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Survival, Height Growth and Damages of Siberian (*Larix sibirica* Ledeb.) and Dahurian (*Larix gmelinii* Rupr.) Larch Provenances in Field Trials Located in Southern and Northern Finland

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The aim of this study was to analyse differences in the survival and height growth of, as well as damages to Siberian (*Larix sibirica* Ledeb.) and Dahurian (*Larix gmelinii* Rupr.) larch provenances over four growing seasons in field trials established in 2006 in southern (Punkaharju) and northern Finland (Kivalo). In this context, the study also investigated if the geographical and climatic conditions of the origin of the provenance could explain the differences between the provenances. The study material consisted of 20 Russian Siberian and Dahurian larch provenances and five seed sources from Finland (4) and Russia (1) as comparison lots. It was found that the Finnish seed sources of Siberian larch survived well in both the Kivalo and Punkaharju trials. Five northern latitude Russian provenances, of which one was Dahurian and the remainder were Siberian larches, had the highest survival in Kivalo. However, the differences observed in survival between provenances were only significant ($p<0.05$) in Kivalo. Regardless of the trial, the differences, however, in height growth were significant and large between provenances. The southern Dahurian larches had a superior height growth in Punkaharju. The northern Dahurian larch provenance from Magadan (59°50´N, 150°40´E) had the largest height growth in Kivalo, among some northern Siberian larches. Damages were diverse, though Dahurian larches had less mammal damage than the Siberian larches. In general, the differences between provenances were not significant. Latitude and altitude best explained the differences between provenances, but also mean temperature, temperature sum and continentality index affected them ($p<0.05$).

Keywords larch, *Larix*, provenance, survival, height growth, seedling damage
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1 Introduction

The Finnish climate has both maritime and continental influences depending on the direction of the air flow (Finland's Climate 2009). This is a result of its geographical position between the 60th and 70th north parallels in the Eurasian continent's coastal zone. However, the mean annual temperature in Finland is, on average, several degrees higher than in other areas at the same latitudes. This is because of the warm Atlantic airflows warmed by the Gulf Stream, abundant inland waters and the warming effect of the Baltic Sea. Changes in air flow direction occasionally extends the continental climate over Finland with its severely cold winter temperatures and extreme heat in summer (Finland's Climate 2009). The varying climate sets limitations regarding the survival and growth of trees, especially for exotic species (Hagman 1993). For example, the extremely cold winter of 1939–1940 was fatal for many exotic tree species trials established in the 1920s and 1930s in Finland. On the other hand, in these trials Russian larch species (*Larix* Miller) have performed well, although some spring frost damages have affected Far Eastern provenances (Heikinheimo 1956, Lähde et al. 1984, Silander et al. 2000).

In Finnish conditions, the importance of suitable provenance or seed source cannot be over emphasized regarding the cultivation of exotic tree species such as Siberian (*Larix sibirica* Ledeb.) and Dahurian larch (*Larix gmelinii* (Rupr.) Rupr.). This is because they have a wide geographical range and, thus, a large natural variation with several differing populations (Farjon 1990, Hämet-Ahti et al. 1992, Hagman 1993). The variation in individual trees and tree populations is caused by adaptation to the prevailing climatic and growing site conditions, which are closely linked to geographic position (latitude, altitude) and photoperiod (Sarvas 2002). Therefore, the growth, quality and hardiness differ between provenances when grown in the same conditions (Eriksson et al. 2006). The most common reason for the failure of exotic tree species has been cold climate and unsuitable annual growth rhythm (Heikinheimo 1956).

Provenance tests, with species from the north temperate zone, have revealed some common trends. Southern provenances usually start their growth later in the spring than the northern ones. Additionally the growth lasts longer in the autumn. As a result, they are less susceptible to late spring frost, but suffer from cold and short summers and early autumn frosts as well as extreme winter cold periods (Wright 1976). Similar to latitude, altitude also affects the adaptation of tree species, generally speaking temperature decreases the higher the altitude (White et al. 2007). In the troposphere, the average temperature drop per hundred meters of increasing elevation is 0.65 °C (Liljeqvist 1962), which corresponds to a transition of approximately one degree latitude to the north (Laaksonen 1976).

The continentality of the climate, which increases on moving inland, also affects the performance of tree species, in addition to the local microclimate, due to the larger annual temperature range compared to that of an oceanic climate (Heikinheimo 1956, Tuhkanen 1984). For example, Tigerstedt et al. (1983) suggested that provenances from continental climates end their growth early in the autumn in northern Finland and have good winter hardiness, but have relative low height growth, respectively. There is also a risk of frost damages in the spring, because they start their growth early. Provenances from too maritime climates, however, will likely suffer frost damages in late summer, because they continue their growth late into the autumn.

The natural range of larch mainly covers the boreal zone of the northern hemisphere, especially its coldest parts, reaching alpine and polar regions (Schmidt 1995, Sarvas 2002). Most larch species have, however, only rather small distribution areas; limited to mountainous areas. Of the ten species commonly recognized in the larch genus, only the Siberian (*Larix sibirica* Ledeb.) and Dahurian larches (*Larix gmelinii* (Rupr.) Rupr.) in Eurasia and the North-American tamarack (*Larix laricina* (Du Roi) C. Koch) have a large natural range (Farjon 1990). In Finland, the Siberian larch can be considered as a returnee species, which has formerly belonged to the Finnish flora (Frenzel 1968, Robertsson 1971, Mäkinen 1982, Hirvas 1991).

Larches, with its fast seedling stage growth, have fewer troubles in competing with undergrowth and can maintain a good health (Vuokila et al. 1983, Sarvas 2002). However, a decline in health can expose a seedling to pathogens and, therefore, the selection of provenance and growing site is vital (Heikinheimo 1956). Russian larch species in old Finnish trials have proven to be quite healthy and resistant to damages. All larch species in Finland are affected by the larch canker (*Lachnellula willkommii*), but on Russian larch species the damages are not usually fatal (Lähde et al. 1984, Silander et al. 2000, Ohenoja 2001).

The small spruce gall aphid (*Adelges laricis*) has also caused damages to young larch stands, especially in northern Finland (Hagman 1995). Aphids can be found on almost every larch cultivation to some extent (Siitonen 1993). Large pine weevil (*Hylobius abietis*) is also a common pest in regeneration areas and it also damages larches (Siitonen 1993, Poteri 1999). The large larch sawfly (*Pristiphora erichsoni*) also causes some damages (Lähde et al. 1984). Mammal damages on larch can be considered to be, on average, the same as for other Finnish forestry tree species (Poteri 1999). Some damages are caused by deer animals of which moose (*Alces alces*) is the most common in Finland. In Northern Finland also reindeer (*Rangifer tarandus tarandus*) can cause damages. Furthermore, hares (*Lepus*) can cause some damages to young seedlings during winter time (Hagman 1995). Additionally, voles (*Arvicolinae*) can cause significant damages to all tree species during the peak of their 3-year cycle (Rousi 1983). It should be noted that no differences have been observed between Siberian larch provenances concerning pests and diseases (Hagman 1995).

Larches have grown best in Finland usually in the southern parts of the country (e.g. Punkaharju) in the oldest experiments established in middle of 19th century (Heikinheimo 1956, Sarvas 2002). However, in experiments established further south than Punkaharju, such as in Ruotsinkylä and Solböle, the growth has been on average lower. Field experiments have also been established for larch in Northern Finland (Kivalo) in the early 20th century (Silander et al. 2000). However, many of the northern experiments have been established with poorly selected provenances (e.g. are too southern in origin). Additionally, a large share of the Siberian larch field trials have been established in Finland with Finnish 2nd generation seed sources originating from Raivola (Ruotsalainen 2006). The Raivola origin Siberian larch has especially been proven to compete with Scots pine in stem wood production, and even in Kivalo (far north of Finland). The good adaptation of the Raivola origin has been contributed to the variable climate in the Arkhangelsk region, where the material originally comes from (Tigerstedt 1990). Kivalo is considered to be, on average, a better growing environment compared to other areas at these latitudes, because of the topography and soil properties (Heikinheimo 1956, Lähde et al. 1984, Silander et al. 2000). Hagman (1995) has suggested Siberian larch from the western parts of Russia to be most promising for Northern Finland, e.g. provenances such as Arkhangelsk (Plesetsk) and Petchora, unlike Siberian and Dahurian larch from Siberia (Hagman 1993). However, the Dahurian larch provenance from Magadan (59°38´N, 151°50´E) has had a 93% survival rate after seven years in a treeline experiment at Utsjoki (69°49´N) (Hagman 1993).

