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Yield of *Larix sukaczewii* Dyl. and Larch Hybrids in Northern Scandinavia

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Abstract

Yield of bulk collected provenances of *Larix sukaczewii* was compared to first generation Russian larch hybrids and three other tree species native to Scandinavia. The hybrids were full sib families of selected European and Russian larch (*L. decidua x L. sukaczewii*) or Japanese and Russian larch (*L. kaempferii x L. sukaczewii*). Two provenances of *L. sukaczewii* were compared. The results after 50 years show that the provenance from Arkhangelsk produced more volume and had better height growth on five of six sites in northern Sweden compared to a provenance from the central Ural Mountains, Sverdlovsk. The hybrid *L. decidua x L. sukaczewii* which is present in two of the sites have produced 24-71% more stem volume than the best growing pure Russian larch provenance. The dominant height was between 29 and 30.5 meter at the age 51 in the two best growing hybrids. This is between 5 and 6.5 m taller than the expected dominant height for Norway spruce (*Picea abies*) grown on farm land at the same age. The volume production could be overestimated due to edge effects but indicate a very high production potential in these hybrids. In a 40 year old species trial in central Sweden yield of *L. sukaczewii* was compared to four other species (*Larix decidua*, *Pinus sylvestris*, *Picea abies*, and *Betula pendula*). *L. decidua* showed best volume production of the compared species. *L. sukaczewii* was second best with a mean growth that was significantly higher than that of Norway spruce and silver birch. A comparison of the yield of the Raivola larch provenance (*L. sukaczewii)* growing at two sites, one with a strong maritime influence at Lat. 67°04´ N and the other site located in a local continental climate at Lat. 60°54´ N, reveal a very wide ecological niche in this provenance.

Key words: Yield, *Larix sukaczewii*, Russian larch hybrids, Scandinavia

Introduction

Larch (*Larix* Mill.) is a genus of deciduous coniferous tree species in the northern hemisphere. Larches have a major role in high elevation forest ecosystems in Central and Eastern Europe, the greater part of Siberia, western North America, Japan, Korea and China. Larch is also adapted to extreme northern latitudes. In Canada, the tamarack (*Larix laricina*) has a range that extends to the northern tree limit (Packee 1995). The greater part of larch forest area in the world is to be found within the Russian territory in Siberia. Four different species of larch dominate 38% of the forest area of Russia (Abaimov *et al*. 1998). Most of this larch is growing on permafrost and is probably the tree species best adapted to this environment.

Russian larch (*L. sukaczewii*) was re-introduced into Fennoscandia in the 19th century and has been used in forestry on a small scale for almost 200 years. The optimal choice of seed source of larch for northern Fennoscandia has not been investigated until recently. In many cases the seed sources of the early larch cultures are unknown but to a great part consist of L. sukaczewii, originating from the famous larch stand in Raivola close to St Petersburg.

In the beginning of the 20th century superior growth performance was shown in hybrids of larch species. The hybrid vigour, or heterosis effect in larch, was first discovered in a spontaneous crossing between *L. decidua* Mill. and *L. kaempferi* Carr. in Dunkeld, Scotland (Henry & Flood 1919). Later this effect has been systematically investigated in breeding programmes and international progeny trials (Dengler 1941, Langner 1951/52, Pâques 1992a, Arcade *et al*. 1996, Langner & Schneck 1998). Since the beginning of the 1960s, hybrid larch (*L x eurolepis* Henry) has been used also in commercial forestry on low elevation in Western Europe, Great Britain, and Scandinavia. The greater part of these plantations was established after 1980. Compared to the parent species hybrid larch has:

- faster juvenile growth
- shorter rotation
- higher total yield of timber
- better site adaptation to low elevation, and
- better resistance to larch canker than *L.decidua*.

In Japan, hybrid larch is produced by another combination: *Larix kaempferi x Larix gmelinii*. (Hamaya & Kurahashi 1981). In this combination the hybrid vigour is demonstrated in better stem straightness, yield of timber, and site adaptation compared to the parent species.

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In Europe, seed of hybrid larch (*Larix x eurolepis* Henry) is produced in seed orchards as first generation offspring of the parent species *L. decidua x L. kaempferi*. Vegetative propagation of a specific hybrid or group of hybrids is practised in France, and this is an efficient method to utilise the effect of heterosis (Pâques 1992b, 2002).

In southern Sweden on medium sites, the total volume production of hybrid larch can exceed 450 m^3 in 35 years (Larsson-Stern 2003). However, *Larix x eurolepis* is not hardy enough for the climate in northern Fennoscandia. Except for *Larix x eurolepis*, few attempts have been made to investigate the site adaptation and volume production of other hybrids of larch in northern Fennoscandia. In the 1950´s however, under the initiation of F. Bergman, Russian larch hybrids were developed in a small scale at the Swedish Society for Forest Tree Breeding at Sundmo in Ångermanland County (Kiellander 1958).

The early results from these small trials were promising but no assessment of these trials has been made since the 1970´s (Jonsson 1978). Therefore it was of great interest to investigate the hybrid vigour for site adaptation and volume production in these larch hybrids, in which the more northern Russian larch (*L. sukaczewii* Dyl.) is one of the parent species.

Russian larch originating from western Russia has been successfully grown in central and northern Fennoscandia and Iceland (Hagman 1995, Eysteinsson and Skúlason 1995, Martinsson and Lesinski 2007). On medium sites or higher site classes in Fennoscandia, earlier research has shown the volume production of larch to be more dependent on site index than Scots pine (Wiksten 1962, Edlund 1966, Martinsson 1995). Comparing production plots with larch including Scots pine and Norway spruce is rare.

