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Growth rhythm, height growth and survival of Russian larch (*Larix* Mill.) provenances in greenhouse and field conditions in Finland

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Academic dissertation

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ABSTRACT

The aim of this study was to analyse the growth rhythm, height growth and survival of seedlings of 20 Russian larch (*Larix* Mill.) provenances and five comparison entries in sowing year in greenhouse conditions and in field conditions in southern (Punkaharju 61°49′N, 29°19′E) and northern (Kivalo 66°19′N, 26°38′E) Finland after third and fourth growing seasons. Geographic and climatic conditions of the origins were used to explain the differences between the provenances.

In the sowing year in greenhouse, latitude explained 74% of the length of the growing period. In the field in Punkaharju, the northern Siberian larches (*Larix sibirica* Ledeb.) had the earliest bud burst and the Dahurian larch (*Larix gmelinii* Rupr.) provenances slightly earlier onset of height growth. The temperature sum and latitude of the provenances explained the differences in shoot elongation. After four growing seasons in the field northern provenances had the best survival and height growth in Kivalo. Survival did not differ significantly between provenances in Punkaharju field experiment. The southern Dahurian larches had a superior height growth in Punkaharju and they had least mammal damages. In Punkaharju, the growth cessation was affected by photoperiod and possibly by declining temperatures in autumn. Provenances from cold northern climates developed their terminal buds first. They also formed autumn colouring and shed their needles earlier than more southern provenances.

Dahurian larches showed potential in height growth and ability to utilize the length of the growing season effectively in Punkaharju. They also seemed to have, on average, smaller amount of mammal damages. Despite this, the currently used Siberian larch of Raivola origin is still the safest choice for larch forestry in whole Finland in terms of adaptation to climate. Further studies are needed still on the potential offered by different species and provenances (and their hybrids) to generalize the findings of this work.

Keywords: provenance, phenology, bud burst, bud set, autumn colouring, seedling damage

PREFACE

Before all else, I would like to thank my supervisors, whom without this work would have not been possible; Seppo Ruotsalainen, Teijo Nikkanen and Heli Peltola. I got to know Seppo and Teijo in 2003 when I was working on my thesis to Nikkarila, Mikkeli University of Applied Sciences. Already then, we were involved with larches as we studied the seedling stage performance of exotic conifers in part of the establishment of new 2nd generation field trials of the original material used by Professor Olli Heikinheimo in the 1920's and 1930's. I decided to continue my studies in the University of Eastern Finland (University of Joensuu until 2010), and I was planning to do my master's thesis on the same material I studied in Nikkarila. However, Teijo and Seppo had new plans because of the SIBLARCH project that had been initiated in 2005. With the aid of Owe Martinsson in Sweden, new larch seed material from the preceding Russian-Scandinavian larch project was delivered also to Finland. Preparations started in Punkaharju in the Finnish Forest Research Institute (METLA) research unit, and I went on to search for a supervisor for my master's thesis in the university. Luckily I met Heli, who took me in her guidance, even thought at that point, I was not yet even officially accepted as a student for the faculty. In 2007, I had completed my master's thesis which later on in 2009 was evolved to our first research article. Now, ten years later, I present to you, with indispensable support from my supervisors, my doctoral dissertation.

I would like to thank the pre-examiners of this thesis, Prof. Heikki Hänninen and Dr. Anneli Viherä-Aarnio, for their valuable comments. Also anonymous referees who made comments on the original article manuscripts are acknowledged. The help and support of tens of people at the Punkaharju, Rovaniemi and Suonenjoki Research Units of the Finnish Forest Research Institute with establishing, tending and measuring the experiments is greatly appreciated. The support provided by the Finnish Forest Research Institute and University of Eastern Finland, School of Forest Sciences, is also acknowledged. The personal grants awarded by the University of Eastern Finland, Foundation for Forest Tree Breeding, Finnish Society of Forest Science and Jenny and Antti Wihuri foundation are gratefully acknowledged. I would also thank our host, Aleksey Fedorkov, of the pleasant stay on our trip to Syktyvkar in Komi, Russia, and other participants of the SIBLARCH project. It was exciting to see larch in its natural range in Russia. Our earlier trip to the Raivola larch forest was also a thrill. I would also like to thank my dendrology teacher in Nikkarila, Erkki Tillikainen, who introduced me to the world of exotic tree species. I thank also my family and friends who supported me on this long effort.

This work was partly funded by the EU Northern Periphery SIBLARCH project, which provided the material used in the study. Field trials have been established with the same larch seed material to Sweden, Norway, Iceland, Russia, France, China, Japan, Canada and the United States making this truly an international research of the Russian larches. Among these, the Finnish field trials offer numerous possibilities for research, of which this work is only the beginning.

Antti J. Lukkarinen

Suonenjoki, May 20th 2013

LIST OF ORIGINAL ARTICLES

This thesis is a summary of the following papers, which are referred to in the text by the Roman numerals I–IV. Articles I, II and III are reproduced with the kind permission from the publishers, while the study IV is the author version.

I Lukkarinen, A.J., Ruotsalainen, S., Nikkanen, T. & Peltola, H. 2009. The growth rhythm and height growth of seedlings of Siberian larch (*Larix sibirica* Ledeb.) and Dahurian (*Larix gmelinii* Rupr.) larch provenances in greenhouse conditions. Silva Fennica 43(1): 5–20.
http://www.metla.fi/silvafennica/full/sf43/sf431005.pdf

II Lukkarinen, A.J., Ruotsalainen, S., Nikkanen, T. & Peltola, H. 2010. Survival, height growth and damages of Siberian larch (*Larix sibirica* Ledeb.) and Dahurian (*Larix gmelinii* Rupr.) larch provenances in field trials located in southern and northern Finland. Silva Fennica 44(5): 727–747.
http://www.metla.fi/silvafennica/full/sf44/sf445727.pdf

III Lukkarinen, A.J., Ruotsalainen, S., Peltola, H. & Nikkanen, T. 2013. Annual growth rhythm of *Larix sibirica* and *Larix gmelinii* provenances in a field trial in southern Finland. Scandinavian Journal of Forest Research. 15 p.
doi: 10.1080/02827581.2013.786125

IV Lukkarinen, A.J., Ruotsalainen, S., Peltola, H. & Nikkanen, T. 2013. Bud set and autumn colouration of *Larix sibirica* (Ledeb.) and *Larix gmelinii* (Rupr.) provenances in a field trial in southern Finland. Manuscript.

Antti J. Lukkarinen had the main responsibility for all the work done in Papers I–IV. The co-authors of the separate Papers I–IV participated in the work mainly by commenting on the manuscripts and supporting the data analyses. Teijo Nikkanen had the main responsibility on designing the greenhouse and field tests.

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1 INTRODUCTION

1.1 Factors affecting growth rhythm, height growth and survival of provenances

When studying the potential of exotic tree species for forestry such as larch (*Larix* Miller), provenance tests are a good way to narrow down the selection and to identify the level of adaptation capacity of the trees, in order to survive in the new environment. To succeed in this, suitable annual growth rhythm is the most important factor in northern conditions like in Finland. Growth should not start too early in the spring nor should it continue too late in the autumn and adequate frost hardiness must be developed before onset of winter, to avoid mortal frost damages. On the other hand, too short growth period will result in poorly utilized growing season, which will ultimately lead to loss in competition with other trees. Overall, provenances that can use the full growing season effectively without frost or other damages would be desired in forestry.

The growth rhythm of a tree is defined by its genotype which is moulded by the climatic and photoperiodic conditions of its origin. Geographical variables such as latitude and altitude act as proxies for the climate (Wright 1976, Sarvas 2002, Partanen 2004, Ruotsalainen 2010). The size and nature of the geographical range is the principal factor affecting the amount of variability of the species (Wright 1976). The growth, quality and hardiness of seedlings of different provenances differ also when they are grown under same kind of conditions (Eriksson et al. 2006). Certain principles have been found in the provenance tests of tree species from the north temperate zone. Provenances of southern origin start their growth later in the spring compared to the more northern ones, making them less susceptible to late spring frost. Southern provenances continue their growth later in the autumn, and therefore, they suffer easier cold and short summers and have a higher risk of damage from early autumn frosts and extreme cold spells in the winter than local or more northern provenances (Wright 1976, Ruotsalainen 2010).

Altitude of the origin affects the adaptation by temperature decrease on moving upwards (White et al. 2007). In the troposphere temperature drops on average 0.65 °C for increase of each hundred-meters (Liljeqvist 1962) which corresponds to a transition of approximately one degree latitude to the north (Laaksonen 1976). The continentality of the climate, which increases when moving inland, affects the growth rhythm of provenances (Heikinheimo 1956, Tuhkanen 1984). Continental provenances have a relatively short and intense growing period that stops abruptly. Provenances from maritime climate have a long growing period that starts and stops slowly and they are sensitive to frost damages in the autumn. Semi-maritime provenances are intermediates between maritime and continental ones. The type of the provenance is genetically determined and follows latitude and altitude clines (Tigerstedt 1993). The performance and survival of provenances at the vulnerable seedling stage particularly is also affected by the local microclimatic conditions (Heikinheimo 1956, Hämet-Ahti et al. 1992).

In order to adapt to Finnish conditions, the provenances should originate from similar kind of climates (Ilvessalo 1920, Hämet-Ahti et al. 1992, Sarvas 2002). The Finnish climate is semi-maritime and has both maritime and continental influences depending on the direction of the air flow (Finnish Meteorological Institute 2013a). 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 extend the continental climate over Finland with its severely cold winter temperatures and extreme heat in summer (Finnish Meteorological Institute 2013a).

The varying climate sets limitations regarding the survival and growth of trees, especially for exotic species like larches (Hagman 1993). For example, the extremely cold winter of 1939–1940 was fatal for many exotic tree species trials established in the 1920's and 1930's in Finland. Areas having similar climatic conditions to Finland are very limited in number, and they are found mainly in northwest Russia and eastern Asia as far as Eurasian larches are concerned (Cajander 1917, Hämet-Ahti et al. 1992). Similar areas in Asia are situated in the coastal areas of the Okhotsk Sea (Hämet-Ahti et al. 1992), e.g. in the eastern and southern parts of Sachalin, north-eastern parts of Hokkaido, Kurile Islands and along the eastern shoreline of the Kamchatka Peninsula (Cajander 1917). Some of these eastern areas are considerably southern, too. Even though the climatic conditions can be similar to Finland, the photoperiod is shorter than in Finnish conditions.

According to Sarvas (2002), the use of exotic tree species in Finnish forestry is practical only if some of the following requirements are satisfied: i) the exotic species produces greater amount of valuable timber than domestic species in corresponding growing conditions, ii) the timber of exotic species has properties that the nearest domestic species does not have, that makes the exotic timber more suitable for one or several uses, iii) the exotic species have some silvicultural advantages compared to domestic species, such as eminent diameter growth or less branchy trunk, better resistance of certain insects, fungi or climatic hazards, better shade tolerance, modest growing site requirements or better ability to utilize the growing site potential, and iv) exotic species can also offer valuable by-products in a form of chemical extracts. However, according to Sarvas (2002) there is also greater risk of failure in cultivation of exotic tree species compared to domestic well adapted species. Also exotic timber with even more desired properties than domestic timber has, may need own industrial processes which are not necessarily cost-effective due to small scale timber harvest compared to domestic species.

1.2 Potential of larch species in Finnish forestry

In Finland, the Siberian larch (*Larix sibirica* Ledeb.) can be considered a returnee species, which has belonged to our flora before the last glacial period (Mäkinen 1982, Hirvas 1991). According to radiocarbon-dated fossil studies by Kullman (1998) larch have existed in the Scandinavian mountains after the last glacial period 8800–7500 years B.P. Nowadays, the range of Siberian larch covers an area extending from the northern parts of European Russia to the central parts of Siberia, south to the Altai Mountains and into north Mongolia and northwest China (Farjon 1990, Sarvas 2002). The natural distribution area of Siberian larch is closest to Finland on the western banks of Lake Onega and on the islands of White Sea in the north. Its western range is fragmented and it grows mostly in mixed stands (Putenikhin and Martinsson 1995). Siberian larch grows on variable site fertility types, and as pure or mixed stands, but it grows best on well-drained sandy or rocky soils (Farjon 1990, Sarvas 2002). Of the Russian larch forests area, Siberian larch occupies approximately 14%. The total area of larch forests is 268 million hectares which is 40% of total forest area in Russia (Milyutin and Vishnevetskaia 1995).

Dahurian larch (*Larix gmelinii* Rupr.) with its many varieties has spread throughout vast areas in eastern Siberia (Farjon 1990, Sarvas 2002). The main variety (*Larix gmelinii* var. *gmelinii* (Rupr.) Rupr.) occurs throughout most of the species distribution area in north-eastern Asia, whereas other varieties grow on the south-eastern edges of the range (Hämet-Ahti et al. 1992). On the western edge of its range Dahurian larch forms mixed stands with Siberian larch (Schmidt 1995, Sarvas 2002), and in the north it forms the timberline (Cajander 1917). Dahurian larch grows on a range of sites and it is undoubtedly the most heterogeneous of the larch species (Farjon 1990). It occupies 83% of larch forest area in Russia (Milyutin and Vishnevetskaia 1995).

The Raivola stand established in 1738 to the Karelian Isthmus has played a crucial role in the Nordic larch forestry and forest research (Sarvas 2002, Redko and Mälkönen 2005). Practically all the larch cultivated in Finland is of Raivola origin, or *land race* (Zobel and Talbert 1984), and seed is from various seed orchards established in Finland (Utilisation areas of seed orchards 2013). Seed from the Finnish larch seed orchards has been sold also to other Nordic countries and this material grows well even in maritime Iceland (Blöndal and Snorrason 1995). The good adaptation of the Raivola origin has been contributed to the variable climate in the Arkhangelsk region, where the material originally comes from and possibly to hybridisation between different provenances in Raivola stand (Metzger 1935, Tigerstedt 1990).

In the oldest experiments in Finland, established in middle of 19th century, larches have usually grown best in the southern parts of the country (e.g. Punkaharju) (Heikinheimo 1956, Sarvas 2002). However, in experiments established further south close to coast, like Ruotsinkylä and Solböle, the growth has been on average lower. Field experiments have also been established in Northern Finland (e.g. Kivalo) in the early 20th century (Silander et al. 2000). Siberian larch has also been used by Metsähallitus in state owned lands in northern Finland especially in the 1970’s and 1980’s. However, many of the early northern experiments have been established with unsuitable provenances (e.g. too southern origin) (Tigerstedt et al. 1983, Hokajärvi 1998, Silander et al. 2000). Due to fast juvenile stage growth, Siberian larch has been commonly used in forestation of agricultural lands and on fertile regeneration sites in southern Finland, especially in the 1990’s (Silander et al. 2000). Siberian larch has also been associated as a domestic tree species in Finnish forest legislation (Valtioneuvoston asetus metsien kestävästä hoidosta ja käytöstä 1234/2010, 14 §). The approximate area of larch stands in Finland is currently about 30 000 hectares (Isomäki, 2002, Lepistö and Napola 2005).