Previously, Tigerstedt et al. (1983) recommended studying the suitability of provenances from areas where continental climate meets maritime climate, e.g. Far Eastern Dahurian larches. This was because they are likely to have a genetic structure with a high tolerance to changing weather conditions. Earlier Finnish experiments with quite narrow research material, suggest, that despite good height growth, that the yield of Dahurian larches is poorer than Siberian larches (Silander et al. 2000, Autio 2002). The Russian larch provenances may have potential to challenge current seed sources used in Finland for exotics.

On medium fertile sites, there are no large differences in growth between larch and Finnish domestic species in Finnish conditions. However, on fertile sites Siberian larch thrives better (Vuokila et al. 1983). According to Silander et al. (2000), in the most successful Finnish experiments the dominant height of 70 year old Siberian and European larch was 36 meters, which exceeds the growth of Norway spruce (*Picea abies* L.), in the same conditions, by 20 percent. Especially in the juvenile stage, the height growth of larches is vigorous and can continue to an older age. However, the growth of some larch species can decline significantly already in middle-age after 40 years, e.g. Japanese larch (*Larix kaempferi* (Lamb.) Carrière) (Sarvas 2002).

The approximate area of larch stands in Finland is currently about 30 000 hectares. Every year 500–1000 hectares area planted for larch, but only using Raivola seed source. The majority of larch plantations in Finland and elsewhere in Nordic countries are sapling stands and young stands of first thinning age (Martinsson and Lesinski 2007). Thus, there is not yet much larch timber available for forest industry in this sense. On the other hand, also other larch provenances may in the future provide proper regeneration material for practical forestry, when adapting forest management to the changing environmental conditions (Ruotsalainen 2006). This would increase harvesting opportunities in larch over time.

The aim of this study was to compare the height growth and survival of, as well as damages to, 20 Siberian and Dahurian larch provenances and five comparison lots over four growing seasons in field trials situated in southern and northern Finland. Survival ability is the first sign of the adaptation of a species to a new site (Hagman 1995). The provenance survival percentage and the amount and nature of damages reveal the adaption and suitability to varying Finnish growing conditions while the height growth estimates the yield potential. In the above context, geographic and climatic properties of the provenance origins were used to explain the differences between provenances. This study is part of a larger international larch provenance test series, covering most of the range of the Russian larches. Provenance test sites with the same material have been established in Sweden, Norway, Iceland, Russia, France, Japan, China, Canada and the United States (Martinsson and Lesinski 2007). This work is also a follow-up study to Lukkarinen et al. (2009) research into the growth rhythm and height growth of seedlings of the same larch provenance material in greenhouse conditions.

2 Material and Methods

2.1 Experiment Data

The material used in this study consisted of fifteen Siberian larch (*Larix sibirica* Ledeb.) and five Dahurian larch (*Larix gmelinii* (Rupr.) Rupr.) provenances (Table 1). Two of the five comparison seed lots originated from Finnish seed orchards, two from the cultivations of the Finnish Forest Research Institute (Metla) in Punkaharju and one from the Raivola stand in Russia (Redko and Mälkönen 2005). Four of five comparison seed lots were Siberian larches and one (Mv135 in Punkaharju) was European larch (*Larix decidua* Miller).

The Siberian larch (*Larix sibirica* Ledeb.) provenances 1B–7C and comparison lots Mv98, Sv309, Sv356 and Raivola stand are considered in Russian nomenclature as *Larix sukaczewii* Dyl. The Dahurian larch (*Larix gmelinii* var. *gmelinii* (Rupr.) Rupr.) provenance 13A Magadan is considered in Russia as *Larix cajanderi* Mayr. In our work the species concept and nomenclature follow those of Farjon (1990) and Hämet-Ahti et al. (1992). The same research material has also been used and described in more detail by Lukkarinen et al. (2009), who analysed the growth rhythm and height growth of seedlings in Siberian and Dahurian larch provenances in greenhouse conditions.

The climatic information for the seed collection sites (for each provenance) was obtained for this study by interpolating it from the high-resolution surface climate data provided by the Climatic Research Unit, UK (Ten minute climatology 2002, New et al. 2002). However, altitude correction for the temperature values (and temperature sum) was also applied by considering the difference between the interpolated altitude and the value provided by the seed collectors (a temperature drop of 0.65 °C for every 100 m in elevation was applied, see Liljeqvist 1962). Interpolation was made by averaging two to four of the closest value points, depending on the location of the seed source in relation to available grid points (if deviation <0.05 degrees, nearest value was used). This approach provided consistent values with the temperature sum map published by Tuhkanen (1984) and also improved the accuracy of climatic information used previously by Lukkarinen et al. (2009).

In this work the following variables were used to describe the climatic conditions of the seed collection sites: temperature sum with +5 °C threshold value, annual mean temperature, mean temperature of the coldest month (minimum temperature), mean temperature of the warmest month (maximum temperature), annual range of the monthly mean temperatures (maximum-minimum temperature),

Table 1. Geographical and climatic information and seed weight of the different provenances. Siberian larches (top), Dahurian larches (middle) and the comparison lots (bottom) are separated from each other with a horizontal line. The same grouping is also used in the figures.

Provenance, name of region	Nearest village/town	Geographical location and elevation			Annual mean temperature, °C	Continentality index	Degree days +5 °C
		Latitude, N°	Longitude, E°	Altitude, m			
1B Nishnij Novgorod	Vetluga	57°30´	45°10´	145	3.1	44	1446
2A Plesetsk	Emtsa	63°05´	40°21´	100	1.1	40	1037
2B Plesetsk	Korasi	63°00´	40°25´	120	1.0	40	1023
2C Plesetsk	Sheleksa	62°09´	40°19´	120	1.3	40	1068
4A Petchora	Usinsk	66°00´	57°48´	75	–3.5	49	692
6A Perm	Okhansk, Yugo-Kamsky	57°19´	55°27´	160	2.2	48	1441
6B Perm	Nyazepetrovsk, Uzaim	56°09´	59°32´	460	1.1	50	1289
6C Perm	Kyshtym	55°43´	60°27´	480	2.2	49	1441
7A Ufa	Maginsk	55°45´	56°58´	370	1.0	51	1324
7B Ufa	Miass	54°58´	60°07´	380	1.9	52	1480
7C Ufa	Zlatoust	55°07´	59°30´	600	0.6	51	1277
9A Boguchany	Boguchany	58°39´	97°30´	158	–2.6	64	1204
11A Altai	Kosh-Agash, Tenedu	50°16´	87°54´	1630	–0.9	49	956
11B Altai	Kosh-Agash, Karnagalu	50°12´	87°47´	1580	0.3	46	1070
11C Altai	Kosh-Agash, Turgune	50°14´	87°03´	1630	–1.1	47	904
13A Magadan	Splavnaya	59°50´	150°40´	60	–3.1	41	650
14A Chabarovsk	Vaninskyi	49°09´	139°00´	100	1.5	54	1315
14B Chabarovsk	Vaninskyi	49°12´	139°00´	125	1.3	54	1295
14C Chabarovsk	Vaninskyi	49°08´	139°00´	90	1.2	54	1267
15A Sachalin	Nogliki	51°50´	143°00´	50	–0.1	51	1021
Raivola forest	Raivola, Russia	60°14´	29°35´	50	4.3	33	1353
Mv98 Punkaharju a), b)	Punkaharju, Finland	61°48´	29°19´	95	2.9	35	1203
Sv309 Lassinmaa a)	Jämsänkoski, Finland	62°04´	25°09´	107	3.0	32	1142
Sv356 Neitsytniemi a)	Imatra, Finland	61°12´	28°48´	70	3.5	34	1258
Mv135 Punkaharju b), c)	Krnov, Czech Republic d)	50°05´ d)	17°40´ d)	330 d)	8.0 d)	24 d)	1789 d)

a) Raivola origin, seed orchard or stand. b) Seed from Metla Punkaharju research forest. c) European larch (*Larix decicua* Miller). d) Values for origin.

latitude (N°), longitude (E°), altitude above sea level and continentality index according to Conrad (1946) in Tuhkanen (1980).