In a material consisting of 21 Russian larch stands, ranging in age between 34-89 years, distributed over northern Sweden between latitudes N 62˚ 26′ and 66˚ 44′, Martinsson (1995) found the yield of volume to exceed that of native conifers by 10-25% on medium sites at 100 years rotation. However, planting on dry or wet sites have lead to low volume productions. On dry sites, Scots pine is superior to the larches (Wiksten 1962, Edlund 1966, Remröd & Strömberg 1977, Martinsson 1995).

The main objective of this investigation was to:

1. Compare height growth and volume production from pure Russian larch with first generation larch hybrids after controlled crossings of selected Russian- and European larch (*L. sukaczewii* and *L. decidua*) or Russian and Japanese larch (*L. sukaczewii* and *L. kaempferi*).
2. Compare volume production from pure Russian larch with the three most commonly used domestic tree species, and also with European larch, in an area which is suitable for all compared species.
3. Show examples of yield in two older trials with Russian larch of Raivola provenance, with large differences in site conditions.

Material and methods

The material reported here is of three different trial categories:

Trial category 1:

This part of the material consists of field trials including hybrids and provenances of Russian larch (*Larix sukaczewii*) and originally also provenances of Siberian larch (*L. sibirica*). The Siberian larch provenances, originating from central Siberia have shown high initial mortality, low production and bad stem quality and are not included in this study. The field trials were established at ten different sites in northern Sweden, by the Swedish Institute of Forest Tree Breeding. Results from six of the sites are included in this report. The exclusion of four of the sites was due to high initial mortality and lack of maintenance in these sites. Site conditions, localities, and experimental designs were according to Table 1-2.

Two different Russian larch provenances, Arkhangelsk (origin from latitude 64°N) and Sverdlovsk (latitude 57°N, elevation 200-300 m) are present in all six field trials. In two of the six field trials different hybrids of larch are included (Table 2). The hybrids are full-sib families after controlled crossings of 11 selected parent trees (Table 3). Five different males of Russian larch and one European larch (*L. decidua*) were crossed with one female of European larch (*L. decidua*), three females of Japanese larch (*L. kaempferi*), and one female of hybrid larch (*L. x eurolepis*) (Table 4).

The experimental design was a completely randomised block design with four replications. The field trials were planted in 1958 to 1960 with three to four-year-old seedlings. Outside the plots, two to three extra rows of trees were planted to minimize edge effects. The hybrids in trial 201 Storbränna was planted on one plot each only, no replications and no edge trees.

Four of the sites were thinned, 1983 (trial 172+201 Storbränna), 1985 (trial 171 Byom and trial 173 Rönnöfors) and in 1986 (trial 193 Robertsfors). In Storbränna a second weak thinning was done in 2003. These thinnings have not been considered in the results. An approximation of the thinned volume was possible to do for the Arkhangelsk provenance. The thinned volume was around 30 m^3 per hectare except in Storbränna (trial 172+201) where around 65 m^3 per hectare has been thinned out. At trial 180 Arvidsjaur and trial 209 Sörånäset no thinning has been done.

In May and June 2006, tree height, dominant height, and breast height diameter were measured in four of the sites: Rönnöfors, Robertsfors, Byom, and Arvidsjaur. In the two sites where hybrids were planted, Storbränna and Sörånäset, measurements were taken in August 2008.

In four of the six sites both height and diameter was measured on all trees. At Storbränna and Sörånäset, all trees were measured for diameter but height was only measured on every 4^{th} systematically sampled tree per plot. Height was measured with Silva height meter and diameter was measured at breast height (1.3 m) with a calliper from two perpendicular directions.

Calculations

All figures for volume are expressed in forest cubic meters. That is volume over bark from stump to top of tree including bark.

Volume over bark was calculated using Carbonnier's (1954) volume function for larch:

$V\ ob = 10^{-4}(0.4801\ (d^2h) + 8.860(d^2) - 0.1012(d^3) - 8.406(dh) + 197.2(h))$

Where: d = DBH (mm). Breast height diameter
h = Total tree height above ground (dm)
V ob = Stem volume above stump, including bark (dm^3)

Sample trees were used to construct a secondary volume function for each of the different provenances and hybrids, to calculate the height and volume for the remaining trees. The formula used for the secondary volume function was according to:

$Ln\ (V) = a*\ln(dbh) + b * [\ln(dbh)]^2 - c$, where a, b and c are constants that are calculated for each of the different provenances.

Dominant height was calculated as equivalent to the mean height of the 100 thickest trees per ha. Trees standing on the edge of plot were not included in dominant height calculations.

Trial category 2:

This part of the material consists of two field trials established by the Swedish University of Agricultural Sciences to compare growth and yield between the following five tree species: European and Russian larch, Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and silver birch (*Betula pendula* Roth). The sites are located at Siljansfors Experimental Forest, in central Sweden. The experimental design was a completely randomised block design with two (trial 9229) and three (trial 9237) replications (Table 5 and 6).

The site at trial 9229 was treated with prescribed burning in 1963 and planted 1964-1966 using bare-root seedlings. Trial 9237 was planted in 1968 using bare-root seedlings, and the soil was manually scarified. Outside the plots, two to three extra rows of trees were planted to minimize edge effects. Thinning was made according to best known treatment for each species. Trees planted in plot edge were treated in the same way as trees within the plots. The trees taken out in thinning are included in the results. Assessments were made seven times in trial 9229 and ten times in trial 9237.