A large share of the Siberian larch field trials has been established in Finland with Finnish 2nd generation seed sources originating from Raivola (Redko and Mälkönen 2005, Ruotsalainen 2006). The Raivola origin Siberian larch has grown well even in Kivalo in northern Finland (Silander et al. 2000). Previously, Tigerstedt (1993) 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. Based on earlier Finnish experiments with quite narrow research material, despite better height growth in juvenile stage, the diameter growth and timber yield is smaller in Dahurian larches than in Siberian larches (Silander et al. 2000, Autio 2002).

On medium fertile sites, there are no large differences in growth between Raivola origin Siberian larch and domestic species in Finland. However, on fertile sites Siberian larch grows better than domestic species (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. This exceeds the growth of Norway spruce (*Picea abies* L.), in the same conditions by 20%. Especially in the juvenile stage, the height growth of larches is vigorous and the growth continues also to older age producing bulky trunks. However, the growth of some larch species can decline significantly already when they pass the age of 40 years, e.g. Japanese larch (*Larix kaempferi* (Lamb.) Carrière) (Sarvas 2002, Takata et al. 2005). The performance of larches in Finland has varied depending on the test site. In general, they have grown especially well in Punkaharju in south-eastern Finland. Silander et al. (2000) suggests that this is because of favourable climatic conditions and fertile site types.

Larches, with their fast growth at young age, have less trouble in competing with undergrowth than domestic species 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). Large pine weevil (*Hylobius abietis*) is a common pest in regeneration areas and it also damages larches (Siitonen 1993, Poteri 1999). 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. No differences have been observed between Siberian larch provenances concerning pests and diseases (Hagman 1995).

Larch timber has, in general, large proportion of heartwood and high wood density. However, these properties vary depending on the tree age, site fertility, growth rate, species and provenance (Martinsson and Lesinski 2007). The proportion of heartwood in mature Siberian larches can be 70–80% of the volume (Lappi-Seppälä 1927, Hakkila and Winter 1973) which is higher than in Scots pine (Venäläinen et al. 2001). The Siberian larch heartwood has high density and high mechanical strength (Koizumi et al. 2003). Larch also holds higher density with wider year rings than Scots pine (Karlman et al. 2005). The good decay resistance of larch heartwood is comparable to Scots pine heartwood (Venäläinen et al. 2001). In Fennoscandia, outdoor timber constructions are exposed to fungi and bacteria which promote decay. Treatments with environmentally hazardous chemical have been used to preserve timber from decay. Use of larch heartwood timber has been suggested as environmentally friendly option to chemically treated timber (Martinsson and Lesinski 2007). Juvenile wood has lower density and 20–25% lower mechanical strength compared to heartwood outside the juvenile wood. Heartwood production is started already in the age of 5–6 years and the sapwood in a 100-year-old tree is usually only a 1–5 cm wide layer on the outer part of the trunk. Density, decay resistance and mechanical strength are greatly influenced by the proportion of latewood which is three times denser than earlywood produced in the beginning of growing season. Latewood formation is dependent on the annual growth rhythm and adaption to the local climate. It also differs between larch species, progenies and individual trees and therefore it is important for tree breeding and provenance selection (Martinsson and Lesinski 2007). Larch heartwood has high concentrations of water-soluble arabinogalactans which affect the density, moisture content and processing properties of the wood (Luostarinen and Heräjärvi 2012).

In its natural distribution area larch is used as timber, plywood, pulp and paper, particleboard and fiberboard, house logs etc. In addition, larch extracts are used in food, pharmaceutical, cosmetic and bio-tech industries (Tuimala 1993, Keegan et al. 1995). During saw milling arabinogalactans can stick to the blades and feed rollers and potentially cause inaccuracies and interruptions to the sawing (Sairanen 1982, Juvonen 1995). For indoor constructions timber is usually kiln dried. Drying time for Siberian larch is longer and dimension changes are greater than with Scots pine (Heikkonen et al. 2007). Small amounts of larch from thinnings can be mixed with pine pulp wood, but larger amounts would need specialized processes in the industry (Nevalainen and Hosia 1969, Hakkila et al. 1972). Majority of the larch stands in Finland are representing sapling stands and young stands in first thinning age. Therefore, there is not much domestic larch timber on the market, but harvesting opportunities will increase over time. For same reason, there is also still very little industry that uses larch in Finland and mainly imported timber from Russia is available in this respect (Lepistö and Napola 2005, Heikkonen et al. 2007). According to Martinsson and Takata (2000) most of the larch imported from Russia originates from central, southern Siberia with very long distance transportation.

1.3 Aims of the study

The aim of this work was to study the differences in growth rhythm, height growth, survival and damages for seedlings of Siberian and Dahurian larch provenances and comparison entries in greenhouse and in field conditions over five growing seasons in southern and northern Finland. The provenance material covers most of the geographic range of Russian larches. No provenances were included from the most continental areas of Siberia. Larches from Finnish seed orchards and research forests were used as comparison entries. Geographic and climatic variables of the origin were used to explain the differences between entries, by which it is possible to evaluate the suitability of the entries to Finnish climatic conditions. The specific objectives of the study were as follows:

i. To study how the larch entries differ in growth rhythm and height growth in greenhouse conditions (**Paper I**);

ii. To study how the larch entries differ in growth rhythm, height growth, survival and damages in field conditions in southern and northern Finland (**Papers II–IV**);

iii. To study which climatic and geographic variables explain the differences between entries (**Papers I–IV**);

iv. To examine if it is possible to predict the performance of seedlings in field conditions based on their performance in greenhouse conditions (**Papers I–IV**).

2 MATERIAL AND METHODS

2.1 Experimental data

The seed material used in this work was originally collected in Russia during 1996–2000 as part of Russian-Scandinavian larch project started in 1994 by Russia, Sweden and Norway (Martinsson and Takata 2000, Abaimov et al. 2002). Seeds were collected from 17 regions, 47 stands and from 1005 individual trees from Kamchatka in the east and Onega in the west. Seedlings were grown in a nursery in Norway in 2002 and field tests were established in Sweden and Norway in 2003 (Martinsson and Lesinski 2007). SIBLARCH-project was established to develop the use of Siberian larch in forestry and products (SIBLARCH 2013). The SIBLARCH-project, with participating organisations from Russia, Sweden, Norway, Iceland and Finland, was active in 2005–2007 and it was supported by the Northern Periphery of the European Community. Field tests with this seed material have also been established to France, China, Japan, United States and Canada (Martinsson and Lesinski 2007).

Larch entries used in this study were chosen from a larger set of provenances by rejecting those that had weak germination or less than ten seed trees (a small number of seed trees was supposed to weaken the representation of the provenance). The study material in Papers II–IV consisted of 15 Siberian larch and five Dahurian larch provenances and five comparison entries from nonautochthonous seed sources. In Paper I, there were 11 Siberian larch and five Dahurian larch provenances and four comparison entries. Two comparison entries were from Finnish seed orchards and two from cultivations of the Finnish Forest Research Institute (Metla) in Punkaharju, and one came from the Raivola stand in Russia (Redko and Mälkönen 2005). Four of the five comparison entries were Siberian larches, and one (Mv135 in Punkaharju) was European larch (Fig 1, Table 1). The Siberian larch comparison entries from Finland are all Raivola origin 2nd generation seed sources.

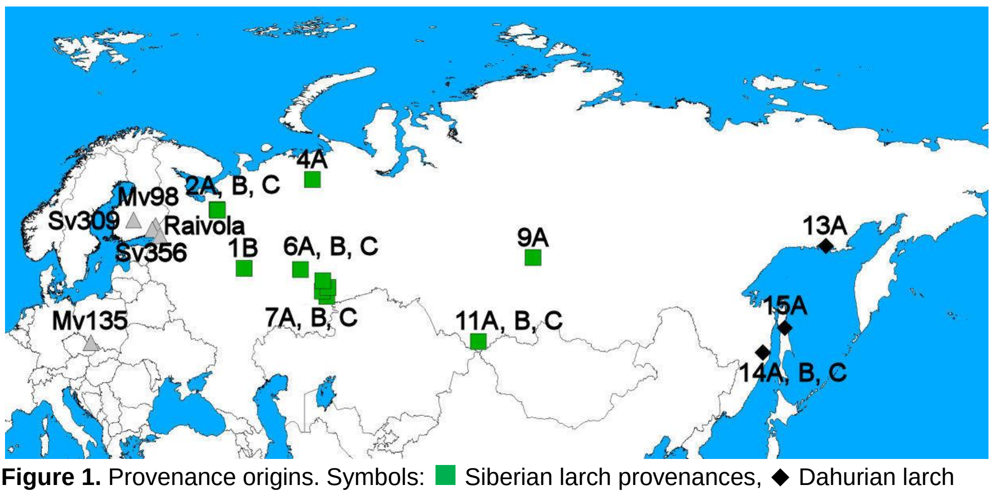


Figure 1. Provenance origins. Symbols: ■ Siberian larch provenances, ◆ Dahurian larch provenances, ▲ comparison entries. Detailed information about all entries is given in Table 1.

Table 1. Geographical and climatic information of the provenances. The Siberian larches (top), Dahurian larches (middle) and the comparison entries (bottom) are separated from each other with horizontal lines.

Provenance Name of region	Nearest village/town	Geographical location and elevation Lat. N°	 Long. E°	 Alt. m	Annual mean temp. °C	Continentality index	Temperature sum d.d.	Seed weight, g/1000 seeds
1B Nishnij Novgorod	Vetluga	57° 30′	45° 10′	145	3.1	44	1446	9.4
2A Plesetsk	Emtsa	63° 05′	40° 21′	100	1.1	40	1037	8.2
2B Plesetsk	Korasi	63° 00′	40° 25′	120	1.0	40	1023	8.5
2C Plesetsk	Sheleksa	62° 09′	40° 19′	120	1.3	40	1068	8.6
4A Petchora	Usinsk	66° 00′	57° 48′	75	-3.5	49	692	8.1
6A Perm	Okhansk, Yugo-Kamsky	57° 19′	55° 27′	160	2.2	48	1441	9.6
6B Perm	Nyazepetrovsk, Uzaim	56° 09′	59° 32′	460	1.1	50	1289	12.9
6C Perm	Kyshtym	55° 43′	60° 27′	480	2.2	49	1441	13.5
7A Ufa	Maginsk	55° 45′	56° 58′	370	1.0	51	1324	8.4
7B Ufa	Miass	54° 58′	60° 07′	380	1.9	52	1480	15.1
7C Ufa	Zlatoust	55° 07′	59° 30′	600	0.6	51	1277	13.4
9A Boguchany	Boguchany	58° 39′	97° 30′	158	-2.6	64	1204	9.7
11A Altai	Kosh-Agash, Tenedu	50° 16′	87° 54′	1 630	-0.9	49	956	7.5
11B Altai	Kosh-Agash, Karnagalu	50° 12′	87° 47′	1 580	0.3	46	1070	6.1
11C Altai	Kosh-Agash, Turgune	50° 14′	87° 03′	1 630	-1.1	47	904	6.9
13A Magadan	Splavnaya	59° 50′	150° 40′	60	-3.1	41	650	2.6
14A Chabarovsk	Vaninskyi	49° 09′	139° 00′	100	1.5	54	1315	3.1
14B Chabarovsk	Vaninskyi	49° 12′	139° 00′	125	1.3	54	1295	3.2
14C Chabarovsk	Vaninskyi	49° 08′	139° 00′	90	1.2	54	1267	3.2
15A Sachalin	Nogliki	51° 50′	143° 00′	50	-0.1	51	1021	2.4
Raivola forest	Raivola, Russia	60° 14′	29° 35′	50	4.3	33	1353	8.6
Mv98 Punkaharju [a), b)]	Punkaharju, Finland	61° 48′	29° 19′	95	2.9	35	1203	9.2
Sv309 Lassinmaa [a)]	Jämsänkoski, Finland	62° 04′	25° 09′	107	3.0	32	1142	12.3
Sv356 Neitsytniemi [a)]	Imatra, Finland	61° 12′	28° 48′	70	3.5	34	1258	11.2
Mv135 Punkaharju [b), c)]	Krnov, Czech Republic [d)]	50° 05′ d)	17° 40′ d)	330 [d)]	8.0 [d)]	24 [d)]	1789 [d)]	5.9

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

In this study, the species concept and nomenclature follow those of Farjon (1990) and Hämet-Ahti et al. (1992). In Russian nomenclature, the Siberian larch (*Larix sibirica* Ledeb.) provenances 1B–7C and comparison entries Mv98, Sv309, Sv356 and the Raivola stand are considered to be *Larix sukaczewii* Dyl. The Dahurian larch (*Larix gmelinii* var. *gmelinii* (Rupr.) Rupr.) provenance 13A Magadan is considered in Russia to be *Larix cajanderi* Mayr. (Milyutin and Vishnevetskaia 1995).

The geographical information about the provenance origins was mainly obtained from literature and available databases (e.g. Martinsson and Takata 2000). The average seed weights for the provenances (mass of thousand seeds) were calculated from single tree seed weights.

Climatic information was obtained for the seed collection sites for each provenance primarily by interpolating from the high-resolution surface climate data provided by the Climatic Research Unit, UK (Ten minute climatology 2002, New et al. 2002). An altitude correction was applied for the temperature values (and temperature sum) by considering the difference between the interpolated altitude and the value provided by the seed collectors (standard atmospheric stability and a temperature drop of 0.65 °C for every 100 m in elevation was applied; e.g., Liljeqvist 1962). The values were interpolated by averaging two to four of the closest value points, depending on the location of the seed source in relation to the available grid points (if the deviation was <0.05 degrees, the nearest value was used). This approach provided values consistent with the temperature sum map published by Tuhkanen (1984).

In this study, the climatic conditions of the seed collection sites were described in terms of i) the temperature sum with +5 °C threshold value, ii) annual mean temperature, iii) mean temperature of the coldest month (minimum temperature), iv) mean temperature of the warmest month (maximum temperature), v) annual range of the monthly mean temperatures (maximum-minimum temperature), vi) latitude (N°), vii) longitude (E°), viii) altitude above sea level and ix) continentality index (Conrad 1946, in Tuhkanen 1980).

2.2 Layout of the experiments and the measurements in them

The experiment was set up in April 2005 at the Punkaharju Research Unit (61°48′N, 29°20′E, 81 m), Finnish Forests Research Institute, when the seeds were sown in greenhouse (Fig. 2). Seven weeks after sowing, seedlings representing the individual provenances were transplanted to Plantek PL-64F seedling trays (115 cm^3). At the same time, the seedlings were grouped into five different blocks, each block consisting of one seedling tray for each provenance (total of 64 seedlings per seedling tray). The growth dynamics was followed on eight seedlings growing at the centre of the tray in order to avoid the edge effect caused by the deviating growing conditions (i.e. a total of 20 provenances × 5 blocks × 8 seedlings = 800 seedlings). Autumn colouring was, however, observed on all the seedlings in the tray. The seedlings were grown in typical greenhouse conditions. The temperature in the greenhouse varied generally between +20–30 °C, but no precise temperature monitoring was conducted. Overheating was avoided by opening the roof windows and by forced air circulation when the temperature exceeded +20 °C. Manual (by hand) watering and fertilization, applied as evenly as possible, were performed frequently. After transplanting, the seedlings were fertilized five times at one-week intervals (starting 20th June) with 0.2% concentration *Turve-Superex* liquid fertilizer (NPK

Table 2. Measurements made in different years in the greenhouse and in the field trials. The number ahead of multiplication sign refer to how many times the measurement was repeated.