2.2 Layout of the Field Experiment and Measurements

In autumn 2005, the seedlings grown in the greenhouse over one growing season (see Lukkarinen et al. 2009) were packed for cold storage in plastic bags and treated with Topsin M fungicide. In June 2006, two field experiments were established with this material, one in Punkaharju (61°49´N, 29°19´E) and the other in Kivalo (66°19´N, 26°38´E), with randomized block design, including one plot of each provenance per block (Table 2). The Punkaharju field trial was established on the shore of Lake Puruvesi, on a rocky, flat, fertile site type (OMT, *Oxalis-Myrtillus*). In the previous year, 2005, the site was harrowed after a clear-cut of a mature Norway spruce (*Picea abies* L.) stand and harvesting of logging residues. On this site a coppice was also cut down in 2008. The Kivalo field trial was established on a medium fertile site type (HMT, *Hylocomium-Myrtillus*). This site was split by a road. In 2004 both the first sub-trial (site 1) was ploughed while the other (site 2) was harrowed, i.e. the year following clear-cut of the mature Norway spruce stand.

Field measurements were done for all sites in 2006, 2008 and 2009 (Table 3), excluding Kivalo site 2 which was not done in 2009, because of its poor condition. On the harrowed Kivalo site 2 the seedlings suffered much more because of competition from other vegetation, and possibly also on the generally poorer growing conditions, than on the ploughed site 1. It has been shown that ploughing considerably improves the temperature and hydrology conditions in northern Finnish soils (Lähde 1978).

In Kivalo, even negative height growth was also obtained in 2009 for some provenances as a result of damages to the top shoot and mortality. Frost damages include, in this work, all damages caused by low temperatures, regardless of what time of the year they occurred. Mammal damages include vole, hare, deer, moose, and reindeer caused damages. Voles were the most common pests based on bite marks (related to high vole cycle peak during winter 2008–2009 in southern Finland).

2.3 Statistical Analysis

The differences between provenances regarding survival, height growth and damages were

Table 2. Description of the field experiments in Punkaharju and Kivalo (sites 1 and 2).

	Punkaharju	Kivalo 1	Kivalo 2
Latitude	61°49´N	66°19´N	
Longitude	29°19´E	26°38´E	
Altitude, m	78	265	267
Temperature sum (degree days)	1235	797	793
Continentality index	35	37	37
Slope direction	S-W	N-W	N-E
Slope, %	~0	4–8	
Experiment size, ha	1.2	1.6	1.4
Provenances	20	17	17
Comparison lots	5	4	4
Blocks	5	3	3
Plots	123	62	54
Plot size	10 × 10 m	16 × 16 m	16 × 16 m
Seedlings in plot	25	49	49
Forest type	OMT	HMT	HMT
Soil type	Sandy moraine	Sandy moraine	Sandy moraine
Scarification method	Harrowing	Ploughing	Harrowing

Table 3. Measurements made on the test sites (PU = Punkaharju, KI 1 and KI 2 = Kivalo sites 1 and 2) in different years.

Measurements	2006			2007			2008			2009		
	PU	KI 1	KI 2	PU	KI 1	KI 2	PU	KI 1	KI 2	PU	KI 1	KI 2
Survival, %	×	×	×				×	×	×	×	×	
Height, cm				$\times^{a)}$	$\times^{a)}$	$\times^{a)}$	×	×	×	×	×	
Frost damages, %							×	×	×	×	×	
Crown forking, %							×	×	×	×	×	
Mammal damages, %							$\times^{b)}$	$\times^{b)}$	$\times^{b)}$	×	$\times^{b)}$	
Sawfly damages, %							$\times^{b)}$	$\times^{b)}$	$\times^{b)}$	×	$\times^{b)}$	

[a] 2007 height was measured in 2008. [b] Was not used in analyses because of low frequencies.

tested with Kruskal-Wallis non-parametric one way analysis of variance (PASW Statistics 18, Rel. 18.0.0 2009. Chicago: SPSS Inc.), because variances in most cases were unequal in Levene's test (sign, $p<0.05$). The relationships between different variables were also studied using Pearson correlation and linear regression analyses, i.e. between measured variables and the climatic and geographical information for provenances. In regression models, the explanatory variables should be statistically significant ($p<0.05$). Transformations of the data (square root, power, and logarithmic) were needed for most of the geographical and climatic variables in order to study nonlinear relationships. The comparison lots were excluded from regression analyses when geographical or climatic variables were used as explanatory variables, as the material was not collected from the original growing sites of the provenances. Kivalo site 2 results are discussed only occasionally when necessary.

3 Results

3.1 Differences between the Provenances

3.1.1 Survival

In 2009, the average survival rate of different provenances was 59% both in Punkaharju and Kivalo site 1. In Punkaharju, provenance 9A Boguchany had the highest survival rate of 87%, followed by Finnish comparison lot Sv309 Lassinmaa with a rate of 76% (Fig. 1). The survival of Dahurian larches was below the average with exception to Kurile larch (*Larix gmelinii* var. *japonica* (Regel) Pilger) 15A Sachalin which had a slightly above average survival rate. As a comparison, in the Kivalo site 1, the northern Siberian larch provenances and Finnish Siberian larch comparison lots and the 13A Magadan Dahurian larch provenance survived best in 2009. Furthermore, European larch had the second poorest survival rate in Kivalo site 1, although it had an average survival in Punkaharju. In Kivalo site 2, the European larch was almost wiped out in 2008, but it still had a higher survival rate in 2009 than the Dahurian larches, except for the Kurile larch 15A Sachalin (being also average in Punkaharju).

The differences in survival rate between the provenances were significant ($p<0.05$) in Kivalo, but not in Punkaharju (Table 4). The drop in survival rate from 2008 to 2009 was 17% in Kivalo, while in Punkaharju it was only 5%. However, in Punkaharju considerable mortality was observed already during the first summer (in 2006). Kivalo site 2 had very low survival, 42% already in 2008, with the southernmost provenances being almost completely wiped out. There was a strong correlation between the Kivalo sites 1 and 2 regarding survival rate in 2008: the provenances that did not succeed on site 2 were also below average on site 1. Dahurian larch 14A Chabarovsk was totally decimated in Kivalo site 2 in 2008.