Measurements and calculations were made according to routines described by Karlsson 1994 and 2003. Following volume functions were used:

Pinus sylvestris: Function 100-04 (Brandel 1990) using d, h, b and k

Picea abies: Function 100-02 (Brandel 1990) using d, h, and k

Betula pendula: Function 100-03 (Brandel 1990) using d, h, and b

Where: d = DBH. Breast height diameter
h = Total tree height above ground
b = Bark thickness
k = Height from ground level up to the first living branch

Larix sukaczewii and *L. decidua*: Carbonnier 1954 (unpublished) using the following function:

$V\ ob=10^{-4}(0.4588\ d^2h + 9.006\ d^2 - 0.08844\ d^3 - 6.46*\ dh + 148.8h - 0.1391dhb + 0.02654d^2k)$

where: V ob = Stem volume above stump, including bark (dm^3)
d = DBH (mm) Breast height diameter
h = Total tree height above ground (dm)
b = Bark thickness (double in mm)
k = Height from ground level up to the first living branch (dm)

The reason why we used another volume function than for trial category 1 was that earlier assessments of the trials established by the Swedish University of Agricultural Sciences have used this function. The assessments of the other tree species in this trial category have also used comparable "greater" functions. In a comparison between the two functions for *Larix sukaczewii*, we found that the difference varied between 0.2 and 1.4%. The comparison was made for standing volume in the five plots in trials 9229 and 9237.

Dominant height was defined as the height of the 100 trees with largest breast height diameter per hectare.

Volume increment is presented as current increment and mean increment. Current increment was defined as the increment between two assessments, in these trials a period of 5-7 years. Mean increment was defined as the mean volume production per year calculated on the period from the birth of the seedling until the time of assessment.

Trial category 3:

Older trial in maritime climate and northern latitude

This trial, 203 Breivik, of Russian larch was established in Northern Norway in 1928, on coarse moraine on a western slope. The provenance used was Raivola (Russian seed stand located 63 km northwest of St Petersburg on the Karelian Isthmus), and the seedlings were planted in 2 x 2 m spacing. The plot size of 0.13 hectare included 59 trees at the time of the last assessment which was done 72 years after planting (76 years total age).

Older trial in continental climate in central Sweden

This trial, 9071 Siljansfors, of Russian larch was established in Central Sweden in 1926, on coarse moraine on even ground. The provenance used was one provenance (Raivola), and the two year old seedlings were planted in 2 x 2 m spacing. Outside the plots, two to three extra rows of trees were planted to minimize edge effects. Thinning was made according to best known treatment for the species. Trees planted in plot edge were treated in the same way as trees within the plots. Thinning was done at ages of 26, 31, 36, 43, 47, 52 and 68. The trees taken out in thinning is included in the results. Assessments were made ten times in this trial. The plot size of 0.12 hectare included 30 trees at the time of the last assessment which was done 84 years after planting.

Climate conditions

Temperature sums, i.e. accumulated daily mean temperature during the growing season exceeding a threshold value of 5°C, were calculated using a function presented by Morén & Perttu, 1994 (Table 1). The temperature sums varied from 520 to 1010 day degrees in trial category 1, and from 960 to 1050 day degrees in trial category 2. The temperature sum in trial category 3 was 790 and 1050 day degrees.

Arvidsjaur (trial category 1) and Siljansfors (trial category 2 and 3) are categorized as local continental areas and Breivik (trial category 3) as a local maritime area.

Statistical analysis

One way analysis of variance, ANOVA, was used to analyse differences between tree species in trial category 2. When the ANOVA revealed a significant difference between groups (five species) at $P < 0.10$, a multiple comparison was performed using Dunnett's comparison with a control (family error rate = 0.10, individual error rate = 0.036). Russian larch was chosen as control.

Table 1. Site description of experimental sites (Trial category 1)

Trial Category	Site	Site category	Field trial established	Lat. N	Long. E	T-sum Degree days	Elev. m A.S.L.	Topography
1	Rönnöfors 173	Farm field	1958	63°39′	14°15′	800	330	Gently W
1	Robertsfors 193	Farm field	1959	64°10′	21°51′	1010	40	Even
1	Byom 171	Farm field	1958	63°00′	15°43′	800	375	Gently N
1	Arvidsjaur 180	*Empetrum* forest	1958	65°42′	19°19′	520	515	S
1	Storbränna 172+201	Farm field	1958 (172) 1959 (201)	63°07′	17°00′	980	150	Even
1	Sörånäset 209	Farm field	1960	63°41′	16°24′	920	200	Gently S
2	Siljansfors 9229	*Vaccinium forest*	1964-66	60°54′	14°22′	1050	230	Gently S
2	Siljansfors 9237	*Vaccinium forest*	1968	60°54′	14°22′	960	340	SW slope
3	Siljansfors 9070	*Vaccinium forest*	1926	60°54′	14°22′	1050	230	Even
3	Breivik 203	*Vaccinium* forest	1928	67°04′	14°28′	790	100	W slope

Table 2. Description of trial category 1

Experimental site	Provenance or hybrid	N of trees planted	Planting space, m	Plot area m^2	N block	Total age
Rönnöfors 173	Arkhangelsk	4x100	2x2	400	4	50
	Sverdlovsk	4x100	2x2	400	4	50
Robertsfors 193	Arkhangelsk	4x144	2x2	576	4	50
	Sverdlovsk	4x144	2x2	576	4	50
Byom 171	Arkhangelsk	4x144	2x2	576	4	49
	Sverdlovsk	4x144	2x2	576	4	49
Arvidsjaur 180	Arkhangelsk	4x144	2x2	576	4	51
	Sverdlovsk	4x144	2x2	576	4	51
Storbränna 172+201	Arkhangelsk	4x100	2x2	400	4	53
	Sverdlovsk	5x100	2x2	400	5	53
	56-1	76	2x2	308	1	52
	56-8 Eb	81	2x2	320	1	52
Sörånäset 209	56-1	4x25	2.5x2.5	156.25	4	51
	56-2	4x25	2.5x2.5	156.25	4	51
	56-3	4x25	2.5x2.5	156.25	4	51
	56-4	4x25	2.5x2.5	156.25	4	51
	56-8	4x25	2.5x2.5	156.25	4	51
	56-8 Eb	4x25	2.5x2.5	156.25	4	51
	56-22 Eb	4x25	2.5x2.5	156.25	4	51
	Arkhangelsk	4x25	2.5x2.5	156.25	4	51
	Sverdlovsk	4x25	2.5x2.5	156.25	4	51