Measured variables	Greenhouse Punkaharju	Field trial Punkaharju	Field trial Kivalo
Bud burst		2008, 2009	
Height growth	2 × 2005		
Total height	2005	2007–2009*)	2007–2009*)
Shoot elongation		10 × 2008, 2009	
Growing period	2005		
Bud set	2005	2008, 2009	
Autumn colouring	3 × 2005	3 × 2008, 2009	1 × 2008, 2009
Needle shedding		3 × 2008, 2009	1 × 2008, 2009
Survival		2006, 2008, 2009	2006, 2008, 2009
Damages		2008, 2009	2008, 2009

*) Total height of 2007 was measured in 2008.

fertilizer with micronutrients designed for peat cultivation). The height growth of the seedlings was measured on July 5–6th and on October 5th (Table 2).

In 2005, the end of height growth was determined by observing the formation of terminal buds based on classification of the bud development into three different stages: 1) no bud, 2) bud formation started and bud greenish in colour, and 3) terminal bud formed and bud brownish in colour. Terminal bud observation was started on 6th of September and continued weekly up until 4th of October. The autumn colouring of the seedlings was recorded at seven-day intervals from the weeks 40–42 (6th, 13th and 20th of October) and classified into four different stages: 1) approximately 76–100 percent of green needles, 2) 51–75 percent, 3) 26–50 percent and 4) 0–25 percent.

In autumn 2005, the seedlings grown in greenhouse over one growing season 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, 78 m, d.d. 1235) and the other in Kivalo (66°19′N, 26°38′E, 265 m, d.d. 797), with randomized block design, including one plot of each provenance per block. 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 stand and harvested of logging residues. The competing woody vegetation was removed in 2008. The Kivalo field trial was established as two sub-trials on a medium fertile site type (HMT, *Hylocomium-Myrtillus*). In 2004, the first sub-trial (site 1) was ploughed while the other one (site 2) was harrowed, following clear-cut of mature Norway spruce stand. Only Kivalo site 1 results are analysed in this study, because on site 2 the regeneration process failed due to light scarification and undergrowth that followed. In 2006, survival after first growing season in the field was measured. Extensive field measurements were done in 2008 and 2009.

The temperature data for the Punkaharju trial was derived from a measuring station of the Finnish Meteorological Institute, which is located only two kilometres from the field experiment (Appendix 1). Corresponding data for Kivalo was produced from Finnish

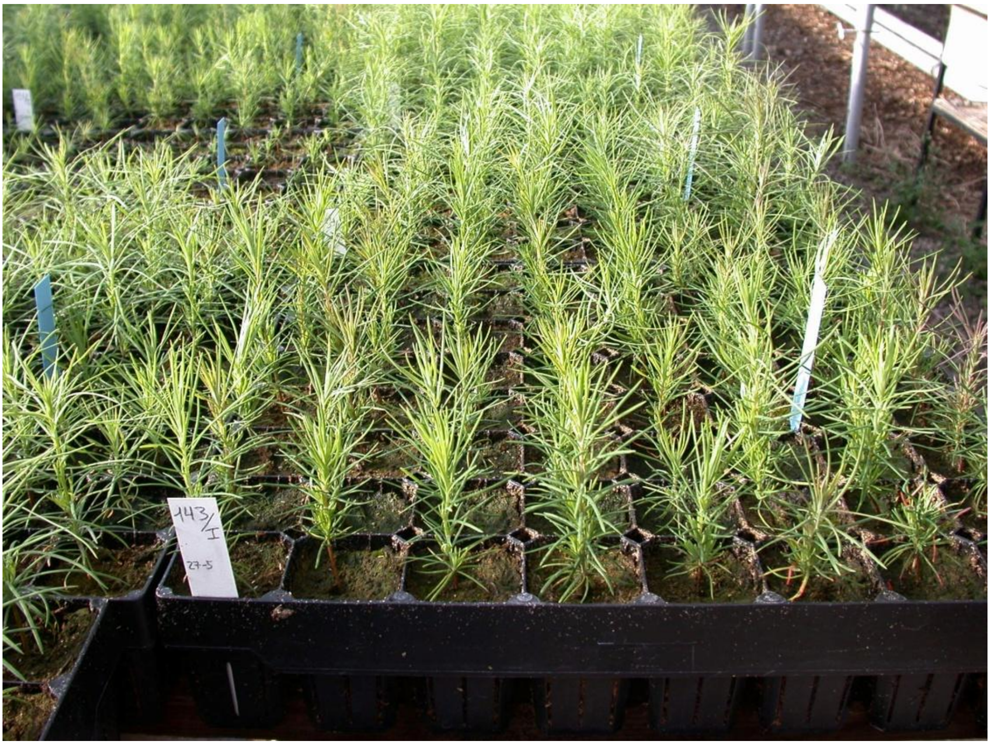


Figure 2. Seedlings of provenance 14C Chabarovsk (foreground) in the greenhouse on 5th of July in 2005. On the left in background smaller seedlings of provenance 4A Petchora. All photographs by Antti Lukkarinen.

Meteorological Institutes 10km×10km grid data (see Venäläinen et al. 2005). In Punkaharju, the thermal growing season started on the 27th of April in 2008 and in 2009 on the 24th of April. In Kivalo, the growing season started on the 23rd of May in 2008 and in 2009 on the 7th of May (Finnish Meteorological Institute 2013b). In 2008, the growing season ended in Punkaharju on the 31st of October and in 2009 on the 28th of September. The temperature sum for 2008 was 1152 d.d. and 1335 d.d. for 2009, so even though the growing season of 2009 was shorter, it was warmer. In Kivalo, the growing season ended on the 28th of September in 2008 (715 d.d.) and 27th of September in 2009 (978 d.d.).

The growth onset, shoot elongation and growth cessation were monitored in 2008 and 2009 in Punkaharju, i.e., during the third and fourth growing seasons after the planting. Growth onset was monitored for all of the seedlings in the plot by assessing the bud burst development of the seedling in whole. For this purpose, the bud burst development was ranked into five following stages: 1) buds are dormant, 2) buds are swollen, 3) buds have opened, 4) needles have opened more and needles are loose, unlike in stage 3. In stage 5, the new shoots and needles are the same length (initiation of growth onset). The progress of growth onset was monitored three times between April and June in 2008 and twice between May and June in 2009.

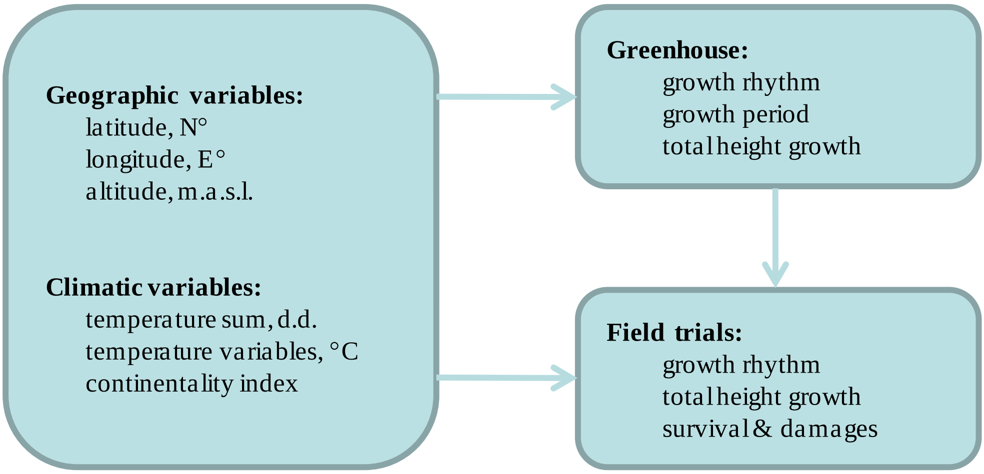


Figure 3. The overview for measurements done in greenhouse and field conditions and geographic and climatic variables used to explain the performance of seedlings representing different provenances. The effect of geographic variables is indirect because provenances have adapted to prevailing climatic conditions and not into geographic location.

The elongation of the terminal shoot was measured in millimetres ten times between the middle of June and the end of October in both years, using an average of six seedlings per plot (with a range of 3–7 depending on availability). However, the same seedlings could not always be measured in 2008 and 2009 because some of the seedlings died or their terminal shoots were damaged. Even negative height growth values were measured in Kivalo in 2009 for some provenances as a result of damages to the top shoot and mortality. Frost damages include, in this study, all damages caused by low temperatures, regardless of what time of the year they occurred. Mammal damages include those caused by vole, hare, deer, moose, and reindeer. Voles were the most common pests based on bite marks (due to high vole density during winter 2008–2009 in southern Finland).

2.3 Data processing and statistical analysis

The measured seedling data and geographic and climatic data were processed with Microsoft Excel 2002 and 2007 spreadsheet software. Statistical analyses were performed with SPSS software package (Version 13.0, Chicago, IL) and PASW statistics (Rel. 18.0.0 2009 Chicago SPSS Inc.). Differences among the provenance means were tested using a Kruskal-Wallis non-parametric one-way analysis of variance for plot means because most of the variances were unequal according to Levene's test. Pair-wise analyses (with Tukey post hoc test, $p<0.05$) were also used. Pearson correlations and linear regression analyses were used to study the relationships among the measured variables and the climatic and geographical variables for the provenances means (Fig 3). In addition to above, also seed weight was used as explanatory variable in the greenhouse. For the regression models, only statistically significant ($p<0.05$) explanatory variables were accepted. Furthermore, data transformation (square root, power, and logarithmic) for the explanatory variables was used if necessary to study nonlinear relationships among the variables. The comparison entries were excluded from correlation and regression analyses because their material was not collected from the original growing sites of the entries and in some cases the exact origin was unknown. Altai mountain provenances 11A–C which showed abnormal performance (and poor adaptation capacity to Finnish conditions) were often excluded from data analyses.

3 RESULTS

3.1 Growth rhythm

Bud burst observed in Punkaharju field trial was affected ($p<0.05$) by provenance (Paper III, table 3). First sight of bud burst was observed with northern Siberian larch provenances but Dahurian larch provenances followed them immediately with more rapid progress (Paper III, fig. 2). Kurile larch (*Larix gmelinii* var. *japonica* (Regel) Pilger) 15A Sachalin was slightly ahead of other Dahurian larch varieties. Of Siberian larches Raivola origin entries had similar bud burst progress than Plesetsk provenances 2A–C from Archangelsk region. Differences between provenances could be explained by both climatic and geographic variables. Provenances from cold climates had earlier bud burst. Early development of eastern Dahurian larches caused a correlation with longitude and results could not be explained merely with latitude, but combination of latitude and longitude lead into R^2 of 0.899 (sig. <0.001) in regression analysis (Paper III, tables 5 and 6).

Differences between provenances to achieve 50 and 90% level of total height increment were best explained with latitude and temperature sum (Paper III, tables 5 and 6). Northern provenances achieved the respective growth percentages earlier and provenances with high temperature sum continued their growth later. The 90% level correlated strongly with longitude as the eastern Dahurian larches continued their growth very late. The effect of temperature sum and latitude to shoot elongation varied during the growing season. In the early part of the growing season the stage of shoot elongation had a strong negative correlation with temperature sum of origin. Latitude of the provenance explained the percentage of shoot elongation better from the beginning of August as shown by the positive correlation (Paper III, fig. 7). The temperature sum required to reach 50% of the total shoot length in 2008 and 2009 was almost identical, i.e., the difference in the average values was only 12 d.d., which is 2.4% of the required average temperature sum and corresponds to approximately one day (Paper III, table 4, fig. 5).

An increase of one latitude degree decreased the amount of temperature sum needed for 50 and 90% shoot elongation by 18–30 degree days (Fig. 4). However, between years there was a difference of six days in the number of days required for the 50% level because the growing period of 2008 was cooler, and the accumulation of the temperature sum was slower (Paper III, fig. 1). The number of days required to reach the 90% level, however, was very similar in 2008 and 2009 (1 day difference) in spite of a large difference (116 d.d.) in the corresponding temperature sums.

Differences among provenances in the timing of bud set were significant ($p<0.05$) (Paper IV, table 2). There was a considerable difference in the timing of bud set between 2008 and 2009 (Paper IV, fig. 2). In August 13th in 2008, most of the provenances had started bud set but in 2009 the same level was achieved a month later (Fig 5). This was

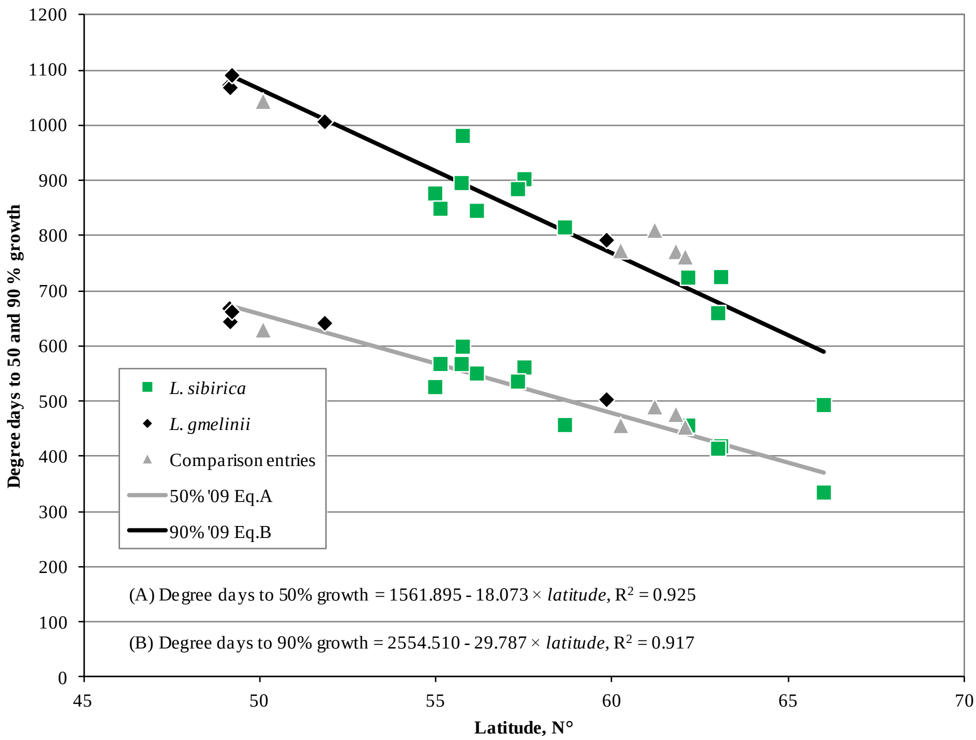


Figure 4. Temperature sum needed to reach 50 and 90% of the total shoot growth in relation to the provenance latitude in 2009 in Punkaharju (n=17, the comparison entries and Altai mountain provenances were excluded from the regression analysis).

most likely caused by differences in the growing conditions. There was a cold spell in beginning of August in 2008 which might have started the terminal bud formation process. Provenances from cold northern climates developed their terminal buds earlier (Paper IV, tables 6 and 7). At first, the differences between provenances were best explained by temperature sum, but later latitude and longitude became more dominant. In August 28th in 2008, an increase of one degree latitude increased bud set by six percent (Fig. 6). Especially the southern Dahurian larch provenances were able to utilize the full length of the growing season.