3.1.2 Height Growth

The differences in total height growth between the provenances were significant ($p<0.05$) both

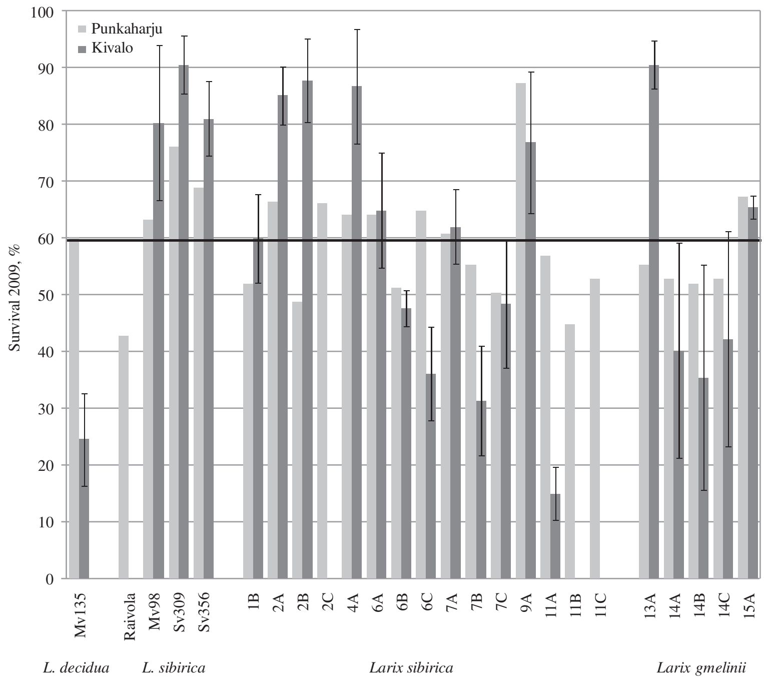

Fig. 1. Average survival rate of different provenances and standard deviations for Kivalo (in Punkaharju, with no statistical differences between the provenances, and the standard deviations were so high that it was unpractical to include them here). The heavy line represents the average survival rate in Punkaharju and Kivalo site 1, which was the same.

Table 4. Means and standard deviations (stdev) of survival %, total height growth, and different damage % over years (statistical significant differences tested with Kruskal-Wallis one-way analysis of variance).

Variable	N, mean ± stdev				Kruskal-Wallis	
	Punkaharju		Kivalo 1		Punkaharju	Kivalo 1
Survival %, 2006	25	73.6 ± 17.18	21	93.2 ± 5.70	0.658	0.047
Survival %, 2008	25	64.3 ± 18.79	21	76.4 ± 19.95	0.231	(<0.001)
Survival %, 2009	25	59.3 ± 20.92	21	59.1 ± 25.00	0.246	(<0.001)
Total height growth cm, 2007	25	76.4 ± 14.75	21	30.7 ± 7.86	(<0.001)	(<0.001)
Total height growth cm, 2008	25	110.4 ± 24.24	21	44.4 ± 10.25	(<0.001)	(<0.001)
Total height growth cm, 2009	25	147.3 ± 40.55	21	49.4 ± 16.29	(<0.001)	(<0.001)
Frost damages %, 2009	25	14.9 ± 15.67	21	32.13 ± 28.94	0.111	0.652
Forking 2009, %	25	19.9 ± 20.74	21	52.6 ± 22.59	0.326	0.001
Mammal damages %, 2009	25	15.8 ± 22.32	21		0.136	
Sawfly damages %, 2009	25	18.2 ± 18.94	21		0.850	

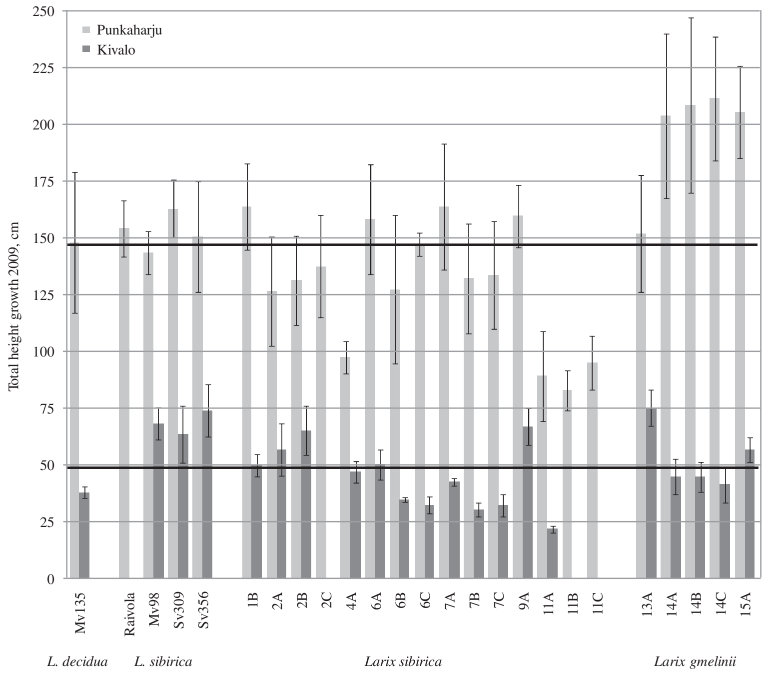

Fig. 2. Average height growth and standard deviations for different provenances. The heavy lines represent the total average height growth in Punkaharju and Kivalo (site 1).

in Punkaharju and Kivalo (Table 4). The average height in Punkaharju was 76 cm in 2007 and 147 cm in 2009. In Kivalo site 1, seedlings were considerably shorter on average, i.e. 31 cm in 2007 and 49 cm in 2009. In Kivalo site 2, total height growth was in line with the results of site 1 for 2008, though still lower on average.

The southern Dahurian larches were clearly the tallest ones in Punkaharju, followed by Siberian larches 1B Nishnij Novgorod, 7A Ufa and Sv309 Lassinmaa (Fig. 2). In Kivalo site 1, the northern Siberian larch provenances, Finnish Siberian larch comparison lots and the northernmost Dahurian larch, 13A Magadan, were the tallest ones. In Punkaharju, the Magadan provenance was the shortest of the Dahurian larches, opposite to Kivalo. Provenances from the Altai Mountains (11A–C) were the shortest both in Punkaharju and Kivalo.

European larch had an average height growth in Punkaharju, while in Kivalo it was below average (Fig. 2). Although being a southern provenance, the European larch did not grow as well as the southernmost Dahurian larch provenances. In Punkaharju, the height growth of the European larch was similar to the shortest and northernmost Dahurian larch, 13A Magadan.

3.1.3 Damages

Frost damages were common in the Kivalo site 1 in 2009, where 32% of the living seedlings were damaged to some extent. In Punkaharju, the corresponding value was 15% (Table 4). The differences between the provenances were significant ($p<0.05$) in Punkaharju, but not in Kivalo.

In 2009, forking was observed in 20% of seedlings in Punkaharju and in 53% of seedlings in Kivalo (Table 4), but differences between provenances were not significant ($p>0.05$) in Punkaharju. In Punkaharju about 16% of the seedlings also had different kinds of mammal caused damage (Table 4). Dahurian larches had less mammal damage than Siberian larches ($p>0.05$). During the 2009 growing period there was also a larch sawfly outbreak in Punkaharju, with about 18% of the seedlings suffering sawfly larvae damages. However, no significant differences (p>0.05) were observed between the provenances (Table 4). Larvae and the nature of the damages indicated the species to be *Lygaeonematus wesmaeli* and *Pristiphora laricis*.

3.2 Explanations for the Differences between Provenances

3.2.1 Survival

In Punkaharju, in 2006, the survival rate correlated with latitude (p<0.05), but this was not the case in 2009 (p>0.05) (Table 5). Survival rate was also dependent on the mean temperature of the coldest month at the origin site (*Cmin*); the lower the mean temperature was the higher was the survival rate (Table 6, Eq. 1, 2 and 3). However, a stronger relationship was observed between the 2009 survival rate and the annual range of monthly mean temperatures (*Cmax-Cmin*); low values in the annual range of monthly mean temperatures resulted in a lower survival rate (Table 6, Eq. 4). Using the continentality index also to explain the survival rate raised the coefficient of determination, r^2, to 52% (Table 6, Eq. 5). Continentality of the provenance origin also increased the survival %.

In Kivalo, latitude alone best explained the differences in survival rate (r=0,81, Table 5). The northern provenances generally had higher survival rate. An increase of one latitude degree increased survival by 3.6% in Kivalo site 1 in 2009 (Table 6, Eq. 15 Fig. 3). However, the relationship was stronger in 2008 (Table 6, Eq. 14). Transfer of over 15 degrees to the north decreased the survival rate significantly. Of the climatic variables, only temperature sum correlated with survival in Kivalo, indicating that provenances from cold climates had higher survival rate (Table 5). The 2009 survival rate was best explained by the latitude and altitude (Table 6, Eq. 16). The survival rate was higher for provenances originating from northern latitudes and low altitudes.

