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Yield of *Larix sukaczewii* Dyl. in Northern Sweden

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Abstract

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The stem volume yield of twenty small stands of larch, mainly Larix sukaczewii Dyl., was studied in northern Sweden. The stand age range was 34–89 years. On the most productive sites trees attain a dominant height of 27 m at age 60 years. Tree height increment is still continuing at age 90 years. The productivity of larch varies widely, depending on site quality. During a 100-year rotation, the total volume yield of larch on medium sites was calculated at 500 m^3 ha^{-1}, and at 1000 m^3 ha^{-1} on the most productive sites (both including bark). On the most productive sites, stem volume yield of larch exceeded that of indigenous conifers by 10–25 per cent (excluding bark). On poor, dry, flat or waterlogged sites the yield of larch was inferior to that of indigenous conifers. On high-altitude sites, surprisingly high yields were observed.

Keywords: volume yield, dominant height, height increment, mean annual increment, conifers, taiga.

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Introduction

Natural distribution of *Larix sukaczewii*

The larches are an ecologically and economically important group of tree species in the boreal forests of the northern hemisphere. Some 10–17 different species are recognised within the genus *Larix* Mill. (Timofeev, 1961). All but three of these species are native to the Eurasian continent. Larch is the most common conifer of the Asian taiga, and makes up 38% of the forest cover of Russia (Milyutin, 1992). *Larix sukaczewii* Dyl. has the most westerly area of distribution of the three most common larch species in Russia. The natural distribution of *L. sukaczewii* is mainly the northern and central taiga of the European part of Russia. The eastern limit of its distribution is approximately the Ob river valley (Dyllis, 1947; Simak, 1979).

Some authors reject the status of *L. sukaczewii* as a separate species. According to Bobrov (1978), *L. sukaczewii* cannot be distinguished from *L. sibirica* Ledeb., which occupies the central part of Siberia. The English name 'Siberian larch' is used for both of the species *L. sukaczewii* Dyl. and *L. sibirica* Lebed. Some authors use the name 'S-larch' to refer specifically to *L. sukaczewii* Dyl. (Simak, 1979).

Larch in Sweden

The genus *Larix* has not occurred naturally in Scandinavia since the latest glaciation, but has been introduced by man. Larch has been grown in Sweden for more than 200 years (Schotte, 1917).

For the past 50 years, the Swedish pulp and paper industry has strongly influenced Swedish forestry. At the beginning of the 1960s, Edlund (1966) investigated the properties of larch wood and concluded that Siberian larch was not well suited for pulp production. Although pulping technology has developed since that time, so that processing on the basis of larch wood is now possible, larch still possesses no advantages over the indigenous conifers as regards the production of pulp and paper, that would justify its large-scale planting in Swedish forests.

However, its chemical and mechanical properties make larch timber useful in other parts of the forest industry, where such properties are in great demand today. Larch heartwood is more resistant to decay fungi than is that of other commercially produced conifers in Scandinavia (Schotte, 1917; Björkman, 1944; Simak, 1960; Paves, 1964; Anon., 1985). The chemical impregnation of wood for protection is an environmental hazard of increasing concern, since heavy metals and other toxic substances usually are involved. In Sweden alone, more than 400 000 m^3 of wood were treated annually up to 1992; most of the treatment was based on compounds containing copper, chromium or arsenic (Nilsson, 1993). The availability of more natural materials to replace chemically impregnated wood would be a great advantage from both the environmental and the economic points of view. The heartwood of larch begins developing at an early age, and the stem volume of the mature tree contains a greater proportion of heartwood than that of Scots pine (*Pinus sylvestris* L.) grown under similar conditions. In many countries where larch wood has been available, it has been used for centuries under conditions in which chemically impregnated wood is used today (Simak, 1960).

There are still many different opinions, and great hesitation, among Swedish foresters as to the use of larch in forestry, depending on:

- The lack of maintenance of older larch stands and existing trial plots.
- The lack of knowledge concerning the choice of site and provenance.
- The lack of suitable seed sources.
- Hesitation as to the properties and use of larch wood.

The earliest plantations of larch in Sweden were made in the 1760s in the southern part of the country. Seedlings of European larch (*Larix decidua* Mill.) had been imported from Scotland, where it was introduced from the Tyrol about a century earlier (Schotte, 1917).

Siberian larch was introduced into northern Sweden later. However, as early as 1754, Linneus wrote a proposal to the Swedish parliament that the Siberian larch and the Siberian stone pine (*Pinus cembra* var. *sibirica* Loud.) should be used for afforestation of the bare Scandinavian mountains. Not until the 1890s was any significant import of larch seed from

Russia undertaken. In 1892, 80 kg of larch seed was imported by the Swedish state forest agency. Some of the best older larch stands still existing in northern Sweden originated from this seed.