Differences between provenances in bud set were similar in the greenhouse and field conditions. There was a high correlation ($r=0.95$, $p<0.05$) between Sep10/2008 results and Sep7/2005 greenhouse results and lower correlation ($r=0.75$, $p<0.05$) with Sep7/2009 and Sep7/2005.

Provenance affected significantly the autumn colouring both in the greenhouse (Paper I, table 2) and the field (Paper IV, table 2). The progress of autumn colouring was a bit earlier in 2008 than in 2009. Needle shedding had an earlier start in 2009, but on the other hand the 2008 progress was faster and 100% shedding was achieved earlier. In general, northern

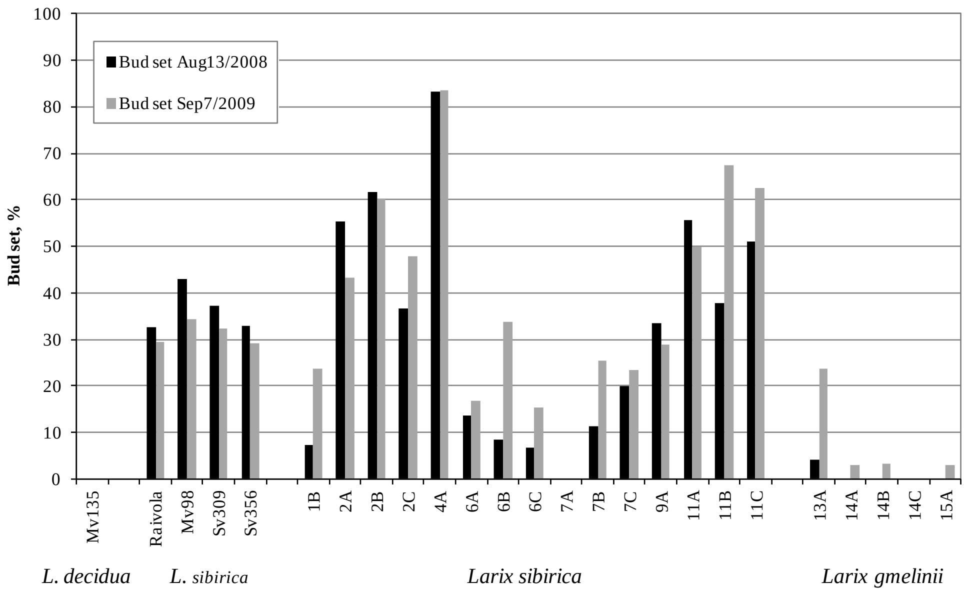


Figure 5. Bud set percentages August 13th 2008 (d.d. 824) and September 9th 2009 (d.d. 1196) in Punkaharju. Provenances with missing values (Mv135, 7A, 14A–C, 15A, see Table 1) did not have any bud set at the time of inventory.

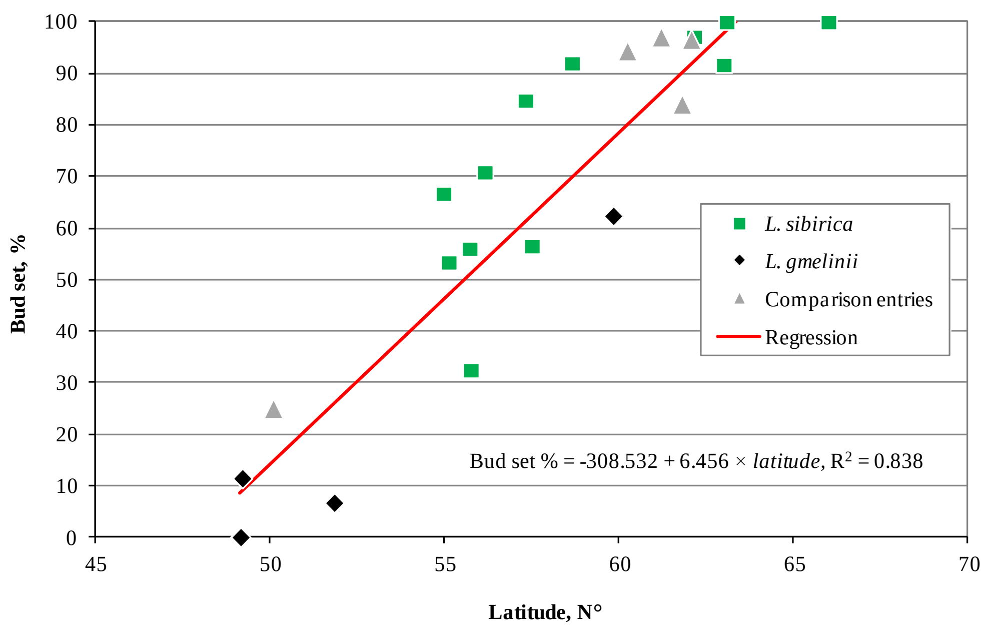


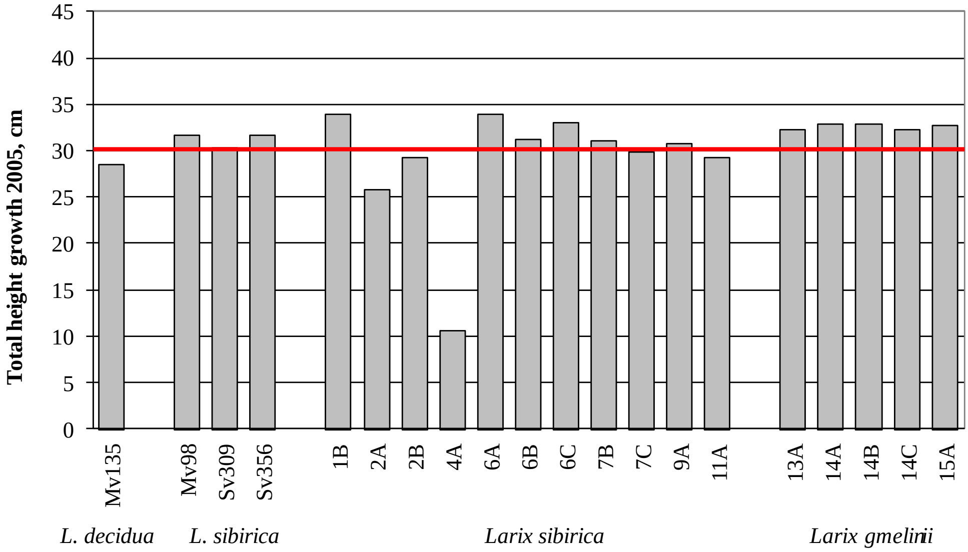
Figure 6. Relationship between bud set progress (%) in 26th of August and provenance latitude in 2008 in Punkaharju (n=17, the comparison entries and Altai mountain provenances were excluded from the regression analysis).

provenances from cold climates turned yellow and shed their needles earlier (Fig. 7) (Paper IV, table 7). Provenances 4A Petchora and 9A Boguchany had earlier yellowing and shedding than rest of the Siberian larches. Also the Dahurian larch 13A Magadan had early yellowing but needle shedding progressed slower than with most of the Siberian larches. The southern Dahurian larches had much later progress than the Magadan provenance. The European larch comparison entry was however the very last to form autumn colouring and shed its needles (Paper IV, fig. 3).

3.2 Total height growth

There were no statistically significant differences between the provenances in height growth in greenhouse in 2005 (Paper I, table 2, fig. 2). The northern Petchora 4A provenance had a very poor growth in the greenhouse (Fig. 8) and also in the field in Punkaharju. In Kivalo, its height was near average. Differences in total height growth between provenances were statistically significant ($p<0.05$) in Punkaharju and Kivalo (Paper II, table 4). Olga Bay larches (*Larix gmelinii* var. *olgensis* (Henry) Ostenf. & Syrach Larsen) (14A–C) and Kurile larch (15A) had superior total height growth of over 200 cm in Punkaharju in 2009 (Fig. 9). Raivola origin and most of the other Siberian larches reached 150 cm height.

Figure 7. Autumn colouring in the greenhouse on 10th of October in 2005. Seedlings of northern provenances had earlier autumn colouring and are more yellowish in the picture.



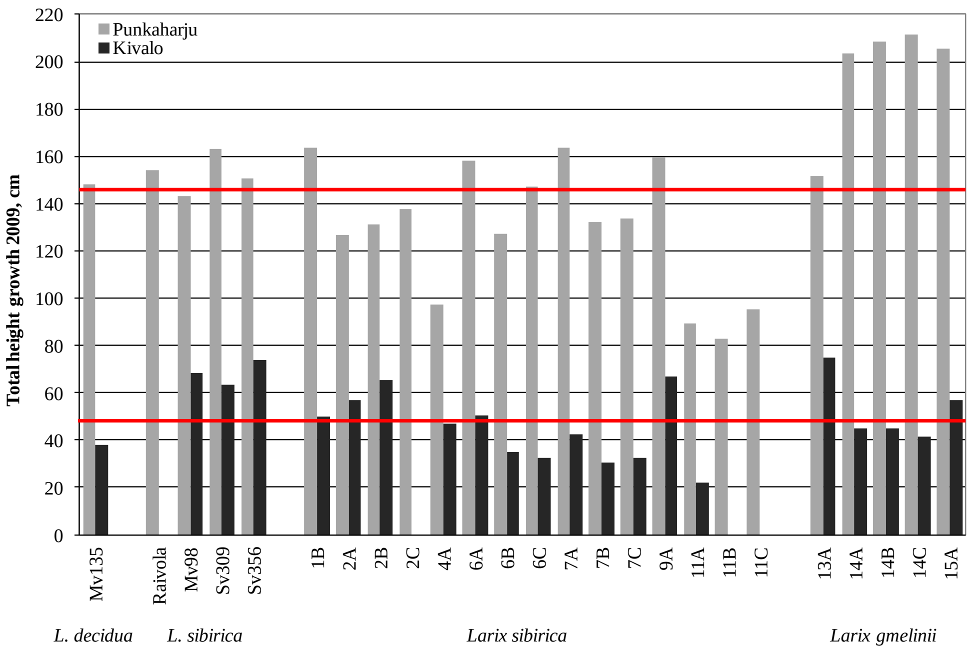


Figure 8. Total height growth of seedlings of different provenances (see Table 1) in greenhouse in 2005 in Punkaharju (top panel) and in field trials after four growing seasons in 2009 in Punkaharju and Kivalo. The red horizontal lines represent the total average height growth in greenhouse and field trials.

Figure 9. Four year old seedlings of provenance Chabarovsk 14C in autumn colour in the Punkaharju field trial on 7th of October in 2008. Lake Puruvesi is seen on the background.

In Kivalo, the Dahurian larch (*Larix gmelinii* var. *gmelinii* (Rupr.) Rupr.) provenance 13A Magadan had the largest height growth together with Raivola origin Siberian larches. Height growth of Altai provenances 11A(–C) was poor in both Punkaharju and Kivalo trials. The provenance from the most continental climate (64), Boguchany 9A Siberian larch, had above average height growth both in Punkaharju and Kivalo, which was a bit surprising. Average height growth of the seedlings in Kivalo was poor compared to Punkaharju and there was a one meter difference in the average height between the locations (Fig. 8). In regression analysis, latitude explained 72% of the differences between provenances in total height growth in Punkaharju in 2009 (n=17). Southern provenances, in general, had better height growth. Adding altitude to the equation, the R^2 rose to 92% since the best grown provenances were from lower altitudes. Altitude acted as a significant variable describing the difference between provenances even when Altai mountain provenances were not included in data analyses (n=17). In Kivalo, altitude explained 52% of the differences in height growth in 2009 (n=17).

3.3 Survival and damages

The average survival after four growing seasons in both Punkaharju and Kivalo was 59% (Paper II, table 4) (Fig. 10). In Punkaharju mortality was high already after first growing season in autumn 2006. At that stage Siberian larches had a survival rate of 76%, Dahurian

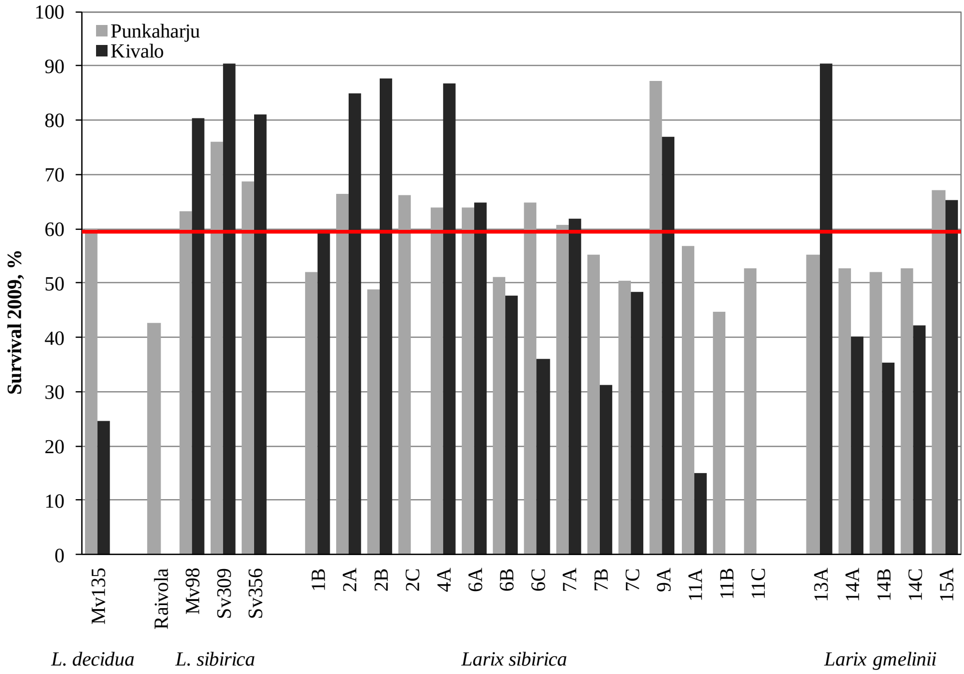


Figure 10. Average survival of seedlings (Table 1) in Punkaharju and Kivalo in 2009. The red line represents the average survival in both trials, which was the same percentage.

larches 69% and the comparison entries 70%. Although damages were not studied in detail, likely causes for the mortality were large pine weevil (*Hylobius abietis*) damages and partly because seedlings were occasionally planted outside the scarification tracks to fit the seedlings into the assigned plot. Decrease in survival from autumn 2006 to 2009 was on average 14% in Punkaharju. In 2009, provenance 9A Boguchany had the highest survival rate of 87% in Punkaharju before Raivola origin comparison entry Sv309 (76%). Survival of Dahurian larches were below average except the Kurile larch 15A Sachalin which was above the average. The European larch comparison entry had an average survival. The differences between provenances in Punkaharju were not statistically significant unlike in Kivalo (Paper II, table 4). In Kivalo, survival after first growing season in 2006 was 94% for Siberian larches, 90% for Dahurian larches and 95% for the comparison entries. In 2009, Raivola origin comparison entries, Plesetsk 2A–B, Petchora 4A, Boguchany 9A and Magadan 13A had 77−90% survival in Kivalo (Fig. 10 and 11). More southern Siberian larches had a lot of variation. Altai provenance 11A had the poorest survival rate in the north. European larch had also very low survival. Of the southern Dahurian larches Kurile larch was slightly over average. In Kivalo, latitude and temperature sum explained the differences in survival between provenances. Northern provenances from cold climates had generally better survival (Fig. 12). Frost damages were common in both sites and in 2009 in Kivalo 32% of the living seedlings were damaged to some extent but the differences between provenances were not statistically significant. In Punkaharju the corresponding percentage was 15% and there were also mammal damages of different kinds in 16% of the seedlings.