Table 3. Origin of parent trees of hybrid progenies in trial category 1

Parent tree number	Species	N Latitude of seed	Elevation, m
248	*Larix decidua*	58°30′ Grensholm (Swe)	63
4	*L. decidua*	58°20′ Omberg (Swe)	160
152	*L. sukaczewii*	61°50′ Punkaharju (Fin)	80
69	*L. sukaczewii*	64°56′ Balstaberg (Swe)	300
72	*L. sukaczewii*	64°56′ Balstaberg (Swe)	300
156	*L. sukaczewii*	64°56′ Balstaberg (Swe)	300
489	*L. sukaczewii*	60°07′ Bjurfors (Swe)	140
247	*L. kaempferi*	59°32′ Grimstad (Swe)	110
488	*L. kaempferi*	58°30′ Skärsnäs (Swe)	100
343	*L. kaempferi*	58°02′ Visingsö (Swe)	120
246	*L. x eurolepis*	60°21′ Ruotsinkylä (Fin)	50

Swe = Sweden, Fin = Finland

Table 4. Crossing scheme for the larch hybrids in trial category 1. (L. s = *Larix sukaczewii*; L. d = *L. decidua*; L. k = *L. kaempferi*; L. e = *L. x eurolepis*). Male trees in the columns and female trees in the rows

Male Female	L. s 69	L. s 72	L. s 156	L. s 489	L. d 4	L. s 152
L. d 248	56-1	56-2	56-3			
L. k 247			56-4			
L. k 488				56-8 Eb		
L. k 343					56-22 Eb	
L. e 246						56-8

Table 5. Description of trial 9229 Siljansfors (Trial category 2)

Tree species	Provenance	Plot area, m²	Spacing	No. of Replications	Year and month of planting	Age of seedlings	Years of thinnings	Assessment years after planting
Larix sukaczewii	Onega (RUS) Lat N 63° Long E 37-38°	2x920	2x2	2	1965, Oct.	3	1987 1992 1999	34
Larix decidua	Wroclaw (POL) Lat N 51°, Long E 17° 400-500 m alt.	1x952 1x936	2x2	2	1964, Oct.	2	1987 1992 1999	35
Pinus sylvestris	Dalarna (SWE) Lat N 60° 200-300 m	2x952	2x2	2	1965, May	3	1992 1999	35
Picea abies	Dalarna (SWE) Lat N 61° 200-300 m	1x960 1x952	2x2	2	1965, Oct.	4	Not thinned	34
Betula pendula	Riihimäki (FIN) Plus tree E 210	1x920 1x960	2x2	2	1966, May	3	1987 1992 1999	34

Table 6. Description of trial 9237 Siljansfors (Trial category 2)

Tree species	Provenance	Plot area, m^2	Spac-ing	No. of Replications	Year of planting	Age of seedlings	Years of thinnings	Assessment years after planting
Larix sukaczewii	Domsjöänget seed orchard (SWE)	1x960 2x1024	2x2	3	1968	3	1989 1994 2004	37
Larix decidua	Tatra mountains (SVK) Lat N 48° 55′ Long E 20° 06′ 1400 m A.S.L.	1x960 2x1024	2x2	3	1968	3	1989 1994 2004	37
Pinus sylvestris	Hälsingland (SWE) Lat N 61° 30′ -62°00′ , 300-349 m A.S.L.	2x960 1x1024	2x2	3	1968	3	1994 2004	37
Picea abies	Hälsingland (SWE) Lat N 61°05′ , 300-350 m A.S.L.	1x960 2x1024	2x2	3	1968	3	One plot thinned 2004	37
Betula pendula	Ockelbo (SWE) Plus tree X 2804 100-199 m A.S.L.	2x960 1x1024	2x2	3	1968	1	1989 1994 2004	37

Results

Trial category 1:

The mean tree height was 29 and 28 meter for the best growing hybrid, No. 56-1(*L. dec x L. suk*), at site Storbränna and Söråнäset, respectively. Corresponding height for the best growing pure Russian larch was 25.5 and 22.6 meters at the two sites, respectively. The hybrid 56-1 also produced most volume, 905 and 956 m^3 ha^{-1} yr^{-1} for the two sites respectively (Table 7). The dominant height of the best growing hybrid at site Söråнäset and Storbränna exceeds that of Norway spruce grown on farmland with site index G35 with 20% respectively 27% (Figure1, Table 7).

Among the pure Russian larch provenances, Arkhangelsk has produced more volume and demonstrated better height growth than Sverdlovsk on five of the six sites (Table 7). The height growth and volume production show great variation between the best and the worst site.

Trial category 2:

In both trials, European larch showed the highest values of tree height, total volume production and current volume increment (Table 8 and 9). Russian larch was second best, except for Basal area in trial 9237, and the mean annual increment from birth for trial 9229 and 9237 was 7.2 and 9.4 m^3/hectare and year, respectively. Corresponding figures for current annual increment was 13.3 and 12.3 m^3/hectare and year. Comparison of mean annual increment of Russian larch against Norway spruce and silver birch revealed a significant superiority of Russian larch. The difference against European larch and Scots pine was not significant.