Seen in an historical perspective, there are strong indications that larch and several other 'exotic' tree species were present in Scandinavia as late as the last interglacial (Frenzel, 1968; Hirvas, 1983; Robertsson & Ambrosiani, 1988). The present poverty of species in Scandinavia is explained by repeated glaciations during pleistocene time and by the geographical barriers which have prevented the original flora from returning. Several tree species, which today are important east or south-east of Scandinavia, probably had a natural distribution in Scandinavia during the early pleistocene, among these being the European silver fir (*Abies alba* Mill.), Siberian fir (*Abies sibirica* Ledeb.), Siberian stone pine (*Pinus cembra* var. *sibirica*), Serbian spruce (*Picea omorika* (Pančič) Purkyně), Macedonian pine (*Pinus peuce* Griseb.) and larches (*L. decidua* Mill. and *L. sukaczewii*). Only 4000 years have passed since Norway spruce (*Picea abies* (L.) Karst.) and beech (*Fagus silvatica* L.) returned to the Scandinavian peninsula. Scots pine and birch (*Betula pendula* Roth) have existed in Scandinavia for more than twice this length of time.

In northern Sweden several small stands of larch (*L. sukaczewii*) were established between 1900 and 1940, and are the oldest stands of larch existing in that region. Some of these stands have been used as trial plots, and investigated two or three times (Wiksten, 1962; Edlund, 1966; Remröd & Strömberg, 1977). The aim of this study is to determine the increment of tree height and the stem volume yield of *L. sukaczewii* on the basis of these stands. However, some of them have suffered from poor maintenance. In some cases the seed sources were not identified, the methods of stand establishment were poor, the area of the stand was too small or there was a combination of these shortcomings. The present investigation should be seen against this background.

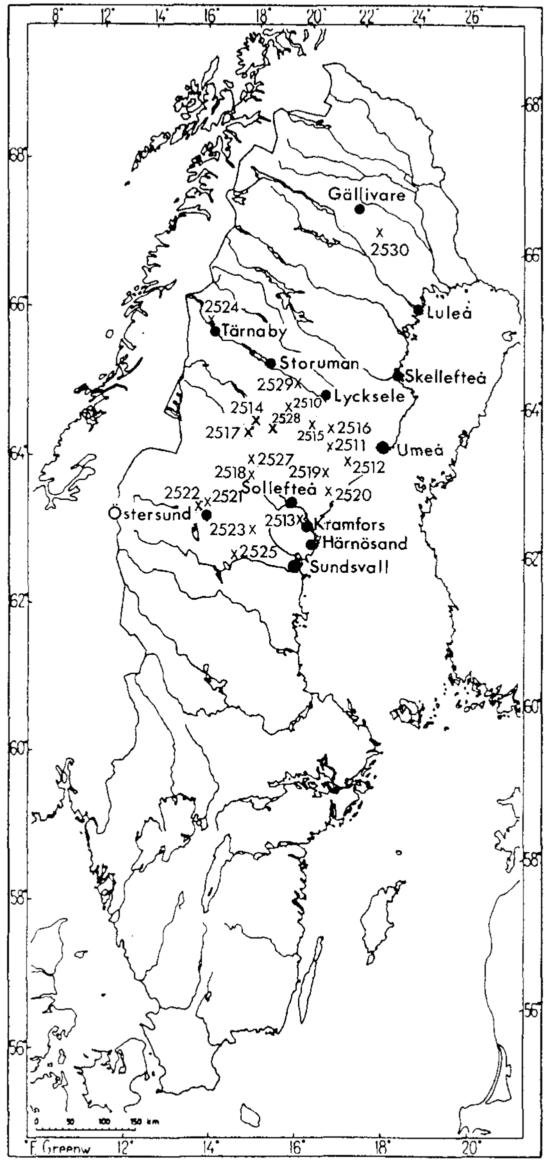

Fig. 1. Geographical distribution of the investigated larch sites.

Material and methods

Data were collected from 20 different larch stands (Fig. 1). Usually only one trial plot existed in each stand, but in four of the stands, two plots had been established. Tree height, diameter at breast height on bark (DBH), dominant height, damage to trees, bark thickness and site index were recorded. In total, 1 456 trees of larch were measured, i.e. 61 trees per plot on the average. The calculated stem volume on the plots was based on records of tree height and DBH. Calculations of the dominant height and site index were based on the age and height of a selected 10 per cent of the number of trees per plot. This selection was based on the DBH of the 10 per cent largest trees.

Where possible, information on site index and dominant height of adjacent stands of indigenous conifers (Norway spruce or Scots pine) was also collected. Basic information for the stands, the trial plots and the site properties is given in Tables 1 and 2. A summary of stem numbers, basal area and earlier thinnings from the first date of measurement to the last, is given in Appendix 1.