Figure 11. Five year old seedlings of provenance Plesetsk 2B in the Kivalo field trial on 17th of September in 2009. Scarification method was ploughing.

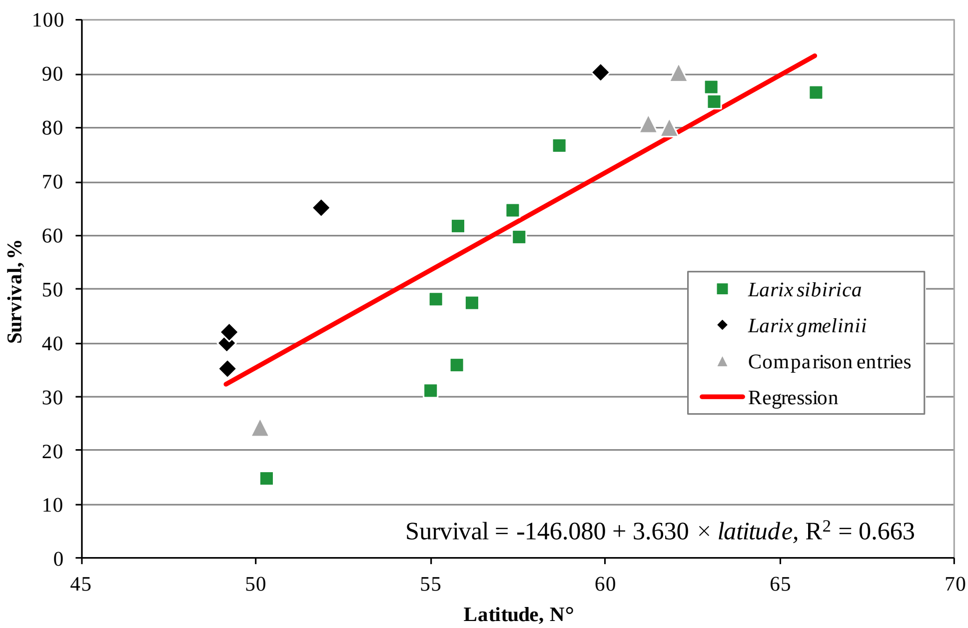


Figure 12. Relationship between survival rate and provenance latitude in Kivalo in 2009 (n=17, the comparison entries and Altai mountain provenances were excluded from the regression analysis).

Forking which was caused by various reasons was found on 20% of the seedlings in Punkaharju and 52% in Kivalo. The amount of mammal damages declined with increasing longitude of the provenance ($r=-0.85$, $p<0.05$) indicating that the Dahurian larches had less mammal damages but the differences between provenances were not statistically significant (Paper II, tables 4 and 5).

4 DISCUSSION AND CONCLUSIONS

4.1 Growth rhythm

For the bud burst, a certain accumulated temperature sum is needed, depending on the tree species, origin and tree age (Grossnickle 2000). In this study (Paper III), northern provenances had the earliest bud burst, but only by a small difference to southern Dahurian larch provenances which had earliest onset of height growth. Common trend of the tree species of the northern temperate zone is that provenances from northern cold climates flush earlier than more southern ones (Wright 1976, Beuker 1994). A series of environmental cues are needed to release trees from winter dormancy. Each species and provenance has its own chilling requirements concerning time and temperature, and these requirements can also vary by age (Grossnickle 2000). Provenances with high chilling requirements, for example, would have smaller risk to break dormancy too early in the spring in maritime conditions with relatively warm winters (Hannerz et al. 2003).

Growth rhythm results (Paper III) were in line with Russian provenance trial in Komi Republic (61°39′N, 50°41′E, 160 m), where the northern provenances had earliest growth onset (the Dahurian larch provenances were not included into Komi trial) (Fedorkov 2012). Highest leader shoot growth was shown by 2A Plesetsk provenance instead of southern provenances. Shoot elongation was not measured in Kivalo, but compared to southern provenances Plesetsk seedlings had good height growth in Kivalo (Fig. 8).

In Punkaharju, height increment was not linear during growing period, but more wavelike perhaps because of changing conditions during the growing season and switch from predetermined growth to free growth (Paper III, fig. 3). In overall, the amount of predetermined growth of trees is mainly controlled by the temperature sum and the conditions of the previous growing season. Whereas, the amount of free growth is affected by the conditions of the prevailing growing season and it ends when the temperature decreases enough and/or the photoperiod shortens past a critical value (Pollard and Logan 1977, Cannell 1990). However, the same environmental factors cause variation in both predetermined growth and free growth, although the effect on predetermined growth is seen on the following growing season (Joyce 1987). The southern Dahurian larch provenances continued their growth late into autumn and seemed to cease growth after temperature started to decline. This can be explained by the longer critical night length requirement of the southern provenances (Cannell 1985, Partanen 2004) and possibly by their ability to detect the twilight more effectively as has been shown with Norway spruce (Dormling 1979, in Partanen 2004). The sensitivity of growth cessation to night length increases with the latitude of the origin of the provenance (Vaartaja 1959, Junttila 1980, Olsen 2010). The southern provenances grew later in the warm summer of 2009 than in the cooler summer of 2008. In a more mature age, the shoot elongation period is shorter than in the seedling stage

(Cannell et al. 1976, Ununger et al. 1988) due to decrease in free growth (Cannell and Johnstone 1978, Ununger et al. 1988).

The growth profile of Olga Bay larches (14A–C) and Sachalin origin Kurile larch (15A) had both continental and maritime characteristics. Their growth started early and vigorously which is more a continental trait. However, the growth continued to late autumn like would be expected from a southern maritime provenance (Tigerstedt 1993). The Magadan (13A) Dahurian larch, however, had an earlier bud set because of its northern origin. Thus, the Dahurian larches had a semi-maritime growth profile which is undoubtedly result of the variable climate in their place of origin in coastal areas of the Okhotsk Sea and Sea of Japan.

The timing of bud set followed the differences among provenances in shoot elongation (Paper IV). The timing of bud set in northern tree species is highly genetic and is in connection with the photoperiod and temperature. There are, however, differences how these factors are emphasized (Dormling et al. 1968, Heide 1974, Koski and Sievänen 1985, Koski 1990, Partanen 2004, Eriksson et al. 2006). According to Simak (1970) the vegetative cycle of larch is regulated by photoperiod, temperature and genetic properties of the provenance. In this study, temperature fluctuations affected the growth and bud set of provenances. The most northern provenance 4A Petchora ceased its growth and started forming terminal buds before temperature started to decline and was affected by the shortening day (photoperiod).

The growth rhythm of Altai mountain provenances11A–C stood out often from other provenances. Bud burst of Altai provenances was slightly behind other Siberian larch provenances and the overall progress towards 100% bud burst was the slowest (Paper III). Shoot elongation was also poor. The terminal bud development started early, but advanced slowly and needles shed without proper autumn colouration (Paper IV). Results with Altai provenance showed that it is hard to predict the field performance of seedlings accurately by their sowing year performance in the greenhouse. It had one of the longest growing periods of the Siberian larches in the greenhouse and average height growth, but it performed poorly in the field. However, the order in which provenances formed their terminal buds and autumn colouring and shed their needles were very much the same in the greenhouse and field. In that sense, some predictions of field performance can be made by the measurements of the seedlings in greenhouse. It is possible that the free growth of Altai provenances is restricted to the first year, and from then on, the growth is mostly predetermined, which is a disadvantage for height growth. In the first year, the growth of seedlings, from seed germination to bud set, is totally free growth (Pollard and Logan 1976). However, the proportion of free growth diminishes gradually in a few years. As a result, the shoot elongation period in older trees is also shorter (Pollard and Logan 1976, Cannell et al. 1976, Ununger et al. 1988). According to Deruzhkin and Kirbisa (1989) a similar Altai provenance had a growth period of only 34 days near Voronezh, Russia (51°40′N, 39°12′E). The Altai provenances have adapted to a short growing season in their place of mountain origin and are not able to fully use the more favourable growing conditions. This study verifies the earlier results by Viherä-Aarnio (1993) and Hagman (1995) that Altai provenances are not suitable for forestry in North-Finland and ads, nor they are suitable for South-Finland.

Development of autumn colouration and needle shedding followed the common trends of northern tree species (Wright 1976) and northern provenances had earlier development than more southern provenances (Paper IV). Even though the bud set was earlier in 2008 than in 2009, the timing of autumn colouring and needle shedding was very similar between the years. Maybe the environmental conditions that affected bud set were not strong enough to initiate the start of autumn colouring. According to Worrall (1993) the timing of autumn colouring in subalpine larch (*Larix lyallii* Parl.) has varied by a month between years, which confirms that the timing of autumn colouring is not fixed only on photoperiodic conditions. The start of autumn colouring was a bit earlier in 2009, but in 2008 the development was faster and 100% needle shedding was achieved earlier. There was a positive correlation between autumn colouration and with both spring and summer temperatures which have been found to promote leaf colouring in European larch and other deciduous species opposite to warm autumn (Estrella and Menzel 2006, Busetto et al. 2010). There were no large differences in spring temperatures but the summer of 2009 was warmer. The autumn instead was warmer in 2008. It is possible that the warm summer of 2009 advanced the autumn colouring. In 2008 the warm autumn slowed the start of autumn colouring but as the temperatures decreased also the rate of colouring and needle shedding increased. The triggers of autumn colouring are, however, known to be a complex mixture of several interacting internal (tree) and external (environment) factors (Estrella and Menzel 2006, Galvagno et al. (2012).

4.2 Total height growth

When comparing the height growth for the same provenances that were present in both Finnish and Swedish field trials, the height after four growing seasons in the field was on average best in Punkaharju (Appendix 2). The differences in height growth between provenances in Punkaharju were also similar to the Swedish field trial in Österbymo (Fig. 13) and the southern Dahurian larches had superior height growth on both sites. Compared to the northernmost Swedish trial, Järvträsk, average height growth was lower in Kivalo (Appendix 2).

Finnish Forest Research Institute has established several field trials during 1971–1983 to northern Finland (65–69°N) with larch seed material mostly from domestic older cultivations. According to Viherä-Aarnio (1993) there was high variation in height growth even within trial entries and individual plots which might be partly a result of hybrid origin of the material (even between species). In Kivalo, after four growing seasons within entry variation was low.

The exact origins of larch provenances used in the exotic tree trials in Finland in the 1920’s and 1930’s are in many cases unknown (Heikinheimo 1956, Lähde et al. 1984, Silander et al 2000). The few Dahurian larch provenances originate from Korea, Kurile Islands and Sachalin. In many cases, the selected growing site has been wet peat field which has lead into high seedling mortality and exposed seedlings to frost damages. The growth of Kurile larch in juvenile stage was promising according to Heikinheimo (1956). The growth of Olga Bay larches was poor in seedling stage but improved at later stage. Dahurian larches (*Larix gmelinii* var. *gmelinii*) had relatively good growth. In general, larches have grown best in Punkaharju compared to more southern Ruotsinkylä and Solböle. This is most likely because of better selection of growing sites in Punkaharju which are also more fertile and have favourable climatic conditions.

It can be concluded, that the earlier experiences with Dahurian larch varieties in Finland are limited because of small amount of provenances and mistakes made in the growing site selection. The best Olga Bay larch trial in Punkaharju (cultivation PH 102, 280 trees/ha) has reached height of over 32.1 metres, diameter of 43 cm and volume of 467 m^3/ha in 70 years (Silander et al. 2000). Growth (yield) of Siberian larch has, however, exceeded in most cases the growth of Dahurian larches. The best Siberian larch trial in Punkaharju (PH 101, 220 trees/ha) in age of 71 years had height of 36.3 metres, diameter of 50 cm and yield of 520 m^3/ha. PH 101 origin is Raivola, which has been the best Siberian larch origin.

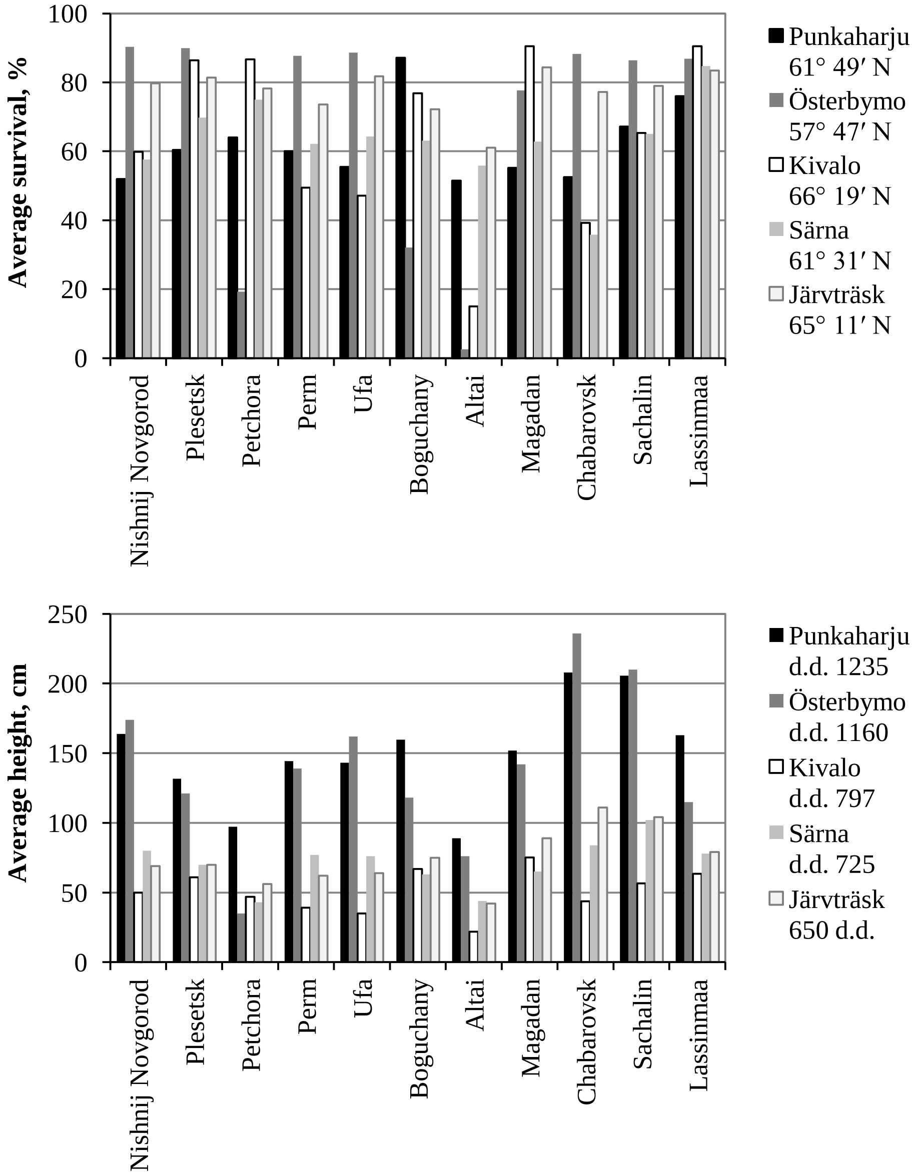


Figure 13. Average height growth (top panel) and survival in Finnish (Punkaharju, Kivalo) and Swedish (Österbymo, Särna, Järvträsk) field trials after four growing seasons. Results from Swedish trials are according to Karlman and Martinsson (2007).

