings were in agreement with those of Lukkarinen et al. (2010) using the same material at the same age for field trial located in Punkaharju (Finland).

Abstract

Vitality and height of *Larix* species and provenances originating from Russia were estimated in a 5-yr field trial performed in the Komi Republic (north-west Russia) using a fully randomized single-tree plot design with 7–8 blocks. Tree provenance had no significant ($p > 0.05$) effect on tree vitality, though for *Larix sukazcewii* originating from the European part of Russia, trees from the northern regions were more vital than those from southern regions. Provenance was a significant ($p < 0.05$) factor for height, where the average height of 136 cm varied considerably (168 cm for trees from Nizhnij Novgorod and 111 cm for trees from Ufa). There were no significant correlations when vitality and height were compared to geographic and climatic variables for the locations.

Keywords provenance trial; Russian larch; tree condition; tree height
Addresses Institute of Biology, Komi Science Center, Russian Academy of Sciences, Syktyvkar, 167982, Kommunisticheskaya st., 28, Russia
E-mail fedorkov@ib.komisc.ru
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1 Introduction

Larch (*Larix* Miller) is an economically and ecologically important group of tree species which grow 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 (Chubinski et al. 1990) suitable for outdoor construction, due to its high mechanical strength and decay resistance (Polubojarinov et al. 2000). In Finland, larch is considered equivalent to Scots pine with respect to decay resistance (Venäläinen et al. 2001). 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 by country (Eysteinsson and Skúlason 1995; Abaimov et al. 2002; Lukkarinen et al. 2009; 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. 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). Recently Lukkarinen et al. (2010) and Karlman et al. (2011) reported on survival, growth and damage to Russian larch material at the age four and five years in the field trials located in Finland and Sweden, respectively.

The objectives of this study were to compare vitality and growth of *L. sukaczewii* and *L. sibirica* seedlings under field conditions; evaluate the relationships between tree vitality and growth with climatic and geographic variables; and to study genotype × environment interaction for *L. sukaczewii* and *L. sibirica* at the provenance level using the findings of Lukkarinen et al. (2010) and Karlman et al. (2011). These results would be important for a proper selection of provenances for commercial planting.

2 Material and methods

2.1 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 accomplished as described in the Russian-Scandinavian Larch Project of 1994–2000 (Abaimov et al. 2002) (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 7–8 blocks (20–25 seedlings from each provenance). The 1068 seedlings were planted in a clear-cut area with sandy soil prepared using a plough.

2.2 Measurements

The height and vitality of all trees on the plantation were estimated after five growing seasons in the field (autumn 2012). Tree vitality was evaluated using the following classification scheme: 1 – healthy tree, shoots healthy, stem straight and growing vigorously; 2 – slightly damaged, good condition, shoots healthy, main stem straight; 3 – seriously damaged tree, poor condition, terminal shoot damaged, bent or dead, retarded growth; and 4 – dead tree. The height of living trees was measured in centimetres and the survival percentage was based upon the proportion of living trees at the time of the assessment.

2.3 Statistical analysis

Statistical analysis was performed on a plot mean basis as independent units. Although vitality was observed on a discontinuous scale, mean values calculated from the original class codes were continuous and normally distributed. The differences in survival, vitality and height between species (*L. sukaczewii vs. L. sibirica*) were analysed by T-test. 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 tree vitality and height were studied using ANOVA. The linear model equation was defined as:

$$y_{ijk} = \mu + P_i + B_j + e_{ij} \tag{1}$$

where y_{ijk} = the vitality/height for plot means of the ith provenance in the jth block, μ = overall mean, P_i = the fixed effect of provenance, $i = 1 \ldots 6$, B_j = the fixed effect of block, $j = 1 \ldots 8$, and e_{ij} = the experimental error.

Differences between the highest mean and lower ones for provenances were analysed by Scheffe's test and dependence between different parameters were tested with the Pearson correlation analysis. The Statistica 6.0 statistical package was used for all statistical analyses (SAS Institute Inc. 2004).

3 Results

The overall estimated survival in September 2012 was 82%, and varied between 78% and 86% according to provenance (Table 1). Differences between species were statistically insignificant ($p > 0.05$) for survival (T = –2.167; p = 0.096), vitality (T = 0.729; p = 0.470) and height (T = 0.713; p = 0.479). Provenance had no significant ($p > 0.05$) effect on tree vitality (Tables 2 and 3), though for *L. sukazcewii* from the European part of Russia, trees from the north were more vital than those from the south.

Provenance was a significant ($p < 0.05$) factor for height (Table 2). The average height was 136 cm, and varied according to provenance (168 cm for Nizhnij Novgorod and 111 cm for Ufa) (Table 3). The block effect was insignificant ($p > 0.05$) for tree vitality and growth (Table 2). There were no significant correlations when vitality and height were compared to geographic and climatic variables of the provenances. For vitality, there was a modest, but insignificant correlation with latitude and temperature sum (Table 4).

Table 1. Identification and survival for the provenances studied.