There were several correlations between the measured variables (Table 7). The survival % of 2006 correlated positively with 2009 survival both in Punkaharju and Kivalo. However, there was no significant correlation (p>0.05) in the survival of provenances between Punkaharju and Kivalo.

Table 5. Pearson correlation coefficients between measured variables and geographical and climatic variables in Punkaharju (n=20) and Kivalo site 1 (n=17). Statistically significant correlations (p<0.05) are highlighted in bold. Punkaharju values are above the line and Kivalo results below it.

Variable	Latitude, N°	Longitude, E°	Altitude, m	Continentality index	Max-Min temperature, °C	Temperature sum, +5 °C
Survival %, 2006	**0.45**	–0.32	0.00	0.12	0.36	–0.24
Survival %, 2009	0.38	–0.06	–0.34	0.36	**0.59**	–0.04
Total height growth cm, 2007	–0.28	**0.54**	**–0.61**	0.43	0.34	0.42
Total height growth cm, 2009	–0.30	**0.56**	**–0.67**	0.39	0.28	0.42
Height growth cm, 2009	–0.31	**0.61**	**–0.65**	0.36	0.24	0.33
Frost damages %, 2009	–0.02	–0.43	**0.60**	–0.27	–0.29	–0.06
Forking 2009, %	**0.50**	**–0.66**	–0.02	–0.18	0.07	0.11
Mammal damages %, 2009	**0.70**	**–0.85**	–0.22	–0.32	–0.01	0.14
Sawfly damages %, 2009	**0.47**	–0.22	**–0.70**	0.07	0.30	0.19
Survival %, 2006	**0.65**	–0.45	–0.04	–0.33	–0.04	–0.23
Survival %, 2009	**0.81**	–0.16	**–0.63**	–0.39	–0.07	**–0.55**
Total height growth cm, 2007	**0.56**	–0.41	0.03	–0.29	–0.02	–0.07
Total height growth cm, 2009	**0.49**	0.23	**–0.69**	–0.23	–0.04	–0.45
Height growth cm, 2009	0.16	**0.53**	**–0.74**	–0.07	–0.05	–0.46
Frost damages %, 2009	0.34	–0.12	–0.39	**–0.52**	–0.41	0.00
Forking 2009, %	**0.53**	0.04	**–0.61**	–0.30	–0.08	–0.33

Table 6. Linear regression models for measured variables in Punkaharju (n = 20) and Kivalo (n = 17) with climatic and geographical variables as fixed factors. Punkaharju and Kivalo equations are divided by line, Punkaharju values are shown on top.

Equation		Factor		Coefficients			Significance			ANOVA		Model summary	
		A	B	Constant	A	B	Constant	A	B	F	Sig.	R^2	SEE
1	Survival 2006	*Cmin*		53.263	–1.239		<0.001	0.046		4.600	0.046	0.204	6.086
2	Survival 2008	*Cmin*		34.065	–1.775		0.013	0.027		5.800	0.027	0.244	7.765
3	Survival 2009	*Cmin*		20.842	–2.241		0.124	0.009		8.546	0.009	0.322	8.077
4	Survival 2009	*Cmax–Cmin*		–8.638	2.001		0.693	0.006		9.729	0.006	0.351	7.903
5	Survival 2009	*Cmax–Cmin*	*Continentality*	–29.309	4.920	–1.580	0.177	0.002	0.025	9.255	0.002	0.521	6.983
6	Height 2007	*Altitude*	*Latitude*	186.989	–0.023	–1.809	<0.001	<0.001	<0.001	30.415	<0.001	0.782	6.438
7	Height 2008	*Altitude*	*Latitude*	308.985	–0.042	–3.250	<0.001	<0.001	<0.001	79.363	<0.001	0.903	7.282
8	Height 2009	*Altitude*	*Latitude*	514.167	–0.077	–6.015	<0.001	<0.001	<0.001	150.363	<0.001	0.946	9.652
9	Height 2009	*Altitude*		167.095	–0.049		<0.001	0.001		14.803	0.001	0.451	30.040
10	Frost 2009	*Altitude ln*		–10.384	4.424		0.152	0.002		12.373	0.002	0.407	6.052
11	Forking 2009	*longitude*		27.942	–0.125		<0.001	0.002		13.543	0.002	0.429	5.768
12	Mammal 2009	*longitude ln*		87.924	–17.254		<0.001	<0.001		55.147	<0.001	0.754	4.665
13	Sawfly 2009	*Altitude*		21.603	–0.009		<0.001	<0.001		17.627	<0.001	0.495	4.823
14	Survival 2008	*Latitude*		–62.859	2.491		0.010	<0.001		42.946	<0.001	0.741	7.765
15	Survival 2009	*Latitude*		–146.080	3.630		0.001	<0.001		29.525	<0.001	0.663	13.648
16	Survival 2009	*Latitude*^{2}	*Altitude ln*	29.924	0.027	–11.263	0.154	<0.001	<0.001	47.408	<0.001	0.871	8.730
17	Height 2008	*Latitude*		–14.529	1.030		0.416	0.004		11.154	0.004	0.426	6.302
18	Height 2009	*Altitude*		54.353	–0.026		<0.001	0.00226		13.491689	0.00226	0.474	10.722427
19	Height 2009	*Altitude ln*	*Latitude ln*	–102.316	–10.724	50.948	0.307	<0.001	0.045	17.358	<0.001	0.713	8.200
20	Height 2009	*Altitude*	*temperature sum*	84.419	–0.026	–0.025	<0.001	<0.001	0.011	14.461	<0.001	0.674	8.736
21	Frost 2009	*Continentality ln*	$\sqrt{continentality}$	2852.459	–1420.551	385.818	0.014	0.019279	0.025	7.906	0.005036	0.530	10.709
22	Forking 2009	*Altitude*		58.320	–0.028		<0.001	0.010		8.650	0.010	0.366	14.738

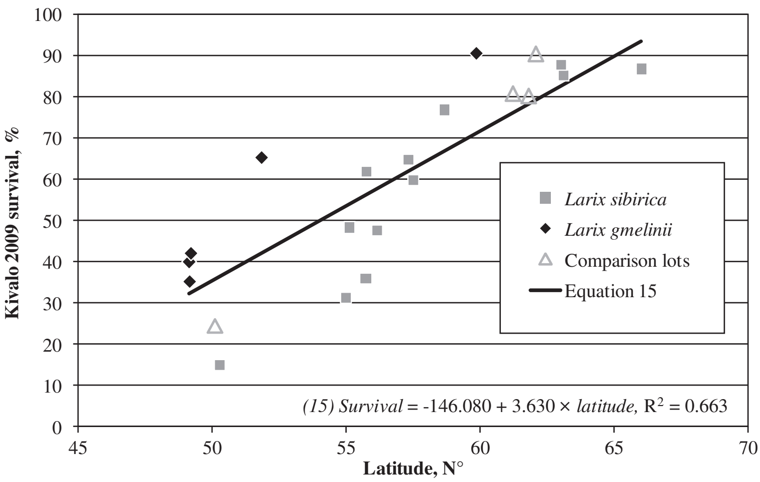

Fig. 3. Relationship between survival rate and provenance latitude in Kivalo in 2009 (n = 17).

Table 7. Pearson correlation coefficients between measured variables in Punkaharju (n = 20) and Kivalo (n = 17). Punkaharju values are shown on top right, Kivalo values on bottom left. Correlations between Punkaharju and Kivalo are shown on the diagonal (boxed).