Dominant height

The processing of data concerning dominant height included information collected earlier (Wiksten, 1962; Edlund, 1966; Remröd & Strömberg, 1977). When data from the last revision were considered, the development of dominant height did not follow the course stated by these authors. However, the development of dominant height over time followed the course reported by Voukila, Gustavsen & Luoma (1983). The site index was therefore determined according to the development of dominant height illustrated by Vuokila et al. (1983), and all trial plots were classified according to four different site classes: L27, L30, L33 or L36, corresponding to the expected height (m) of dominant trees of *L. sukaczewii* at age 100 years. Thus site class L30 denotes a site on which dominant trees of *L. sukaczewii* are expected to reach a height of 30 m at age 100 years.

Functions for dominant height over time were developed from the collected material, according to two different methods. The one method follows the function of Vuokila et al. (1983) for dominant height, with the addition of a correction term. The other was that developed by Tveite (1968).

Dominant height according to Vuokila et al.

According to Vuokila et al. (1983), the increment of dominant height of larch in Finland follows the function:

$$Ih5 = e^{(1.874-1.0035*\ln(T)+1.10264*\ln(H)-0.0411495*H)} \quad (1)$$

where

$Ih5$ = Increment of dominant height (m) during the next five years

T = Age of the stand, years

H = The present dominant height, m.

In Vuokila et al. (1983) curves of dominant height development are presented for site index L27, L30, L33 and L36 between age 40 and age 100 years. The dominant heights at stand age 40 years from these curves were used as starting points in the present study. Using function (1) and the collected data, the course of dominant height development to age 100 years was calculated. The calculated course of dominant height deviated more or less from that recorded in the field, and deviations usually increased with age. On the basis of differences between the calculated and the recorded dominant heights, a correction (C) was calculated according to the following model:

$$C = a + b(A)$$

where A is the age of the larch stand, years.

Using this correction term, new curves of dominant height development were constructed, based on the function of Vuokila et al. (1983).

Dominant height according to Tveite

This method is also known as 'the deviation method', and was described by Tveite (1968). Starting from a fixed level for dominant height at a certain age, e.g. 40 years, the course of dominant height development is determined by the mean value and the standard deviation of the dominant height recorded on the plots. This mean value is calculated for five-year intervals. The form of the curve largely depends on the level of the starting point. In the present study, the curves were calculated so as to coincide with dominant heights 12.95, 15.40, 18.00 and 20.90 m at age 40 years. These dominant heights are identical to the dominant height for site index L27, L30, L33 and L36 according to Vuokila et al. (1983), at the same age.

Stem volume

The stem volume of the stands was calculated from measurements of DBH and total tree height for individual trees, according to functions by Carbonnier (1954):

$$vob = 10-4(0.4801(d^2h)+8.860(d^2) -0.1012(d^3)-8.406(dh) +197.2(h)) \quad (2)$$

Table 1. *Names, geographical location and date of establishment and revision of the experimental plots*

Plot No.	Site	Lat, °N	Long, °E	Alt, m	Plot area, m^2	Establishment		Date of measurement		
						Year*	Method**	I	II	III
2510	Sandsjö	64°29′	17°41′	535	590	1938 v	p	6212–	771018	870521
2511	Bredträsk	63°53′	18°33′	290	750	1940 v	p	610714	761006	870514
2512	Toböle	63°37′	19°15′	75	383	1931 v	p	—	761005	870504
2513	Öd	62°57′	17°46′	40	288	1928 v	p	611129	760921	870506
2514	Måntorp	64°22′	16°25′	445	516	1937 v	p	—	761118	870523
2515-1	Norrby	64°16′	18°18′	460	1000	1940	p	610711	761112	870519
2515-2	Norrby	64°16′	18°18′	460	1000	1940	p	610712	761112	870519
2516	Vargålandet	64°12′	18°48′	300	1190	1936	p	611116	761103	870519
2517-1	Valåberget	64°08′	16°11′	300	927	1932 h	p	591010	761116	870524
2517-2	Valåberget	64°08′	16°11′	300	1050	1932 h	p	591011	761117	870525
2518	Täxan	63°41′	15°57′	350	450***	1934 v	p	611206	761122	870510
2519	Nybyn	63°37′	18°23′	370	632	1930 v	s	581013	761110	870513
2520-1	Moliden	63°24′	18°25′	70	745***	1930 v	s	581016	761111	870512
2520-2	Moliden	63°24′	18°25′	70	745***	1930 v	s	581016	761111	870512
2521	Lit	63°17′	14°50′	370	390	1935 v	p	6212–	761123	870509
2522	Ås	63°15′	14°33′	390	600	1915 v	p	6212–	761123	870509
2523	Kälarne	62°54′	16°06′	360	635	1918 v	p	611208	761124	870508
2524-1	Tärnaby	65°43′	15°22′	540	253***	1898 v	s	611212	761107	870526
2524-2	Tärnaby	65°43′	15°22′	540	485	1953 v	s	—	—	870526
2525	Alby	62°29′	15°29′	220	375***	1935 v	p	6212–	761126	870507
2527	Smedsböle	63°53′	16°15′	214	465***	1904	p	4410–	5509–	870525
2528	Åsele	64°12′	17°17′	320	893	1900	p	6609–	7108–	870522
2529	Åskilje	64°56′	17°48′	280	755	1898	p	6308–	7008–	870302
2530	Sarvisvaara	66°44′	21°17′	400	450	1952 p	p	—	—	870818