The difference between current annual volume increment and mean annual volume increment was large for all species except for silver birch, showing that mean annual increment from birth probably will increase for some years ahead, except for silver birch (Figure.2).

Trial category 3:

The mean annual volume increment from birth was 6.8 m^3/hectare and year in 203 Breivik, while corresponding increment in 9071 Siljansfors was 7.0 m^3/ha and year (Table 10). The current increment at last assessment in Siljansfors was 5.6 m^3/ha and year. The mean annual volume increment culminated at about 50 year's age (Figure 3).

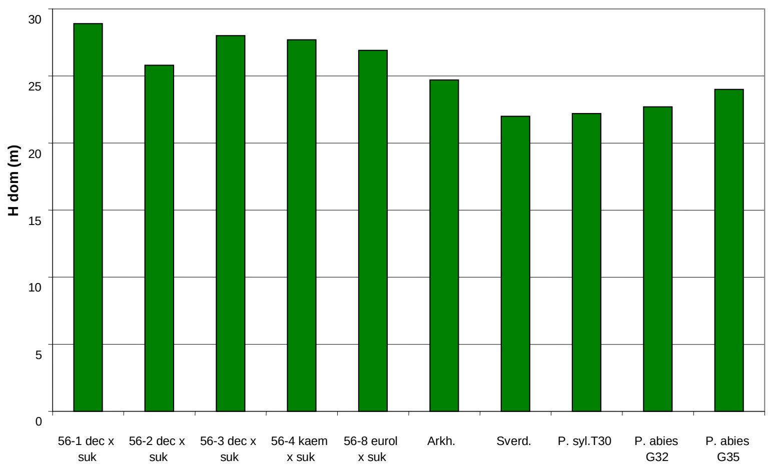

Fig. 1. Dominant height of five different larch hybrids and two provenances of Russian larch (*Larix sukaczewii*) in Söråнäset, at the total age of 51 years. As comparison the estimated dominant height at similar age of Scots pine and Norway spruce at the most fertile sites on forest land in northern Sweden is presented. Site index T30 in Scots pine corresponds to a dominant height of 30 m at the total age of 100 years. Norway spruce G 35 shows the dominant height of the most productive spruce stand on abandoned farm land in northern Sweden. (Johansson 1996). Parents of hybrids are defined in Tables 3 and 4.

Table 7. Results of trial category 1, including larch hybrids (in bold) and two Russian larch provenances

Experimental site	Provenance or hybrid	N trees and trees/ha	Tot. Age	Mean dbh, cm	Mean tree height,	Dom. height, m	m^3/tree	SV m^3 ha-1	MAI m^3 ha-1yr-1
Rönnöfors[1]	Arkhangelsk	161 (1006)	50	23.7	16.7	19.1	0.304	306	6.1
	Sverdlovsk	138 (863)	50	24.1	13.6	17.9	0.155	134	2.7
Robertsfors[1]	Arkhangelsk	144 (625)	50	25.6	20.7	23.2	0.453	283	5.7
	Sverdlovsk	156 (677)	50	26.4	20.3	22.7	0.47	318	6.4
Byom[1]	Arkhangelsk	194 (842)	50	25.3	18.9	21.7	0.372	313	6.3
	Sverdlovsk	187 (812)	50	25.0	16.8	20.7	0.306	248	5.0
Arvidsjaur	Arkhangelsk	158 (686)	51	19.4	9.5	13.7	0.101	69	1.4
	Sverdlovsk	139 (603)	51	16.8	8.1	12.2	0.061	37	0.7
Storbränna[1]	**56-1 dec x suk**	**22 (714)**	**52**	**34.5**	**29.0**	**30.5**	**1.267**	**905**	**17.4**
	56-8 Eb kae x suk	**16 (519)**	**52**	**33.8**	**26.3**	**28.8**	**1.078**	**560**	**10.8**
	Arkhangelsk	109 (681)	53	27.2	25.1	28.0	0.715	487	9.2
	Sverdlovsk	100 (625)	53	29.1	25.5	27.1	0.669	418	7.9
Sörånäset	**56-1 dec x suk**	**60 (960)**	**51**	**31.3**	**28.0**	**28.9**	**0.996**	**956**	**18.7**
	56-2 dec x suk	**69 (1104)**	**51**	**25.5**	**25.0**	**25.8**	**0.629**	**694**	**13.6**
	56-3 dec x suk	**66 (1056)**	**51**	**28.3**	**26.4**	**28.0**	**0.785**	**829**	**16.2**
	56-4 kae x suk	**61 (976)**	**51**	**27.6**	**26.9**	**27.7**	**0.766**	**748**	**14.7**
	56-8 eur x suk	**25 (400)**	**51**	**30.7**	**25.2**	**26.9**	**0.875**	**350**	**6.9**
	56-8 Eb kae x suk	**12 (192)**	**51**	**30.1**	**23.0**	**29.5**	**0.958**	**184**	**3.6**
	56-22 Eb L. eur[2]	**2 (32)**	**51**				**0.625**	**20**	**0.4**
	Arkhangelsk	71 (1136)	51	24.3	22.6	24.7	0.493	560	11.0
	Sverdlovsk	62 (992)	51	22.5	19.9	22.0	0.389	386	7.6

Table 8. Results of trial 9229 Siljansfors, Central Sweden, (Trial category 2)