The late development of Dahurian larches might expose them to frost damages. The European larch comparison entry had, however, even later development. Earlier experiences since the 19^{th} century with European larch in Finland indicate that when wet lowlands are avoided in regeneration the European larch does not suffer frost damages in a lethal degree (Heikinheimo 1956, Lähde et al. 1984, Silander et al. 2000). The stand which functioned as a seed source to the comparison entry of European larch in the study, Mv135, has produced yield of 507 m^3/ha and grown 35.9 m/48 cm in 69 years in Punkaharju research forest (Silander et al. 2000).

The Petchora provenance stood out from the rest of the Siberian larches with its poor growth in Punkaharju (Papers I–III). This can be explained by its northern origin (66°00′N; day length of 23 h on 1^{st} July) and by the shorter day length in Punkaharju (61°48′N, day length of 19½ h on 1^{st} July) than that to which it is adapted, giving a false signal of a change of season. In general, the night length required for growth cessation of seedlings of northern origin is shorter than for southern ones (Vaartaja 1957, Partanen 2004). In Kivalo (66° 19′N), Petchora provenance had decent height growth compared to the average.

The height growth measured in greenhouse during the first growing season correlated moderately with the height growth measured in field conditions in Punkaharju ($r=0.56$, $p<0.05$), but not in Kivalo ($r=0.06$, $p>0.05$). The genetic differences between provenances did not manifest themselves to full extent in the favourable greenhouse conditions. Dahurian larch has, in general, distinctly smaller seed than Siberian larch (Farjon 1990, Sarvas 2002), (Table 1) which levels the seedling stage differences in total height growth between species in the sowing year. The early summer growth had correlation with seed weight ($r=0.66$, $p<0.05$) and Siberian larches had larger early growth (Paper I, table 4). However, seed weight did not have statistically significant correlation with total height growth. After four growing season in the field, the differences between provenances were profound and Dahurian larches had significantly better height growth (Paper II).

4.3 Survival and damages

Compared to results in Sweden (Karlman and Martinsson 2007) with the same material after four growing seasons, the survival in Punkaharju (Paper II) was similar to Särna (61°31′N, 13°00′E, 540 m, 725 d.d.) with some exceptions (Appendix 2). Continental provenance Boguchany had higher survival rate in Punkaharju as well as the Olga Bay larches (14A–C). Provenances from continental climates, in general, had poor survival in semi-maritime Sweden (Karlman et al. 2011). Compared to the northernmost Swedish trial, Järvträsk (65°11′N, 19°31′E, 410 m, 650 d.d.), northern provenances and the continental Boguchany provenance had slightly higher survival in Kivalo than southern provenances, which survived better in Järvträsk. Raivola origin comparison entry Lassinmaa had 90% survival in Kivalo. Lassinmaa comes from a seed orchard which has been established with plus trees selected from northern Finland, to produce seed material for northern conditions (750–1050 d.d.) (Utilisation areas of seed orchards 2013).

Finnish and Swedish results differ from those of Norwegian field test in maritime Bergen (60°N, 5°E), where Olga Bay larches had highest survival after three growing seasons (Øyen et al. 2007). In Komi republic in Russia (61°39′N, 50°41′E, 160 m), the survival on the second growing season in the field was high and varied between 92% and 97%, but in addition to the younger age, fewer provenances were included in the trial (Fedorkov 2012).

According to Viherä-Aarnio (1993), survival in field trials in northern Finland was poor (average survival of Russian larches 29–48%, at age 18–24 years) except for the northernmost trial in Inari (69°N) (average survival of Russian larches 65%, at age of 11–12 years). Survival was especially poor on flat sites with dense soils. Mortalities had occurred in different periods, some seedlings died in a very early phase, some in a height of 2–4 meters. Small spruce gall aphid (*Adelges laricis*) was probably partial reason for the mortality (Viherä-Aarnio 1993, Siitonen 1993, Hagman 1995). Aphid damages were also present in small amounts in Punkaharju and Kivalo trials (Paper II). In Punkaharju, there was a larch sawfly outbreak in 2009 with about 18% of the seedlings suffering from *Lygaeonematus wesmaeli* and *Pristiphora laricis* larvae damages.

In artificial freezing tests the Dahurian larches were found to suffer frost injuries in both spring and autumn while Plesetsk 2A–C and Petchora 4A provenances and the Raivola origin comparison entry Sv309 showed the least damages (Eysteinsson et al. 2009). The southern Siberian larch provenances Perm 6A and Ufa 7A showed some autumn frost damages but spring damages were comparable to the northern Siberian larches. The good frost tolerance of north-western Siberian larches is possibly due to adaptation to variable climatic conditions in the proximity of the Barents Sea, which is often ice free in late winter (Tigerstedt 1990, Eysteinsson et al. 2009). In Punkaharju, the Dahurian larches did not suffer noticeably from frost damages (Paper II).

Dahurian larches had less mammal damages than Siberian larches although the result was not statistically significant (Paper II). The faster height development of the seedlings might have affected the amount of mammal damages, but they were still easily available for all browsers. Viherä-Aarnio and Heikkilä (2006) found earlier that sapling height had an effect on proportion of browsed silver birch (*Betula pendula* Roth) trees and browsing damages by moose decreased with increasing sapling height. The better vole damage resistance of Dahurian larches compared to Japanese larch has been studied in more detail in Japan and utilized in creating vigorously growing hybrid larches resistant for vole damages (Chiba 1963, Takahaski and Nishiguchi 1966, Kurahashi 1970, Nishiguchi et al. 1977, Takata et al. 2005). Larch hybrids are not studied in Finland comprehensively and seedlings used in experiments have mostly been naturally born hybrids in domestic cultivations. These mostly small scale experiments have often shown good growth and yield (Silander et al. 2000). In Swedish experiments larch hybrids have been promising (Larsson-Stern 2003, Karlman 2010). There is one record of Siberian larch and Kurile larch hybrids (*Larix sibirica* x *Larix gmelinii* var. *japonica*) in Finland in Torne Valley (Ruotsalainen 1993). The test trial was established in peat field and the number of trees was very low. The hybrid had, however, better growth than Siberian larch, but slightly poorer than Kurile larch. It would be interesting to hybridize Raivola origin with Olga Bay or Kurile larch to study growth and yield and resistance for mammal damages. Some initial experiments for Siberian and European larch hybrid seed production in Finland has been made earlier (Nikkanen 1993).

4.4 Potential of larch in Finnish forestry

Russian larch species could have large potential for forestry in Finland due to their production potential (large timber yield), which is comparable to Norway spruce on fertile sites (Vuokila et al. 1983, Silander et al. 2000). The amount of valuable heartwood in larch is also greater than in domestic species and wood density is higher despite of greater radial growth than in Scots pine. Larch heartwood can be utilized in places where good weather durability or high mechanical strength is needed. Larch wood has also esthetical properties suitable for indoor use (Venäläinen et al. 2001, Verkasalo and Viitanen 2001, Koizumi et al. 2003, Karlman et al. 2005, Martinsson and Lesinski 2007). None of the domestic species can produce as bulky stems in same time period (Parviainen 1985, Isomäki 2002). Dahurian larches have resistance against mammal damages (Takata et al. 2005). The amount of volatile organic compounds in larch timber is low compared to Scots pine which is a useful characteristic in indoor use (Viitanen et al. 2001, Heikkonen et al. 2007). Larch extracts can be used in food, pharmaceutical, cosmetic and bio-tech industries (Tuimala 1993, Keegan et al. 1995).

The small amount of larch cultivations in Finland causes a vicious circle that Sarvas (2002) predicted in which forest industries interest in larch remains low (demand) and the forest owners desire to cultivate larch (supply) remains also low. For forest industry it is also easy to use only two conifer species so that there is no need for many different processes.

The established field trials also serve climatic adaptation studies in respect to the global climatic change (e.g. Parry 2000, Carter et al. 2002, IPCC 2007), which is expected to affect growth of trees in the long run and cause adaptation challenges which might have a significant impact on forestry (Hänninen and Tanino 2011). Ge et al. (2011) predict that increasing water loss through evaporation caused by climate change will create suboptimal environment for Norway spruce in southern Finland due to decreasing availability of water in the soil particularly on upland sites with lower groundwater table. Deeper root system and deciduous nature of larches makes them less vulnerable to drought and storm winds than Norway spruce in Finland (Heikinheimo 1926, Grossnickle 2000, Sarvas 2002). For preparation to the warming climate use of more southern provenances has already been proposed (Partanen and Beuker 1999, Marttila et al. 2005), with some reservations (Beuker 1996, Koski 1996). Also use of exotic tree species has been proposed (Ruotsalainen 2006). The Raivola origin Siberian larch has its advantages as it is capable of adapting to various kinds of climates. Isomäki (2011) has even argued that larches can be useful in slowing down the climatic warming by increasing the albedo as deciduous forest reflect more sunshine than evergreen forests during snow cover.

4.5 Conclusions

In this study, even though some provenances of the Russian larches showed better height growth and better utilization of the length of growing season, use of current Raivola origin seed sources is still recommended. In Punkaharju field trial, there were no statistically significant differences in survival between provenances after four growing seasons. A large share of the decrease in survival occurred during the planting year and was influenced by large pine weevil damages and regeneration flaws. Especially the Olga Bay larches and Kurile larch had superior height growth and they utilized growing season from early spring to late autumn without suffering significant frost damages. Old field experiments in Finland show however, that frost damages can occur especially if site selection is wrong and total yield with Dahurian larches can be smaller than with Siberian larches (Silander et al. 2000). Warmer than average summers during the experiment, might also have affected in a positive manner to the adaptation and growth favouring the southern provenances. Especially Siberian larch provenance Boguchany 9A from quite continental climate adapted surprisingly well to Punkaharju and decently to Kivalo. Few provenances were able to adapt to conditions in Kivalo and none of them very well. The Raivola origin seems to be most suitable for North-Finland also.

Geographical variables were, in general, better in explaining the differences between provenances than climatic variables. Geographic variables are, however, proxies for climatic conditions as, for example, temperature generally decreases northwards in the northern hemisphere. It is also possible that there were some inaccuracies in the climatic data that subsequently affected the results of the statistical analysis. Climatic variables represented also averages of the area of the provenance origin rather than of a precise location. Microclimatic conditions can vary especially in mountainous areas. The geographical composition of the provenance material promoted variables such as longitude because the climatic conditions and species were different in east and west.

The growth rhythm of larches seemed to be controlled by interactions between the photoperiod and temperature. Day length during growing season increases when moving from south to north. The northern Petchora 4A provenance ceased growth even in favourable temperature conditions because of too short photoperiod in Punkaharju. Southern provenances grew late into autumn in the longer photoperiod and shoot elongation began to cease when temperature started to decline. Cold spell in August 2008 might have caused the earlier growth cessation and formation of terminal buds compared to 2009.

The prediction of the growth of the seedlings in field trials based on their growth in greenhouse conditions was difficult, although the results correlated with Punkaharju field test results after four growing seasons ($r=0.57$, $p<0.05$). The very poor growth of Petchora provenance in the greenhouse repeated predictably in the field but poor performance of the Altai provenances was a slight surprise since they grew well in the greenhouse. Nor it was possible to predict the superior height growth of Dahurian larches in the field. Otherwise the general order of the provenances in which they formed, for example, terminal buds was very similar in greenhouse and field. Thus, some general predictions can be made by the provenance phenology in the greenhouse, but individual provenances may have deviating performance that is difficult to predict. And though seedling phenology was similar in greenhouse and field, predicting growth in the field is difficult, because it is affected also by other genetic factors than those regulating phenology, as well as environmental factors, such as temperature and water availability.

The field trials in Punkaharju and Kivalo must be followed in a longer time perspective to confirm the obtained results. The differences between provenances can be expected to become more profound in time and stem quality and other features can also be studied. According to Mikola (1993), instead of further breeding of Raivola origin, development of hybridization programs should be considered. In this study, Dahurian larches had superior seedling stage height growth. Southern Olga bay larch and Kurile larch had potentially suitable growth rhythm for southern Finland and the name variety Dahurian larch (Magadan 13A) might succeed in northern Finland. According to Japanese studies (Takata et al. 2005) Dahurian larches have resistance to vole damages, which trait was seen also in this study. In the future in Finland, hybridization of Raivola origin larches for different utilization areas and the studied Dahurian larches, should be studied in addition to further research of the established field trials. A hybrid with best characteristics of Raivola origin larch and Dahurian larch could have potential for Finnish forestry.

REFERENCES

Abaimov, A.P., Barzut, V.M., Berkutenko, A.N., Buitink, J., Martinsson, O., Milyutin, L.I., Polezhaev, A., Putenikhin, V.P. & Takata, K. 2002. Seed collection and seed quality of *Larix* spp. from Russia, initial phase on the Russian-Scandinavian larch project. Eurasian Journal of Forest Research 4: 39–49.

Autio, A. 2002. The cultivated larches (*Larix*) of Arboretum Mustila. Sorbifolia 33(3): 100–111. (In Finnish with English summary).

Beuker, E. 1994. Adaptation to climatic changes of the timing of bud burst in populations of *Pinus sylvestris* L. and *Picea abies* (L.) Karst. Tree Physiology 14: 961–970.

— 1996. Implications of climate adaptability in provenance trials with Scots pine and Norway spruce in Finland for the possible effects of climate warming. Research Notes, University of Joensuu, Faculty of Forestry. 33 p.

Blöndal, S. & Snorrason A. 1995. The role of *Larix* in Icelandic forestry. In: Schmidt, W.C. & McDonald, K.J. (eds.). Ecology and management of *Larix* forests: a look ahead. Proceedings of an international symposium; 1992 October 5-9; Whitefish, MT, U.S.A. Gen. Tech. Rep. GTR-INT-319. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 220–226.

Busetto L., Colombo R., Migliavacca M., Cremonese E., Meroni M., Galvagno M., Rossini M., Siniscalco C., Morra di Cella U., Pari E. 2010. Remote sensing of larch phenological cycle and analysis of relationships with climate in the Alpine region. Global Change Biology 16: 2504–2517.

Cajander, A.K. 1917. Metsänhoidon perusteet 2. Suomen dendrologian pääpiirteet. Werner Söderström Oy, Porvoo. 652 p. (In Finnish).

Cannell, M.G.R. 1985. Analysis of risks of frost damages to forest trees in Britain. In: Tigerstedt, P., Puttonen, P. & Koski, V. (eds.). Crop Physiology of Forest Trees. Helsinki University Press, Helsinki. p. 153–166.

— 1990. Modelling the phenology of trees. Silva Carelica 15: 11–27.