Variable	Survival %, 2006	Survival %, 2009	Total height growth cm, 2007	Total height growth cm, 2009	Height growth cm, 2009	Frost damages %, 2009	Forking 2009, %	Mammal damages %, 2009	Sawfly damages %, 2009
Survival %, 2006	0.36	0.68	–0.26	–0.37	–0.40	0.15	0.61	0.47	0.31
Survival %, 2009	0.57	0.33	0.33	0.14	0.03	–0.13	0.39	0.27	0.55
Total height growth cm, 2007	0.67	0.42	–0.21	0.94	0.85	–0.47	–0.20	–0.30	0.35
Total height growth cm, 2009	0.35	0.86	0.42	0.24	0.97	–0.57	–0.33	–0.31	0.38
Height growth cm, 2009	–0.03	0.66	–0.15	0.83	0.61	–0.58	–0.42	–0.35	0.35
Frost damages %, 2009	0.49	0.50	0.61	0.58	0.28	–0.11	0.44	0.30	–0.32
Forking 2009, %	0.54	0.86	0.53	0.90	0.66	0.72	0.19	0.81	0.19
Mammal damages %, 2009									0.51

3.2.2 Height Growth

Of all the geographic variables longitude and altitude best explained the differences in total height growth between provenances in Punkaharju (Table 5). However, the fast growing Dahurian larches from the east account for the strong correlation between the longitude and height growth. When the Dahurian larches were excluded from the analyses no significant correlations between height and longitude existed ($p > 0.05$), instead a strong negative correlation between height growth and latitude was observed. This reveals that the southern provenances grew taller, on average. In Punkaharju, total height and the 2009 height growth had rather similar correlation with geographic variables, but this was not the case in Kivalo; where eastern provenances had larger height growth in 2009, but not total height.

Poor growth of the Altai Mountains provenances resulted in a negative correlation between height growth and altitude. Altai provenances caused the same phenomena in Kivalo in 2009. Instead of longitude, the latitude had a positive correlation

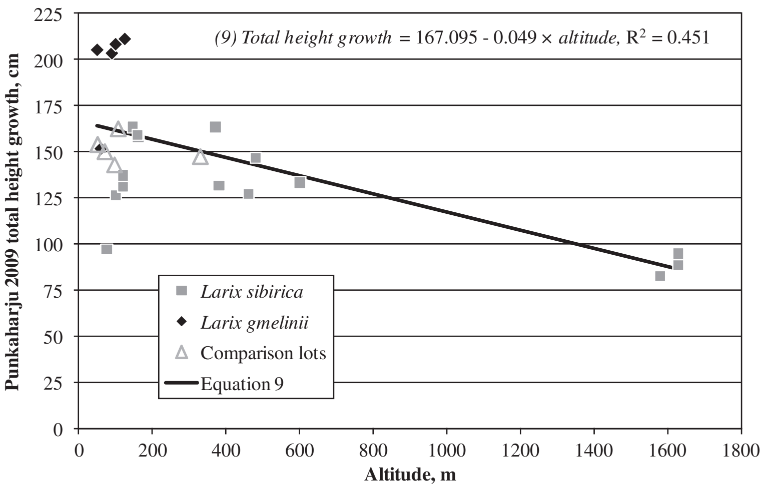

Fig. 4. Total height growth in Punkaharju 2009 in relation to altitude (n = 20).

with height growth in Kivalo (Table 5), so that northern provenances had larger growth than the more southern ones. In Punkaharju, the relationship was the opposite ($p > 0.05$). No significant correlations between the climatic variables and height growth ($p > 0.05$) were observed, although in Punkaharju provenances, with its high temperature sum, seemed to have a larger height growth, on average. In Kivalo an opposite trend was observed.

Altitude explained 45% of the total height growth in Punkaharju in 2009 (Table 6, Eq. 9, Fig. 4). A decrease of one hundred metres in provenance altitude increased total height growth by five centimetres. When latitude was added as a second explanatory variable, the r^2 rose to 95% (Table 6, Eq. 8). A decrease of altitude and latitude increased the total height growth. The same tendency was observed in 2008 and 2007 (Table 6, Eq. 6 and 7).

Altitude and latitude best explained the differences between provenances, also in Kivalo (Table 5). Compared to Punkaharju, altitude had a similar effect in Kivalo (Table 6, Eq. 18). When altitude and latitude were used together, r^2 rose to 71% (Table 6, Eq. 19). The height growth of 2009 had a negative correlation with altitude in Punkaharju and Kivalo, but a positive correlation with longitude (Table 5). A decrease in altitude and temperature sum together increased the total height growth (Table 6, Eq. 20). Provenances from low altitudes and cold climates had larger growth in Kivalo. In 2008, of all the geographic variables in Kivalo latitude best explained the growth. According to equation 17 (Table 6), an increase of one degree in latitude increases the total height growth by one centimetre.

In Punkaharju, all the height growth variables correlated together very strongly (Table 7). In Kivalo, only the total height and height growth of 2009 had a positive correlation. Height growth of 2009 was also the only height growth variable for provenances that correlated between Punkaharju and Kivalo.

Survival correlated positively with height variables in Kivalo, indicating that provenances with a high survival rate also had larger average height growth (Table 7). In Punkaharju there was no correlation between survival and height growth.

3.2.3 Damages

In Punkaharju, frost damages were dependent on altitude so that provenances from high altitudes had more damages caused by sub-zero temperature degrees (Tables 5 and 6, Eq. 10, $r^2 = 41\%$). In Kivalo, frost damages had a negative correlation with continentality index, indicating that provenances from continental climates had less frost damages (Table 6, Eq. 21, $r^2 = 53\%$).

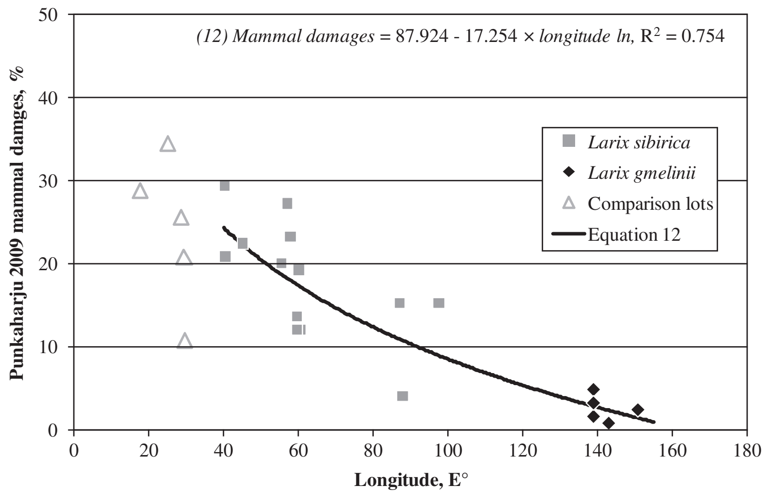

Fig. 5. Mammal damage % in relation to provenance longitude in Punkaharju (n = 20).

Forking had a negative correlation with longitude, though a positive correlation with latitude (Table 5). The eastern provenances, which were all Dahurian larches and also very southern with exception to 13A Magadan, had less forking (Table 6, Eq. 11). When Dahurian larches were excluded from the analyses, there were no significant correlations ($p > 0.05$). In Kivalo, forking had a positive correlation with latitude, but stronger negative correlation with altitude. Provenances from high altitudes had less forking (Table 6, Eq. 22).

In Punkaharju, provenance longitude and latitude explained well the mammal damages, with the eastern and southern provenances seeming to have less damages (Table 5). Longitude explained 75% of the variation in mammal damages between provenances (Table 6, Eq. 12, Fig. 5) The trend was similar, although not so strong ($r^2 = 0{,}504$) also when Dahurian larches were excluded from the analyses.

Sawfly damages had a negative correlation with altitude and positive correlation with latitude (Table 5). Damages seemed to be more common in northern provenances from low altitudes. However, sawfly damages were best explained by altitude (Table 6, Eq. 13). When Altai provenances (11A–C) were excluded from the analysis, there were no significant correlations ($p > 0.05$).