Provenance[a)]	Geographical location and elevation			Annual mean temperature (ºC)	Continentality index	Degree days +5°	Field survival (%)
	Lat. (Nº)	Long. (Eº)	Alt. (m)				
Larix sukaczewii Dyl.							
1 Nizhnij Novgorod	57°30´	45°10´	145	3.1	44	1446	81
2 Plesetsk	63°05´	40°21´	100	1.1	40	1037	84
6 Perm	55°43´	60°27´	480	2.2	49	1441	79
7 Ufa	54°58´	60°07´	380	1.9	52	1480	78
Larix sibirica Ledeb.							
9 Boguchany	58°39´	97°30´	158	–2.6	64	1204	84
10 Novokuznetsk	53°48´	88°00´	400	1.9	54	1753	86

a) According to Abaimov et al. (2002).

Table 2. The effects of provenance and block on tree vitality and height.

Variable	df [a)]	MS [b)]	F-value	p-value
Vitality				
Provenance	5	0.129	0.601	0.699
Block	7	0.489	2.284	0.052
Error	33	0.214		
Total	45	0.247		
Height				
Provenance	5	2911	6.893	<0.001
Block	7	559	1.322	0.271
Error	33	422		
Total	45	720		

a) degrees of freedom
b) mean sum of squares

Table 3. The mean tree vitality expressed by a class code and tree height (in cm) after 5 years.

Provenance	Tree vitality			Tree height		
	Mean	SD [a)]	p-value [b)]	Mean	SD [a)]	p-value [b)]
1 Nizhnij Novgorod	1.96	0.47	0.973	168	22	-
2 Plesetsk	1.82	0.54	0.820	145	26	0.498
6 Perm	2.03	0.46	0.996	127	15	**0.020**
7 Ufa	2.17	0.52	-	111	17	**<0.001**
9 Boguchany	1.81	0.49	0.765	132	26	0.058
10 Novokuznetsk	1.98	0.59	0.984	131	19	0.059

a) standard deviation
b) p-values obtained by Scheffe's test. Statistically significant values ($p < 0.05$) are in bold.

Table 4. Pearson correlation coefficients between the measured variables ($n = 6$) and p-values (in parenthesis).

Variable	Vitality	Tree height
Continentality index	–0.049 (0.927)	0.493 (0.320)
Degree days +5 °C	0.641 (0.170)	–0.217 (0.679)
Latitude	–0.747 (0.088)	0.446 (0.375)
Longitude	–0.149 (0.778)	–0.425 (0.401)

4 Discussion and conclusions

The results obtained by Lukkarinen et al. (2010) and Karlman et al. (2011) using similar materials (of approximately the same age) for field trials in Finland and Sweden offered an opportunity to compare larch tree vitality and growth along a longitudinal gradient. The field trials at Särna (61°31´N, 13°00´E) in Sweden and at Punkaharju (61°49´N, 29°19´E) in Finland were at similar latitudes (but a different longitude) to the Syktyvkar field trial (see Materials and methods). The longitudinal distances between Syktyvkar and the sites of the two other field trials, Särna and Punkaharju, were ~40º and 20º (approximately 2000 and 1000 km), respectively. The comparison between survival (vitality) and height (for similar materials) between these trials can provide information about the effects of longitude on these parameters.

The overall survival was higher (by about 20%) for the Syktyvkar field trial compared to the Särna and Punkaharju trials. The reason for the lower survival at Punkaharju was pine weevil damage to the seedlings (Lukkarinen et al. 2010), while Särna has very stony soil conditions, resulting in occasional poor soil scarification (Karlman et al. 2011). The higher altitude at Särna could also be an additional reason for increased seedling mortality. The difference between species survival was significant at the Särna (Sweden) site, but insignificant at Syktyvkar, where these differences between species at the Russian site could be explained by the low number of provenances investigated. Provenance had no effect on tree survival at Punkaharju and tree vitality at Syktyvkar, but this effect on survival was significant at Särna.

Results obtained by Rehfeldt et al. (2003) with respect to provenance for three larch species (*L. sukaczewi*, *L .sibirica*, and *L. gmelinii*) from throughout the former Soviet Union indicated that growth and survival of most populations are enhanced when populations are transferred to warmer climates. In both the Punkaharju and Syktyvkar field trials, trees from western and central Siberia had higher survival, while those from Särna had reduced survival which could be attributed to the higher altitude.

In general, tree growth was better in Punkaharju compared to the Syktyvkar and Särna sites, which was consistent with predictions made by Rehfeldt et al. (2003) indicating the temperature sum (1235 d.d.) was highest at Punkaharju. Among the provenances studied, the best growth at all three sites was seen for trees from Nizhnij Novgorod. The reduced growth for trees of southern origins (Perm and Ufa) seen in this study was attributed to the higher proportion of damaged trees having dead leader shoots and consequently, reduced height (Tables 1 and 3).

The overall findings from extensive provenance experiments within Scandinavia indicate that latitude has a significant effect on Scots pine hardiness and survival (Persson 1994; Persson and Ståhl 1990), a common pattern for general geographic variation of most forest tree species in the northern hemisphere (Wright 1976). The results obtained by Lukkarinen et al. (2010) at Punkaharju were similar to those of this study, but the correlation coefficient between survival and latitude was low (and insignificant) at Särna (Karlman et al. 2011). For tree height, the situation was reversed, where the correlation coefficient between height and latitude was low (and insignificant) at Punkaharju but highly significant at Särna. Although the correlation coefficient between tree vitality and latitude was insignificant in this study, there was a trend in greater vitality for trees of northern origin (Table 4). The non-significant correlation coefficients observed between the measured variables may be explained by the low number of the provenances investigated.

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

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