— & Johnstone, R.C.B. 1978. Phenology of bud burst in Douglas-fir related to provenance, photoperiod, chilling and flushing temperature. Botanical Gazette 136(3): 290–298.

— , Thompson, S. & Lines, R. 1976. An analysis of inherent differences in shoot growth within some north temperate conifers. In: Tree physiology and yield improvement (ed. M.G.R. Cannell & F. T. Last). Academic Press, New York. p. 173–205.

Carter, T., Bärlund, I., Fronzek, S., Kankaanpää, S., Kaivo-oja, J., Luukkanen, J., Wilenius, M., Tuomenvirta, H., Jylhä, K., Kahma, K., Johansson, M., Boman, H., Launiainen, J., Laurila, T., Lindfors, V., Tuovinen, J.-P., Aurela, M., Syri, S., Forsius, M. & Karvosenoja, N. 2002. The FINSKEN global change scenarios. In: Käyhkö, J. & Talve, L. (eds.). Understanding the global system, The Finnish perspective. Painosalama, Turku. p. 27–40.

Chiba, S. 1963. Studies on the breeding of *Larix* species. (I) Variation between species on the gnawing by the mountain hares and the wild mice. Technical Note No. 29. Oji institute for forest tree improvement. Oji Paper Co., Ltd. Kuriyama, Hokkaido, Japan. 14 p. (Handout translation in Finnish).

Conrad, V. 1946. Usual formulas of continentality and their limits of validity. Trans. Am. Geophys. Union, 27. 663 p.

Deruzhkin, R. I. & Kirbisa, M. 1989. Results of larch breeding in the central black soil zone (CBSZ). Forest genetics, breeding and physiology of woody plants. Proceedings of the international symposium, September 24–30 1989, Voronezh. p. 159–160.

Dormling, I. 1979. Influence of light intensity and temperature on photoperiodic response of Norway spruce provenances. IUFRO Norway Spruce meeting S 2.03.11–S 2.02.11 Bucharest, Romania 1979. p. 398–408.

— , Gustafsson, Å. & von Wettstein D. 1968. The experimental control of the life cycle in *Picea abies* (L.) Karst. I Some basic experiments on the vegetative cycle. Silvae Genetica 17: 44–64.

Eriksson, G., Ekberg, I. & Clapham, D. 2006. An introduction to forest genetics. Second edition. Swedish university of agricultural sciences. Department of plant biology and forest genetics. [Online journal].
Available at: http://vaxt2.vbsg.slu.se/forgen/Forest_Genetics.pdf

Estrella, N. & Menzel, A. 2006. Responses of lead colouring in four deciduous tree species to climate and weather in Germany. Climate Research 32: 253–267.

Eysteinsson, T., Karlman, L., Fries, A., Martinsson, O. and Skúlason, B. 2009. Variation in spring and autumn frost tolerance among provenances of Russian larches (*Larix* Mill.). Scandinavian Journal of Forest Research, 24(2): 100–110.

Farjon, A. 1990. Pinaceae. Drawings and descriptions of the genera *Abies*, *Cedrus*, *Pseudolarix*, *Keteleeria*, *Nothotsuga*, *Tsuga*, *Cathaya*, *Pseudotsuga*, *Larix* and *Picea*. Koeltz scientific books. Königsten, Germany. 330 p.

Fedorkov, A. 2012. Variation in the leader shoot elongation patterns in *Larix* species and provenances in the North-West of Russia. Baltic Forestry Vol. 18, No. 1(34): 119–124.

Finnish Meteorological Institute. 2013a. [Internet site]. FMI – Finnish Meteorological Institute. Available at: http://en.ilmatieteenlaitos.fi/climate. [Cited 4 Mar 2013].

— 2013b. [Internet site]. FMI – Finnish Meteorological Institute. Available at: http://ilmatieteenlaitos.fi/terminen-kasvukausi. [Cited 5 May 2013].

Galvagno, M., Rossini, M., Migliavacca, M., Cremonese, E., Colombo, R. & Morra di Cella, U. 2012. Seasonal course of photosynthetic efficiency in *Larix decidua* Mill. in response to temperature and change in pigment composition during senescence. [Epublification ahead of print]. International Journal of Biometeorology. 10 p.

Ge, Z.-M., Kellomäki, S., Zhou, X., Wang, K., Peltola, H., Väisänen, H. & Strandman H. 2011. Effects of climate change on evapotranspiration and soil water availability in Norway spruce forests in Southern Finland: an ecosystem model based approach. Ecohydrology. Volume 6(1): 51–63.

Grossnickle, S. 2000. Ecophysiology of northern spruce species. NRC Research Press, Ottawa. 407 p.

Hagman, M. 1993. Potential species and provenances for forest development in cold climates. In: Alden, J., Mastrantonio, J. L. & Ødum, S. (eds.). Forest development in cold climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18–23 1991. Plenum Press. New York and London. 251–263.

— 1995. Experiences with *Larix* species in northern Finland. In: Ritari, A., Saarenmaa, H., Saarela, M. and Poikajärvi, H. (eds.). Northern Silviculture and Management. The Finnish Forest Research Institute, Research Papers 567: 111–123.

Hakkila, P. & Winter, A. 1973. On the properties of larch wood in Finland. Communicationes Instituti Forestalis Fenniae 79(7): 1–45.

— , Nikki, M. & Palenius, I. 1972. Suitability of larch as pulpwood in Finland. Paperi ja Puu 54(2): 111–123.

Hämet-Ahti, L., Palmén, A., Alanko, P. & Tigerstedt, P. 1992. Woody Flora of Finland (second fully revised edition). Dendrologian Seura, Helsinki. 373 p. (In Finnish with English summary).
Hannerz, M., Ekberg, I. & Norell, L. 2003. Variation in chilling requirements for completing bud rest between provenances of Norway Spruce. Silvae Genetica 52(3–4): 161–168.
Hänninen, H. & Tanino, K. Tree seasonality in a warming climate. Trends in Plant Science. Vol. 16(8): 412–416.
Heide, O.M. 1974. Growth and dormancy in Norway spruce ecotypes. I. Interaction of photoperiod and temperature. Physiologia Plantarum 30: 1–12.
Heikinheimo, O. 1926. Myrskytuhoista Raivolan lehtikuusimetsässä syyskuun 23. päivänä 1924. Eripainos metsätieteellisen koelaitoksen julkaisusta 12. 58 p. (In Finnish with German summary).
— 1956. Tuloksia ulkomaisten puulajien viljelystä Suomessa. Communicationes Instituti Forestalis Fenniae 46(3): 129 p. (In Finnish with German summary).
Heikkonen, S., Luostarinen, K. & Piispa, K. 2007. Kiln drying of Siberian larch (*Larix sibirica*) timber. Mikkeli University of Applied Sciences – Research Reports 26. 78 p. + app. 4 p.
Hirvas, H. 1991. Pleistocene stratigraphy of Finnish Lapland. Geological Survey of Finland. Bulletin 354. 127 p.
Hokajärvi, T. (ed.) 1998. Erikoispuulajien kasvatus. Metsähallituksen metsätalouden julkaisuja 14. 27 p. (In Finnish).
Ilvessalo, L. 1920. Ulkomaisten puulajien viljelemismahdollisuudet Suomen oloja silmälläpitäen. Acta Forestalia Fennica 17. 112 p. (In Finnish).
IPCC. 2007. Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 996 p.
Isomäki, A. 2002. Larch in growth and yield experiments. Sorbifolia 33(2): 54–62. (In Finnish with English summary).
Isomäki, R. 2011. 66 ways to absorb carbon and improve the earth's reflectivity – from reasonable options to mad scientist solutions. Into publishing, Helsinki, Finland. 274 p.
Joyce, D.G. 1987. Phenotypic variation in predetermined and free growth in sapling size western larch. Canadian Journal of Forest Research 17(3): 200–204.
Junttila, O. 1980. Effect of photoperiod and temperature on apical growth cessation in two ecotypes of *Salix* and *Betula*. Physiologia Plantarum 48: 347–352.
Juvonen, R. 1995. Properties of *Larix* in Finnish sawmilling industry. In: Ritari, A. & Saarenmaa, H. (eds.). Northern silviculture and management. Finnish Forest Research Institute, Research Papers 567: 265.
Karlman, L. 2010. Genetic variation in frost tolerance, juvenile growth and timber production in Russian larches (*Larix* Mill.) – implications for use in Sweden. Doctoral thesis. Acta Universitatis Agriculturae Sueciae 2010(30). 91 p.

— & Martinsson, O. 2007. Siberian larch provenance trial on three locations in Sweden – Survival and height growth after four growing seasons. In: Perron, M. (ed.). LARIX 2007: International Symposium of the IUFRO Working Group S2.02.07 (Larch Breeding and Genetic Resources). Integrated research activities for supply of improved larch to tree planting: tree improvement, floral biology and nursery production. Proceedings: Saint-Michel-des-Saints and Québec City, September 16-21, 2007. p. 123–127.

— , Mörling, T., and Martinsson, O. 2005. Wood density, annual ring width and late wood content in larch and Scots pine. Eurasian Journal of Forest Research 8(2): 91–96.

— , Fries, A., Martinsson, O. and Westin J. 2011. Juvenile growth of provenances and open pollinated families of four Russian larch species (*Larix* Mill.) in Swedish field tests. Silvae Genetica 60(5): 165–177.

Keegan, C.E. III, Blatner, K.A. & Wichman, D.P. 1995. Use and value of western larch as commercial timber species. In: Schmidt, W.C. & McDonald, K.J. (eds.). Ecology and management of *Larix* forests: a look ahead. Proceedings of an international symposium; 1992 October 5-9; Whitefish, MT, U.S.A. Gen. Tech. Rep. GTR-INT-319. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 155–157.

Koizumi, A., Takata, K., Yamashita, K. & Nakada, R. 2003. Anatomical characteristics and mechanical properties of *Larix sibirica* grown in south-central Siberia. IAWA Journal. Vol. 24(4): 355–370.

Koski, V. 1990. Joint effects of day length and temperature on dormancy processes. Silva Carelica 15: 47–50.

— 1996. Breeding plans in case of global warming. Euphytica 92: 235–239.

— & Sievänen, R. 1985. Timing of growth cessation in relation to the variations in the growing season. In: Tigerstedt, P., Puttonen, P. & Koski, V. (eds.). Crop Physiology of Forest Trees. Helsinki University Press, Helsinki. p. 167–193.

Kullman, L. 1998. Paleoecological, biogeographical and paleoclimatological implications of early Holocene immigration of *Larix sibirica* into the Scandes Mountains, Sweden Global Ecology and Biogeography Letters 7: 181–188.

Kurahashi, A. 1970. Improvement of larches by species hybridization. Reprinted from the bulletin of the Tokyo University Forests, No. 79 August 1988. (Handout in Japanese with English Summary).

Laaksonen, K. 1976. The dependence of mean air temperatures upon latitude and altitude in Fennoscandia (1921–1950). Annales Academiae Scientiarum Fennicae A(119): 5–19.

Lähde, E., Werren, M. Etholén, K. & Silander, V. 1984. Ulkomaisten havupuiden varttuneista viljelmistä Suomessa. Summary: Older forest trials of exotic conifer species in Finland. Communicationes Instituti Forestalis Fenniae 125. 87 p. (In Finnish with English summary).

Lappi-Seppälä, M. 1927. Tutkimuksia siperialaisen lehtikuusen kasvusta Suomessa. Communicationes Instituti Forestalis Fenniae 12. 72 p. (In Finnish with German summary).

Larsson-Stern, M. 2003. Aspects of hybrid larch (*Larix* x *eurolepis* Henry) as a potential tree species in southern Swedish forestry. Licentiate thesis. Swedish University of Agricultural Sciences, Alnarp. 28 p.

Lepistö, M. & Napola, J. 2005. Siperianlehtikuusi – viljely, käyttö ja jalostus. Metsätieteen aikakauskirja 2/2005: 186–193. (In Finnish).

Liljeqvist, G. 1962. Meteorologi. Generalstabens litografiska anstalts förlag. Stockholm. 438 p. (In Swedish).

Luostarinen, K. & Heräjärvi, H. 2012. Relation of arabinogalactans to density, growth rate and shear strength in wood of cultivated Siberian larch. European Journal of Wood and Wood Products 71: 29–36.

Mäkinen, K. 1982. Tiedonanto Vuotson interglasiaalisesta lehtikuusen rungosta. Summary: Report on interglacial *Larix* trunk at Vuotso; Northern Finland. Geologi 34(9–10): 183–185. (In Finnish).

Martinsson, O. & Lesinski, J. 2007. Siberian larch forestry and timber in a Scandinavian perspective. JiLU Jämtlands County Council institute of Rural Development. Prinfo Accidenstryckeriet. ISBN: 978-91-633-1794-1. 92 p.

— & Takata, K. 2000. The Russian-Scandinavian larch project. Final report on seed collection and seed germination. Swedish University of Agricultural Sciences, Umeå, Sweden. Working Papers 159. 15 p.

Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatuki, H., Järvinen, H., Liski, J., Merivirta, R. & Paunio, M. 2005. Finland's National Strategy for Adaptation to Climate Change. Publications of the Ministry of Agriculture and Forestry 1/2005. 258 p.

Metzger, C. 1935. Zur Kenntnis der sibirischen Lärche (Schlus). Silva 23(28): 217–223. (In German).

Mikola, J. 1993. Lehtikuusen valintajalostuksen mahdollisuudet. In: Moilanen, M. & Murtovaara, I. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Finnish Forest Research Institute Research Papers 464: 20–31. (In Finnish).

Milyutin, L.I. & Visnevetskaia, K.D. 1995. Larch and larch forests of Siberia. In: Schmidt, W.C. & McDonald, K.J. (eds.). Ecology and management of *Larix* forests: a look ahead. Proceedings of an international symposium; 1992 October 5-9; Whitefish, MT, U.S.A. Gen. Tech. Rep. GTR-INT-319. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 50–53.

Nevalainen, K. & Hosia, M. 1969. The suitability of larch as fibre raw material. Part II: Lach as fibre material. Paperi ja Puu 51(6): 503–510.

New, M., Lister, D., Hulme, M. & Makin, I. 2002. A high-resolution data set of surface climate over global land areas. Climate Research 21. 25 p.

Nichiguchi, C., Arisawa, H. & Ilzuka, T. 1977. Studies on the resistance of forest trees to red-backed vole, *Clethrionomys rufocanus bedfordiae*. (IV) Chemical substances taking part in the resistance of Saghalin larch, *Larix gmelinii*, to biting by the cole. Journal of the Japanese Forest Society 59: 167–172. (In Japanese with English summary).

Nikkanen, T. 1993. Risteymäsiementä kahden lehtikuusilajin siemenviljelykseltä. In: Moilanen, M. & Murtovaara, I. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Finnish Forest Research Institute Research Papers 464: 36–44. (In Finnish).

Ohenoja, E. 2001. Fungi associated with *Larix* in Finland. Sorbifolia 32(4): 179–182. (In Finnish with English summary).

Olsen, J. 2010. Light and temperature sensing and signalling in induction of bud dormancy in woody plants. Plant Molecular Biology 73: 37–47.

Øyen, B.-H., Skage, J.-O., Nyeggen, H. & Østgård, Å. 2007. Russerlerk – dyrkningspotensial på Vestlandet? Norsk Skogbruk 53(1): 34–36. (In Norwegian).