The damage variables had several significant correlations ($p < 0.05$) with other measured variables (Table 7). In Punkaharju there was no dependence between survival and frost damages, but forking, mammal and sawfly damages seemed to be more common in provenances with a high survival rate. In Kivalo frost damages and forking were more frequent for provenances with a high survival rate. In Punkaharju, all the height growth variables had negative correlations with frost damages. Seedlings with high height growth suffered less frost damages. In Kivalo, the result was the opposite, as the total height of 2007 and 2009 had a positive correlation with frost damages. In the north, taller seedlings had more frost damages, additionally they had more frequent crown forking. Frost damages had a significant ($p < 0.05$) positive correlation with forking in Kivalo, but not in Punkaharju. Forking had a positive correlation with mammal damages in Punkaharju. These indicate that forking was partly caused by frost and mammal damages. Sawfly damages were more common for provenances that had suffered mammal damages.

4 Discussion and Conclusions

4.1. Survival

After four growing seasons in the field, the average survival rate of the provenances in both Punkaharju and Kivalo had already declined to 59%. Differences in survival between provenances were only significant ($p<0.05$) in Kivalo. In Punkaharju, mortality was already high after the first growing season in 2006. Survival of Siberian larches was on average 76%, while it was 69% for the Dahurian larches and 70% in the comparison lots. In Kivalo site 1, the corresponding values were considerably higher, i.e. 94, 90 and 95%. Survival in Kivalo site 2 was in line with the results of site 1. The damage to the seedlings was not studied in detail in 2006, but large pine weevil damages were common in Punkaharju. The large pine weevil can be considered to be the main reason for the increased mortality in addition to partly insufficient soil scarification (seedlings were occasionally planted outside the scarification tracks).

In Punkaharju, the provenance from the most continental climate, 9A Boguchany, had clearly the highest survival rate. In a comparable Swedish field experiment in Särna (N61°31´, E13°00´, 540 m) the Boguchany provenance survival was 24% lower than in Punkaharju (Karlman 2010). This difference can be explained by the more maritime climate in Särna (continentality index 29 versus 35 in Punkaharju). In the Swedish experiment, the provenances from strongly continental areas had, in general, poor survival and growth (Karlman 2010). Our results were opposite in this sense, i.e. continentality of the provenance origin increased survival in Punkaharju (Table 6, Eq. 5). The Swedish Särna site is on the same latitude as Punkaharju, but its altitude is significantly higher, therefore representing a lower temperature sum (725 d.d.). The Swedish study material also included a few provenances from even more continental climates (continentality index 78–83), which can explain these contradictory results. In addition to the differences in study material, there are also differences in the used explanatory climatic variables (and their accuracy) between these studies. In our work, we also considered the effect of provenance altitude regarding the temperature values and temperature sum, which increased the accuracy of the climatic data.

Raivola origin seed sources were above average regarding survival, except the seed source straight from the Raivola forest. The reason for its low survival, in comparison with the others, might be just a combination of random damages and the fact that it had only three plots instead of five in the field test. European larch had an average survival rate. From the Dahurian larches (*Larix gmelinii* Rupr.), the Kurile larch 15A Sachalin had an above average survival rate both in Punkaharju and Kivalo, and also a higher survival rate than Olga Bay larches (*Larix gmelinii* var. *olgensis* (Henry) Ostenf. & Syrach Larsen) 14A–C from Chabarovsk and Dahurian larch 13A Magadan in Punkaharju. Our results concerning the survival of different provenances have been, with the exception of the most continental provenances, quite similar to those in Sweden in Särna and in Järvträsk (N65°11´, E19°31´, 410 m, 650 d.d.) which is the northernmost of the three test sites in Sweden (Karlman 2010). Both Swedish and Finnish results differ from Norwegian field trial results from Bergen (60°N). In southern maritime conditions, Olga Bay larches from Chabarovsk had the best survival and height growth after three growing seasons (Øyen et al. 2007).

In Kivalo, the provenances originating from northern latitudes had the highest survival % (Table 6, Eq. 14, 15). Provenance 13A Magadan and comparison lot Sv309 Lassinmaa had a survival rate of 90%. Raivola origin Lassinmaa seed orchard has been established with plus trees from northern Finland; including some from Kivalo (Evira 2010). Raivola origin seed has proven to be adaptive to different climatic conditions and is used throughout Finland (Mikola 1992, Vakkari et al. 1995) and also in the maritime climate of Iceland (Blöndal and Snorrason 1995). According to Blöndal and Snorrason (1995), most of the larch seed used in Iceland since 1986 has been obtained from seed orchard Neitsytniemi Sv356 (Evira 2010). For use in the most northern locations in Finland, Vakkari et al. (1995) recommended more northern provenances than the Raivola origin, such as Pinega River in Arkhangelsk. However, in Kivalo, situated 25 km south from the Arctic Circle, there was no difference in survival between the Lassinmaa seed orchard material and the Plesetsk provenances originating near Pinega River.

In Punkaharju, the rather small differences in survival rates could not be well explained with any geographical or climatic variables. Variables connected to continentality seemed to have some influence on survival. Continentality increased survival (Table 5, Table 6, Eq. 1–5). In Särna, and in the southernmost Swedish test site Österbymo (N 57°47´, E 15°37´, 250 m, 1160 d.d.), continentality had an opposite effect, although it was significant ($p<0.05$) only for the Dahurian larches. In Österbymo, latitude had similar but stronger effect than in Punkaharju; the northern provenances had a lower survival rate (Karlman 2010).

In Kivalo, the northern provenances had a higher survival rate; latitude was the best variable in explaining survival (see Table 5). In Järvträsk, the results were similar concerning Siberian larches, but among the Dahurian larches, the result was opposite although non-significant ($p>0.05$). This is probably because there were more Dahurian larch provenances in the Swedish experiments (Karlman 2010). In general, the climatic variables poorly explained the differences in survival compared to the geographic variables. However, there was a weak indication that the provenances from warm climates had a lower survival rate (Table 5). In Järvträsk, the result was similar but non-significant ($p>0.05$) for Siberian larches. The results with Dahurian larches again differed strongly and the dependence was opposite.

4.2 Height Growth

The height growth differences between the two test sites became large after four growing seasons in the field experiments. In 2007 in Punkaharju, the average height of the seedlings had doubled from 31 cm in the greenhouse (Lukkarinen et al. 2009) to 76 cm (Table 4). In Kivalo, after two years in the field, the average height was still the same than in the greenhouse. Height growth in Kivalo was very slow, since average heights were 44 and 49 cm in 2008 and 2009, respectively. The difference to Punkaharju was considerable, since the average height there in 2009 was 147 cm.

The differences between provenances in height growth were significant ($p<0.05$). The tallest provenances in Punkaharju were the southern Dahurian larches 14A–C Chabarovsk and 15A Sachalin (slightly over 200 cm). Provenances 4A Petchora and 11A–C Altai were clearly below the average height (less than 100 cm). The best Siberian larch provenances did not differ from the Raivola origin comparison lots (Fig. 2). In Kivalo, in addition to shorter height, the order of the provenances, with regards to height, was different than in Punkaharju. The southern Dahurian larches, which were the tallest in Punkaharju, were average in Kivalo. The tallest provenance in Kivalo was the northernmost Dahurian larch provenance 13A Magadan, followed by the northernmost Siberian larches, 9A Boguchany and the Raivola origin comparison lots. The Punkaharju height growth differences between provenances were in line with the Swedish field experiments, but the results in Kivalo differed clearly from them (Karlman and Martinsson 2007). The poor agreement was probably caused by the fact that it is the northernmost test site.