Tree species	N of trees/ha after last thinning	Total Age Years	Mean dbh, cm	Mean tree height, m	Dom. Height m	Basal area m^2/ha	Standing Volume m^3/ha	Total prod. m^3/ha	m^3 /tree	Mean annual Increment from birth m^3/ha and year	Mean annual increment 1992-1999 m^3/ha and year
L. sukaczewii	592	37	19.8	17.4	18.2	18.2	150	267	0.254	7.2	13.3
L. decidua	466	37	22.8	21.7	22.9	18.4	189	320	0.428	8.6	15.4
Pinus sylv.	1192	38	15.7	14.5	15.6	23.1	166	259	0.139	6.8	9.6
Picea abies	2405	38	8.4	8.9	11.1	13.4	63	64	0.026	1.7	4.4
Betula pendula	699	37	14.0	17.3	18.0	10.7	86	151	0.125	4.1	5.1

Table 9. Results of trial 9237 Siljansfors, Central Sweden, (Trial category 2)

Tree species	N of trees/ha after last thinning	Total Age Years	Mean dbh, cm	Mean tree height, m	Dom. Height m	Basal area m^2/ha	Standing stem volume m^3/ha	Total Stem volume m^3/ha	m^3 /tree	Mean annual Increment from birth m^3/ha/year	Mean annual increment 1994-2004 m^3/ha and year
L. sukaczewii	553	40	24.5	21.3	22.3	19	184	375	0.502	9.4	12.3
L. decidua	608	40	25.9	23.4	24.4	18	201	406	0.586	10.2	15.7
Pinus sylvestris	1295	40	18.7	15.6	16.4	22	170	324	0.212	8.1	11.7
Picea abies	2040	40	12.2	12.4	15.2	21	134	156	0.079	3.9	9.2
Betula pendula	786	38	18.5	19.7	20.5	16	143	242	0.242	6.4	7.8

Table 10. Results of field trial 9071 Siljansfors, Sweden and 201 Breivik, Norway

Experimental site	Tree species	Provenance	N of trees at revision	Total Age years	Mean dbh, cm	Mean tree height, m	Dominant height, m	Basal area, m^2	Total Production, (including thinning), m^3/ha	Mean annual increment, m^3/ha and year
Siljansfors 9071	*Larix sukaczewii*	Raivola	30	86	35.8	28.5	29.7	24.9	604	7.0
Breivik 201	*Larix sukaczewii*	Raivola	59	76	32.0	26.1	29.2	36.3	516	6.8

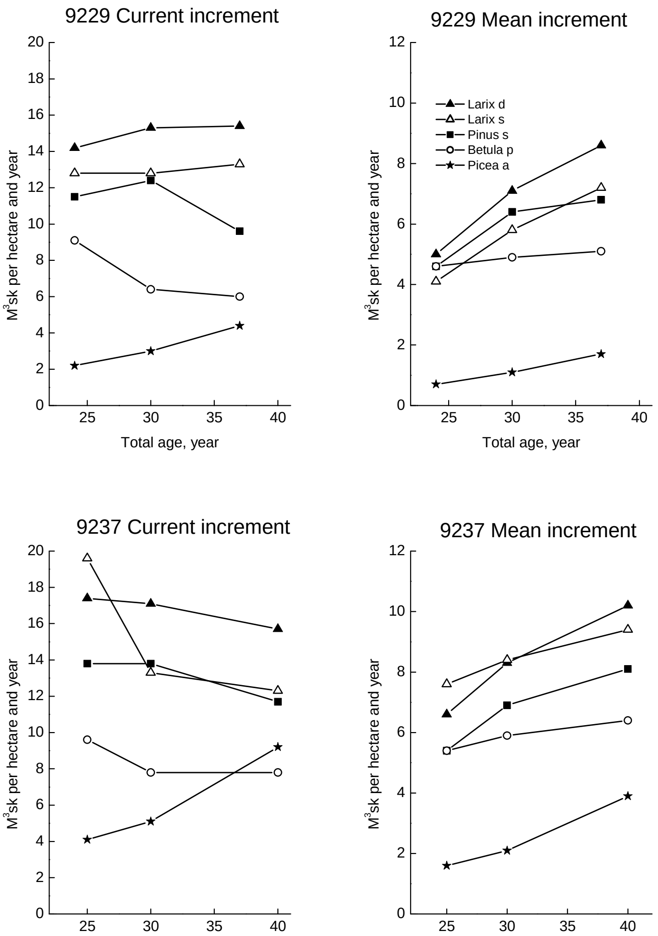

Fig. 2. Current and mean increment in trials 9229 and 9237 of trial category 2. Current increment is the growth between two assessments (5-7 years).

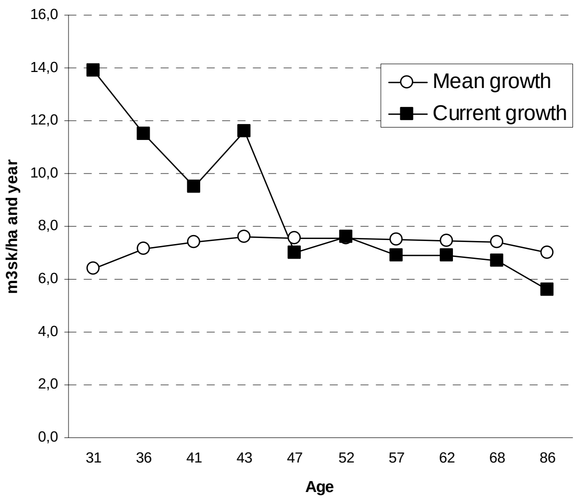

Fig. 3. Mean and current volume increment in trial 9071of trial category 3. Current increment is the growth between two assessments (2-18 years).
Thinning was done at ages 26, 31, 36, 43, 47, 52 and 68 years.