Parry, M. (ed.). 2000. Assessment of potential effects and adaptations for climate change in Europe. The European Acacia Project. Report of a concerted action of the Environment Programme of the Research Directorate General of the Commission of the European Community. Jackson Environment Institute, School of Environmental Sciences. University of East Anglia, United Kingdom. 320 p.

Partanen, J. 2004. Regulation of growth onset and cessation in Norway spruce, Scots pine and silver birch. Finnish Forest Research Institute, Research Papers 921. 39 p. + appendix.

Partanen, J. & Beuker, E. 1999. Effects of photoperiod and thermal time on the growth rhythm of *Pinus sylvestris* seedlings. Scandinavian Journal of Forest Research 14: 487–497.

Parviainen, J. 1985. Growth of young Scots pine, Norway spruce, Siberian larch and silver birch plantations. Silva Fennica 19(4): 355–364. (In Finnish with English summary).

Pollard, D.F.W. & Logan, K.T. 1976. Inherent variation in “free” growth in relation to numbers of needles produced by provenances of *Picea mariana*. In: Tree Physiology and Yield Improvement. Eds. M.G.R. Cannell and F.T. Last. Academic Press, New York. p. 245–252.

Poteri, M. (ed.). 1999. Taimituho-opas. Finnish Forest Research Institute, Research Papers 737. 128 p. (In Finnish).

Redko, G. & Mälkönen, E. 2005. The Lintula larch forest. Scandinavian Journal of Forest Research 20: 252–282.

Ruotsalainen, S. 1993. Päätelmiä lehtikuusihybriden kasvusta Torniojokilaaksossa. In: Moilanen, M. & Murtovaara, I. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Finnish Forest Research Institute Research Papers 464: 54–59. (In Finnish).

— 2006. Tree species experiments at the northern timberline region in Finland. Eurasian Journal of Forest Research 9(2): 51–60.

— 2010. The importance of provenance for the performance of forest trees. Sorbifolia 41(4): 149–172. (In Finnish with English summary).

Sairanen, P. 1982. Lehtikuusen ominaisuudet ja käyttö Neuvostoliiton mekaanisessa metsäteollisuudessa. Finnish Forest Research Institute, Research Papers 72. 25 p. (In Finnish).

Sarvas, R. 2002. Havupuut. Näköispainos vuonna 1964 ilmestyneestä teoksesta. Metsälehti Kustannus. ISBN: 952-5118-33-9.531 p. (In Finnish).

Schmidt, W.C. 1995. Around the world with *Larix*: an introduction. In Schmidt, W.C. & McDonald, K.J. (eds.). Ecology and management of *Larix* forests: a look ahead. Proceedings of an international symposium; 1992 October 5-9; Whitefish, MT, U.S.A. Gen. Tech. Rep. GTR-INT-319. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 6–10.

SIBLARCH. 2013. [Online document]. SIBLARCH a northern periphery project to develop Siberian larch in Forestry and products. Available at: http://www.northernperiphery.net/managers/Library%5CProject%20Publications%5CSiblarch%5CSiblarch%20Case%20Study.pdf. [Cited 3 Mar 2013].

Siitonen, J. 1993. Lehtikuusen tuhohyönteiset Suomessa. In: Moilanen, M. & Murtovaara, I. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Finnish Forest Research Institute, Research Papers 464: 71–78. (In Finnish).

Silander, V., Lehtonen, J. & Nikkanen, T. 2000. Performance of exotic conifers in Southern Finland. Finnish Forest Research Institute, Research Papers 787. 127 p. (In Finnish with English summary).

Simak, M. 1970. Photo- and thermoperiodic responses of different larch provenances (*Larix decidua* Mill.). Studia Forestalia Suecica 86. 31 p.

Takahashi, N. & Nishiguchi, C. 1966. Studies on the resistance of forest trees to the red-backed vole, *Clethrionomys rufocanus bedfordiae* (Thomas). (I) Reletive feeding preference of the vole for seedlings of conifers under laboratory conditions. Reprinted from the Bulletin of the Tokyo University Forests, No 62 June, 1966. (Handout in Japanese with English summary).

Takata, K., Kurinobu, S., Koizumi, A., Yasue, K., Tamai, Y. & Kisanuki, M. 2005. Bibliography on Japanese larch (*Larix kaempferi* (Lamb.) Carr.). Eurasian Journal of Forest Research 8-2: 111–126.

Ten minute climatology. 2002. [Internet site]. CRU – Climatic Research Unit. Available at: http://www.cru.uea.ac.uk/cru/data/tmc.htm. [Cited 3 Mar 2013].

Tigerstedt, P.M.A. 1990. Adaptability of seed sources across geographic zones – 90 years of experimenting in Finland. In: Joint Meeting of Western Forest Genetics Association and IUFRO Working Parties S2.02-05, 06, 12 and 14, Olympia, Washington, USA August 20–24, 1990: 2.322-. 10 p.

— 1993. Genetic diversity of tree populations at their arctic limits. Forest development in cold climates (eds. J. Alden, J.l. Mastrantonio and S. Odum). NATO ASI Series A: Life Science 244. Plenum press, New York. p. 241–250.

— , Pohtila, E. & Nevala, S. 1983. Lehtikuusestako Lapin puulaji? In: Kortesharju, J. (ed.). Uutta ilmettä Lapin metsävarojen hyväksikäyttöön. Research Institute of Northern Finland. University of Oulu. Seminar report C 47: 47– 55. (In Finnish).

Tuhkanen, S. 1984. A circumboreal system of climatic-phytogeographical regions. Acta Botanica Fennica 127. 50 p.

— 1980. Climatic parameters and indices in plant geography. Acta Phytogeographica Suecica 67. 105 p.

Tuimala, A. 1993. Lehtikuusipuun ominaisuudet ja käyttö. In: Moilanen, M. & Murtovaara, I. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Finnish Forest Research Institute, Research Papers 464: 79–90. (In Finnish).

Ununger, J., Ekberg, I. & Kang, H. 1988. Genetic control and age-related changes of juvenile growth characters in *Picea abies*. Scandinavian Journal of Forest Research 3: 55–66.

Utilisation areas of seed orchards. 2013. [Internet site]. Evira. Available at: http://www.evira.fi/portal/en/plants/cultivation_and_production/forestry/maps/utilisation_areas_of_seed_orchards/. [Cited 4 Mar 2013].

Vaartaja, O. 1957. Photoperiodic responses in seedlings of northern tree species. Canadian Journal of Botany 35: 133–138.

— 1959. Evidence of photoperiodic ecotypes in trees. Ecological Monographs 29: 91–111.

Valtioneuvoston asetus metsien kestävästä hoidosta ja käytöstä. 2010. 1234/2010.

Venäläinen, A., Tuomenvirta, H., Pirinen, P. & Drebs, A.. 2005. A basic Finnish climate data set 1961–2000 – description and illustrations. Finnish Meteorological Institute Reports 2005:5. 27 p.

Venäläinen, M., Harju, A.M., Nikkanen, T., Paajanen, L., Velling, P. & Viitanen, H. 2001. Genetic variation in the decay resistance of Siberian larch (*Larix sibirica* Lebed.) wood. Holzforschung 55(1): 1-6

Verkasalo, E. & Viitanen, H. (eds.) Lehtikuusi puusepänteollisuuden raaka-aineena. Yhteistutkimushankkeen loppujulkaisu. Finnish Forest Research Institute, Research Papers 809. 125 p. (In Finnish).

Viherä-Aarnio, A. 1993. Lehtikuusen provenienssikokeet Pohjois-Suomessa. In: Moilanen, M. & Murtovaara, I. (eds.). Metsäntutkimuspäivä Kajaanissa 1992. Finnish Forest Research Institute, Research Papers 464: 9–19. (In Finnish).

— & Heikkilä, R. 2006. Effect of the latitude of seed origin on moose (*Alces alces*) browsing on silver birch (*Betula pendula*). Forest Ecology and Management 229: 325–332.

Viitanen, H., Villberg, K., & Saarela, K. 2001. Lehtikuusen haihtuvat orgaaniset yhdisteet ja niiden merkitys käytölle. In: Verkasalo, E. & Viitanen, H. (eds.) Lehtikuusi puusepänteollisuuden raaka-aineena. Yhteistutkimushankkeen loppujulkaisu. Finnish Forest Research Institute, Research Papers 809: 99–114. (In Finnish).

Vuokila, Y., Gustavsen, H.G. & Luoma, P. 1983. Siperianlehtikuusikoiden kasvupaikkojen luokittelu ja harvennusmallit. Summary: Site classification and thinning models for Siberian larch (*Larix sibirica*) stands in Finland. Folia Forestalia 554. 1–12 p. (In Finnish with English summary).

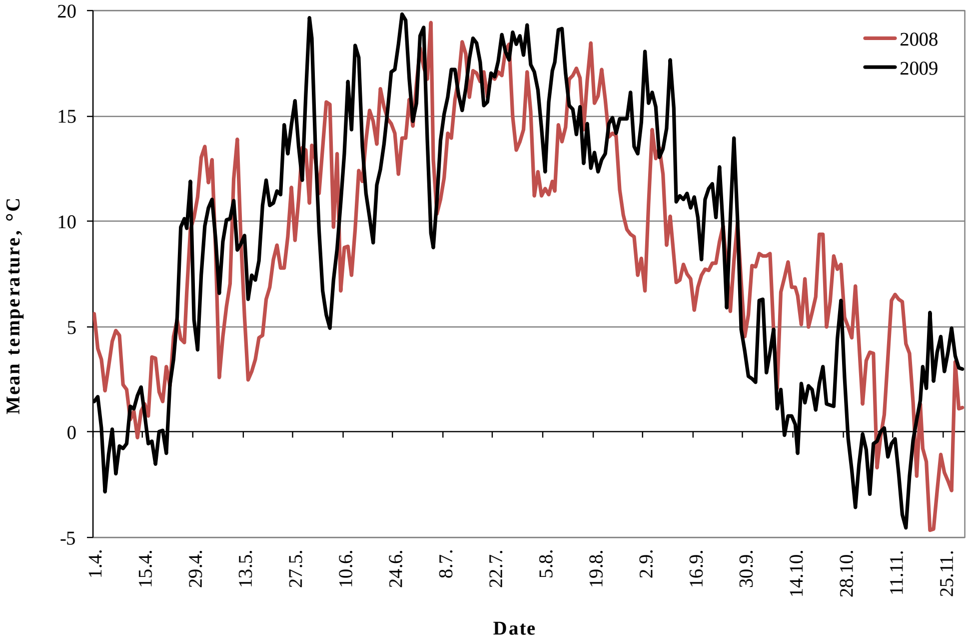
White, T.L., Adams, W.T. & Neale, D. B. 2007. Forest genetics. CABI Publishing. ISBN: 978-0-85199-348-5. 682 p.

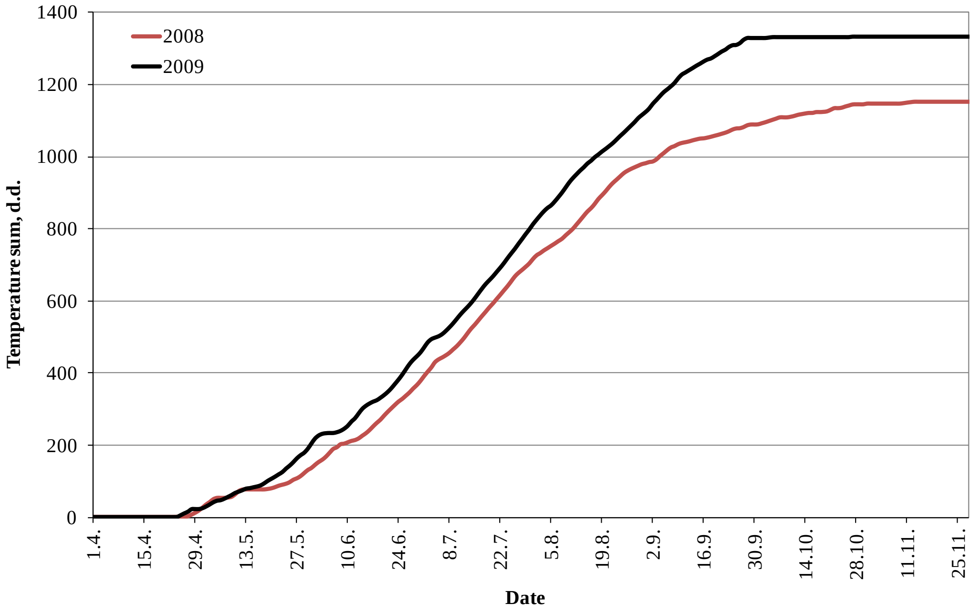
Worrall, J. 1993. Temperature effects on bud burst and leaf fall in subalpine larch. Journal of Sustainable Forestry 1(2): 1–18.

Wright, J.W. 1976. Introduction to forest genetics. Academic Press. 463 p.

Zobel, B. & Talbert, J. 1984. Applied forest tree improvement. John Wiley & Sons, Inc. 505 p.

Appendix 1. Average daily mean temperatures (top) and temperature sum accumulation (bottom) in 2008 and 2009 in Punkaharju.





Appendix 2. Average survival and height growth after four growing seasons in the field in Finland and Sweden. Information of the Swedish trials are according to Karlman and Martinsson (2007) and Karlman (2010).

Trial site	Punkaharju Finland	Österbymo Sweden	Kivalo Finland	Särna Sweden	Järvträsk Sweden
Latitude, N°	61° 49′	57° 47′	66° 19′	61° 31′	65° 11′
Longitude, E°	29° 19′	15° 37′	26° 38′	13° 00′	19° 31′
Altitude, m	78	250	265	540	410
Temp. sum, d.d.	1235	1160	797	725	650
Cont. index	35	21	37	29	34
Soil	Sandy morain	Gravelly morain	Sandy morain	Stony morain	Sandy morain
Topography	Flat lake shore	Slight southern slope	Slight north-west slope	Slight western slope	Steep eastern slope
Survival, %	Punkaharju	Österbymo	Kivalo	Särna	Järvträsk
1 Nishnij Novgorod	52	90	60	58	80
2 Plesetsk	60	90	86	70	81
4 Petchora	64	19	87	75	78
6 Perm	60	88	49	62	74
7 Ufa	55	89	47	64	82
9 Boguchany	87	32	77	63	72
11 Altai	51	3	15	56	61
13 Magadan	55	78	90	63	84
14 Chabarovsk	53	88	39	36	77
15 Sachalin	67	86	65	65	79
Sv309 Lassinmaa	76	87	90	85	83
Average	62	68	64	63	77
Height, cm	Punkaharju	Österbymo	Kivalo	Särna	Järvträsk
1 Nishnij Novgorod	164	174	50	80	69
2 Plesetsk	132	121	61	70	70
4 Petchora	97	35	47	43	56
6 Perm	144	139	39	77	62
7 Ufa	143	162	35	76	64
9 Boguchany	160	118	67	63	75
11 Altai	89	76	22	44	42
13 Magadan	152	142	75	65	89
14 Chabarovsk	208	236	44	84	111
15 Sachalin	206	210	57	102	104
Sv309 Lassinmaa	163	115	64	78	79
Average	151	139	51	71	75