The differences between provenances could be explained by the geographical variables and in some cases also by climatic variables. Altitude was the best single explanatory variable, mainly due to Altai provenances (11A–C), which were from significantly higher altitudes than the other provenances. They had poor growth both in Punkaharju and Kivalo. Probably the decisive factor for their poor growth was their unique combination of southern latitude and high altitude (cold climate). The southern latitude cannot solely account for their poor growth, since there were rather well growing provenances (14A–C Chabarovsk, 15A Sachalin and Mv135 European larch) in corresponding latitudes. In addition to latitudinal transfer of provenances, the altitude is a significant variable since mean temperature declines when altitude increases (Liljeqvist 1962). According to Viherä-Aarnio (1993), a provenance from Altai (altitude 2000 m) was the worst of the Siberian larch provenances having both poor survival rate and growth in a field test in Inari (69°03´N, 27°05´E, 170 m). Our results verify that provenances from high altitudes of the Altai Mountains are not suitable for forestry in Finland.

In Punkaharju, there was a slight, statistically non-significant ($p>0.05$), trend that an increase in latitude decreased height growth. In Kivalo, the effect was the opposite (Table 5). Altitude together with latitude explained very well height growth both in Punkaharju (Eq. 8, $r^2 > 90\%$) and in Kivalo (Eq. 19, r^2 70%). In Sweden, the increase in latitude always decreased height growth, although in Järvträsk, the result was not significant ($p > 0.05$) (Karlman 2010).

After the first growing season in the greenhouse in Punkaharju in 2005, no significant differences ($p > 0.05$) were observed in height growth between provenances (Lukkarinen et al. 2009). After four growing seasons in field conditions in Punkaharju, the differences between provenances were profound. The Dahurian larches did not differ from the tallest Siberian larches in the greenhouse, but in the field the Dahurian larches were clearly taller. All the Dahurian larch provenances had very similar height growth in the greenhouse, but in field conditions the northern Magadan provenance was significantly shorter. Altai provenances had average growth in the greenhouse, but had poor growth in the field. European larch was average, regarding growth, both in the greenhouse and field. In the greenhouse during the first growing season, the genetic differences between provenances did not yet manifest themselves to their full extent. This is partly because of the optimal greenhouse conditions, but also because the seedlings were transplanted after sowing to seedling trays, which might have had a levelling effect. The differences in seed weight were also a factor since southern provenances of Siberian larch had larger seeds than northern Siberian larches or the Dahurian larches (Lukkarinen et al. 2009). This change in the seed weight and height growth relationship with age was in good agreement with the findings of Mikola (1980) for Scots pine and Norway spruce. It is also a clear continuation of the changes in correlations between seed weight and height growth in early and late summer in the same material (Lukkarinen et al. 2009).

4.3 Damages

Damages were common on both sites. In 2009, 20% of the seedlings had forking in Punkaharju and 52% in Kivalo. However, damages to the crown were caused by various reasons, such as the climate, insects, fungi and mammals. Mammal damages were clearly less common on Dahurian larch than Siberian larch (Eq. 12). The reasons for this are not clear, but faster development from the small seedling size might be one factor. Moose browsing damages of Scots pine (*Pinus sylvestris* L.) and silver birch (*Betula pendula* Roth) has been shown to correlate negatively with latitude of the geographic origin so that the southern origins are more inclined to be damaged (Niemelä et al. 1989, Viherä-Aarnio and Heikkilä 2006). Rousi (1983) draws the same conclusion concerning vole damages with some spruce (*Picea* A. Dietr.) and pine (*Pinus* L.) species. This is contrary to our results as the northern provenances had more mammal damage. Viherä-Aarnio and Heikkilä (2006) also found that the sapling height had a significant effect on the proportion of browsed silver birch trees; damages decreasing with increasing sapling height. In this study, there was no correlation between total height growth and mammal damages, but the saplings were still all quite short and therefore easily available for moose browsing.

It is interesting to observe that in a vole damage study by Rousi (1983) in Northern Finland, the North American tamarack (*Larix laricina* (Du Roi) C. Koch) did not suffer any damages. Maybe Dahurian larch and tamarack, which have distribution areas relatively close to each other, share some gene pool proving resistant to rodent damages. According to LePage and Basinger (1995) the Russian larch species and tamarack belong to the same morphological group and have common evolutionary history. However, the larch phylogeny indicates a clear separation between American and Eurasian species and gene flow since the last glaciations is considered to have been unlikely (Semerikov et al. 1999, 2003). Instead of recent genetic contact these species can share, from an evolutionary perspective, a recent common environment. Their good mammal resistance has perhaps evolved as an adaptation to browsing by megaherbivores in ice free refugia during the Pleistocene as hypothesized by Bryant et al. (1989).

In this study no statistically significant differences were found between the provenances regarding frost tolerance (Table 4). In an artificial freezing test with similar study material, Eysteinsson et al. (2009) found highly significant differences in frost damages. Furthermore, they found a correlation between autumn frost damage and provenance latitude and longitude, as well as one between spring frost damage and longitude. Provenances from north-western Russia showed the least damages while the far-eastern provenances had the most damage in both spring and autumn frost tests. However, there was no correlation between frost damage and provenance altitude. In Punkaharju, the eastern Dahurian larch provenances had, on average, a lower rate of frost damage than Siberian larches. There was also a strong correlation between frost damages and provenance altitude indicating that damages were more common in provenances from high altitudes. The reasons for these differences, in artificial freezing tests, might be that autumn and spring frosts were not separated in our results, because in our field measurements it was too difficult to say reliably if the damage was caused by autumn or spring frost. Also the research material differed and there were more high altitude provenances in our study. When the three provenances from Altai Mountains were excluded from the analysis, altitude was no longer a significant variable ($p>0.05$); instead longitude had significant negative correlation with frost damages in Punkaharju, and Dahurian larches had less frost damages.

Eysteinsson et al. (2009) found that provenances from Magadan had high levels of both spring and autumn frost damages. In Kivalo, 13A Magadan had the highest number of frost damages, but in Punkaharju damages were below average. Dahurian and Siberian larches did not differ much in frost damage percentage in Kivalo, although the general appearance of Dahurian larches and the European larch comparison lot was more bush-like. Top shoots that were above the snow during winter time seemed to perish and cause the bush-like appearance. These provenances with high or medium growth in Punkaharju seemed to have the same potential in Kivalo, as was evident by the clearly higher correlation in height growth than in total height between the sites (Table 7). However, they were suffering from the less favorable conditions and growing more horizontally.

4.4 Conclusions

The field experiments in Punkaharju and Kivalo have a distance of 500 kilometres between them and provide a preliminary picture of how the different Siberian and Dahurian larch provenances will grow in geographically and climatically differing Finnish growing conditions. Larch has been found to grow well in Southern Finland, especially in Punkaharju, based on old experiments. Raivola origin Siberian larch has also proven to compete with Scots pine in stem wood production even in Kivalo, which is considered to be a better growing environment than most of the areas at these latitudes, however. Also the Dahurian larch provenance from Magadan have had previously very good survival in the northernmost parts of Finland (Utsjoki, 69°49´N) (Hagman 1993).

Our findings are in agreement with the previous results. Provenances from north western Russia (Plesetsk, Petchora) and from Magadan were among the best regarding survival in Kivalo. Siberian larch provenance 9A from Boguchany had also good growth and survival in Kivalo and should be studied in more detail as the field trials grow older. Tigerstedt et al. (1983) and Tigerstedt (1990) suggested that provenances from areas where continental climate meets maritime climate are likely to have high tolerance to changing weather conditions. Dahurian larch provenance 13A Magadan and Siberian larches from north-western Russia fit well to this description. Dahurian larches from Chabarovsk (14A, 14B, 14C) and Sachalin (15A) showed good growth in Punkaharju in our work. However, their adaption to Finnish climatic conditions, in addition to if the speed of height growth starts to decline in older age should still be studied in more detail. This is because earlier Finnish experiments with quite narrow research material, suggest, that despite good height growth, the yield of Dahurian larches is poorer than Siberian larches (Silander et al. 2000, Autio 2002).

To conclude, the Russian larch material contains interesting provenances which may, in the future, have potential to challenge current seed sources used in Finland. However, this study again proved that the comparison lots descending from Raivola have both good height growth and survival. Few of the Russian provenances could, thus, challenge them in both categories based on our work.

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