Discussion

Russian larch compared to Russian larch hybrids

The two compared provenances of *L. sukaczewii*, Arkhangelsk and Sverdlovsk originate from relatively different localities in western Russia. Arkhangelsk (Lat. N 64°) is located in the northwest part of Russia close to the White Sea, and Sverdlovsk is from the middle part of the Ural mountains (Lat. N 57°). Probably neither is optimal seed sources for the test sites used in this study, but nevertheless these sources have been used in several forest plantations in Scandinavia. The seed of the two provenances was collected as bulk, most likely in connection to with forest operations. Therefore the seed trees were not selected and the seed collection represents an average of trees in the stand in contrast to the hybrids where the parent trees were selected plus trees. Unfortunately it is not possible to separate the effect of individual parent tree selection and the hybrid effect between two larch species. Probably a part of the superiority of the hybrids is related to the selection of the parent trees.

In Storbränna the larch hybrids are represented by a small material without replications and significant edge effect can be suspected. The small plots, especially in Sörånäset make it difficult to draw certain conclusions about the production capacity of the tested material. Although edge trees are present, except for the hybrids in Storbränna, edge effects surely influence the results. Within the sites the uneven results between the tested provenances gives edge effects even if a plot is surrounded by other weaker growing provenances. Elfving (2005) recommend 1000 m^2 plots for yield plots. However, the results of the Russian larch hybrids are anyway interesting. They outgrow the fast growing Russian larches on the same site both in height and in volume per hectare. Earlier studies have shown a superior volume production of Russian larch compared to Scots pine, on medium to fertile sites in northern Sweden (Edlund 1966, Martinsson 1995).

The best growing hybrids 56-1 and 56-3 are crossing between a European larch mother tree grown in southern Sweden (Lat 58°´30´ N) and a Russian larch father from Lat 64° 56´ N in northern Sweden (Table 3 and 4). Also the hybrid 56-2 has parents from the same localities. These hybrids exceed the two Russian provenances in yield, basal area, and dominant height (Table 7, Figure 1). The tallest and biggest tree in the whole experiment (height 31 m, dbh 55 cm) is found in the hybrid 56-4, an offspring of the Japanese larch mother (L k 247) and Russian larch father (L s 156). The yield of volume from these four larch hybrids are 33-66% superior to that of the Arkhangelsk provenance and 95-143% superior to the Sverdlovsk provenance. The hybrid 56-8 is a crossing in which *L. x eurolepis* has been used as mother and Russian larch as father tree (Ls 152) and is evidently inferior to the other larch hybrids. The hybrids 56-8Eb and 56-22 Eb having Japanese mothers and Russian respectively European father trees are not adapted to the site in Sörånäset and are outcompeted.

The development of the dominant height (Figure 1 and 4) which is not in the same way influenced by the small plots is probably a better measure on the growth capacity of these hybrids. The highest site index for larch in Sweden is L 36 (i.e. dominant height at 100 years total age) which corresponds to a height of about 25 meters at 51 years of age. The best hybrids have a dominant height 4-5 meters taller than that. Also compared to Norway spruce (*Picea abies*) grown on farm land in northern Sweden, the height development is impressive. The dominant height of the most productive spruce on abandoned farmland (G35) in northern Sweden is about 24 m at the age of 51 (Johansson 1996).

Jonsson (1978) studied growth, survival and stem quality at age 20 years in the same stands (Sörånäset and Storbränna) as included in our report and found the Russian larch hybrids to have superior juvenile growth compared to the pure *L. sukaczewii*. The hybrid between *L. decidua* and *L. sukaczewii* was developing best, concerning height development and quality aspects like forking and double stems compared to the other hybrids. Kiellander and Lindgren (1978) studied different larch hybrids in southern Sweden and concluded that the hybrid *L. decidua x L. sibirica* was not suited for southern Sweden since it did not utilize the growing season long enough. The hybrid between Siberian larch and Japanese larch was considered more promising in southern Sweden.

The site conditions of the six sites in trial category 1 are not equivalent. The development of the two provenances, Arkhangelsk and Sverdlovsk, reflects the great site differences. In Arvidsjaur the site index is low and has resulted in the lowest volume production. This site is the only one in trial category 1 that was originally forest site. In Arvidsjaur the site was also burned in 1933 and treated with herbicides in 1954 to kill broadleaved vegetation before establishment of the larch experiment. It may have had an influence on the fertility of the site. The other five sites are all former farm fields of different qualities.

Russian larch compared to European larch, Scots pine, Norway spruce and silver birch

The tree species trials in Siljansfors are the youngest of the three trial categories and established on the most southern locality, but at a relatively high elevation (230-340 m). In these sites it is possible to compare Russian larch with European larch and three other tree species under optimal management. The high production of the two different provenances of European larch, one Polish and one from high altitude (1400 m.a.s.l.) in the Tatra Mountains. (Slovakia) gives an illustration on the broad adaptability of this species.

The interest for growing European larch has been very low in Sweden, since serious attacks of larch canker (*Lachnellula willkomii*) mainly in maritime localities in southern Sweden. In the middle part of Sweden however, it is possible that this species have a future. The results from Siljansfors show that. Further north in Sweden, there is lack of experience on the adaptation of European larch. Lähde *et al*. (1984), however, reported good hardiness of European larch in major parts of Finland, although the quality of stems was inferior to Siberian larch (Martinsson and Winsa 1989).

Although situated on a climatically more favourable site the Russian larch at site 9229 has lower mean annual increment than at site 9237 (Table 8 and 9). The general result that all species has shown better growth at trial 9237, might be influenced by its location in a slope. Although not indicated in differences in ground vegetation, both sites belong to the *Vaccinium* forest type, site 9237 is situated in a slope and is probably a better site for the larches which growth is positively affected by moving groundwater (Schotte 1917, Edlund 1966, Martinsson 1995). The different seed sources of Russian larch used, in site 9237 seed orchard seeds from Domsjöänget (Sweden), while at trial 9229 the Russian provenance Onega also could play a role in the better production at site 9237.

The higher production of Russian larch compared to Scots pine on this type of site is in accordance with earlier research (Wiksten 1962, Edlund 1966, Martinsson 1995). Site index for Scots pine on the two sites is T 28 (dominant height of 28 m at 100 years total age) which represents a rather fertile site in this area. Martinsson (1995), studying the production of *L. sukaczewii* in northern Sweden, found that with increasing site index the superiority of larch compared to Scots pine increased. The significant superiority in yield (317% respectively 140% on the two sites) compared to Norway spruce could partly be explained by the low age of the stand. Norway spruce has a low production the first half of the rotation time. It is shown in figure 2 that the current increment of spruce is increasing fast between 30 and 40 years of age. The annual increment of Russian larch is, however, still considerably higher than in Norway spruce during the last 10 years period. It will be interesting to see how long this superiority last.

In the tree species trials (trial category 2) it is also interesting to compare at which age mean volume increment culminates, indicating optimal rotation period for each species (Figure 2). So far, no species has reached that age. Thinning regimes probably also affect the rotation period.

An advantage of using larch is its ability to develop merchantable timber in a shorter time than the indigenous conifer tree species (Hakkila *et al.*1972). This was clearly shown in the Siljansfors trial where Russian larch had mean volumes per tree between 2.36 to 6.35 times greater than Scots pine and Norway spruce respectively (Table 9).

Raivola larch in various climatic types

The two older stands 201 Breivik and 9071 Siljansfors (trial category 3) are of interest because of that the same seed source, Raivola, could be compared at two sites with two different types of climates. Breivik is located close to the coast in northern Norway (Lat 67° 04´N) with a strong maritime influence, temperature fluctuations around 0°C is common during winter, while Siljansfors has a local continental climate. The winters are milder and summers cooler in Breivik and the precipitation much higher. Temperature sum is 260 degree days higher in Siljansfors. Therefore a superiority in growth would be expected. The results after 76 respectively 86 years, however show almost identical mean annual productions between the two sites (Table 10).

Raivola larch forest, a man made plantation of *L. sukaczewii* with seeds originating from the Arkhangelsk district is situated on the Karelian Isthmus 63 km north-west of St Petersburg (Redko and Mälkönen 2005). The stand is situated within 15 km from the coast of the Finnish Gulf and is under a certain maritime influence. The Raivola seed source has been widely used in Finland, Sweden and Iceland and has been shown to have a very wide ecological niche (Mikola & Vakkari 1995). It tolerates the climate in major parts of Finland. They found the main reason for this to be due to its high individual physiological plasticity. If climate change will progress according to IPCC's scenarios (IPCC 2007), the climate in northern Sweden will become more maritime, with higher temperature rises in the winter than in summer. It is therefore of interest to use provenances that are adapted to sudden mild spells during winter. Raivola seed source seem as a good alternative in this perspective.

The larch stand in trial category 3 represents the type of early larch cultures established in Sweden in the 1930s and on which the dominant tree height developments in Figure 4 are based. These graphs have up till now been used for estimating the development of Russian larch in Sweden. For comparison the dominant heights of the hybrids in Sörånäset is marked in the same figure. It is evident that the height development of the larch hybrids in Sörånäset at the age of 51 years exceeds the height development of earlier used standards.

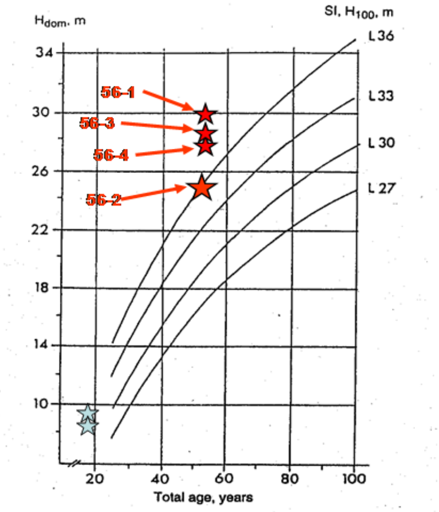

Fig. 4. Development of dominant tree height in Russian larch (*Larix sukaczewii*) in four different site index (L36 corresponds to a dominant height of 36 m at 100 years total age), based on 21 stands in northern Sweden 30-80 year old (Martinsson 1995), and with stars, the dominant height of the four larch hybrids in Sörånäset (Ramsele). The small stars in the left of the diagram are the heights of the hybrids 56-1 and 56-8 Eb at the age of 19 (Jonsson 1978).

Conclusions

The most noticeable results of this report are the growth rates of the Russian larch hybrids. Although the experimental plots were small and edge effects definitely influence the results the dominant height and volume production of the best hybrids indicate a very high production potential.

The Raivola larch provenance demonstrated a very wide ecological niche showing high yield for a period of 76 years in a coastal area in northern Norway and showed similar yield in a local continental area in Dalarna, Sweden. The yield was not affected by temperature sum, which was considerably lower at the Norwegian site.

A comparison between Russian and European larch, Scots pine, Norway spruce and silver birch tested in Dalarna, show that up to 40 years of age, the larches have faster growth than the other tree species.

Considering the growth potential in Russian larch hybrids, future research on these hybrids is of great interest. Frost resistance, site requirements and silvicultural methods need to be investigated. Establishment of seed orchards for Russian larch hybrids would also be of great interest.

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