*v = spring, h = autumn. **p = planting. s = seeding. ***The plot area is not identical with that in earlier revisions.

Table 2. *Site conditions on the experimental plots*

Plot No.	Site	Soil texture	Type of vegetation	Aspect	Mobility of ground water*	Site class, H100, m
2510	Sandsjö	Fine till	Grass	SW	L	L30 T20
2511	Bredträsk	Fine till	Vacc.myrt.	Level	N	L33 T26
2512	Toböle	Fine sand	Grass	Level	N	L33 T26
2513	Öd	Silt	Low herbs	NE	L	L36 T30
2514	Måntorp	Fine till	Grass	Level	S	L30 T24
2515-1	Norrby	Medium till	Grass	Level	N	L27 T22
2515-2	Norrby	Medium till	Grass	NW	S	L30 T22
2516	Vargålandet	Medium till	Vacc.myrt.	E	L	L33 G22
2517-1	Valåberget	Medium till	Low herbs	SE	L	L33 G26
2517-2	Valåberget	Medium till	Grass	SE	L	L30 G26
2518	Täxan	Medium till	Low herbs	SW	L	L36 G30
2519	Nybyn	Medium till	Grass	SW	L	L27 G24
2520-1	Moliden	Medium till	Vacc.myrt.	E	L	L27 G26
2520-2	Moliden	Medium till	Vacc.myrt.	E	L	L27 G26
2521	Lit	Fine till	Low herbs	Level	N	L33 T22
2522	Ås	Fine till	Low herbs	Level	S	L30 T22
2523	Kälarne	Medium till	Vacc.myrt.	Level	N	L27 G26
2524-1	Tärnaby	Fine till	Low herbs	SW	L	L24 G22
2524-2	Tärnaby	Fine till	Low herbs	SW	L	(L36)
2525	Alby	Coarse till	Low herbs	W	S	L30 T23
2527	Smedsböle	Fine till	Vacc.myrt.	Level	S	L30 G18
2528	Åsele	Fine till	Vacc vi.id.	Level	N	L24 T20
2529	Åskilje	Medium till	Grass	Level	N	L27 T20
2530	Sarvisvaara	Fine till	Vacc.vi.id	Level	N	L27 T20

*L = long periods. S = short periods. N = non-existing.

$$vub = 10-4(0.4716(d^2h)+4.572(d^2) -0.09787(d^3)-3.111(dh) +82.28(h)) \quad (3)$$

where

h = Total tree height above ground, dm

d = DBH, mm

vob = Stem volume above stump, including bark, dm^3

vub = Stem volume above stump, excluding bark, dm^3.

According to Eichhorn (1904), a general relationship exists between the stem volume of the stand and dominant height. Stand volume is approximately proportional to the square of the mean height of the stand. The dominant height exceeds the mean height by 1.0–1.5 m. Hence, the same relationship should exist for stand volume over dominant height reduced by 1.0–1.5 m.

The relationship between stand volume, with and without bark, and dominant height reduced by 0.0, 1.0 and 2.0 m, was calculated by regression analysis. Of the three relationships, that using dominant height reduced by 1.0 m gave the best correlation. Stand volume yield was predicted for each site index using this relationship. For this purpose, the calculated dominant height according to Tveite (1968) was used.

Comparison with volume yield of other tree species

The volume yield of larch was compared with that of indigenous conifers in two ways:

1. Recorded volume yield of larch was compared with the expected yield at a similar age of Scots pine or Norway spruce in adjacent stands, where the site index had been determined according to the dominant height and yield according to yield tables by Ekö (1985).
2. Expected volume yield of larch for site class index L27, L30, L33 and L36 was compared to expected yield of Scots pine according to Ekö (1985).

On four different sites, the yield of larch was also compared to that of Lodgepole pine (*Pinus contorta* Dougl.) and at a single site with that of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco).

Results

Dominant height

The recorded development of dominant height for 19 larch stands, based on measurements on

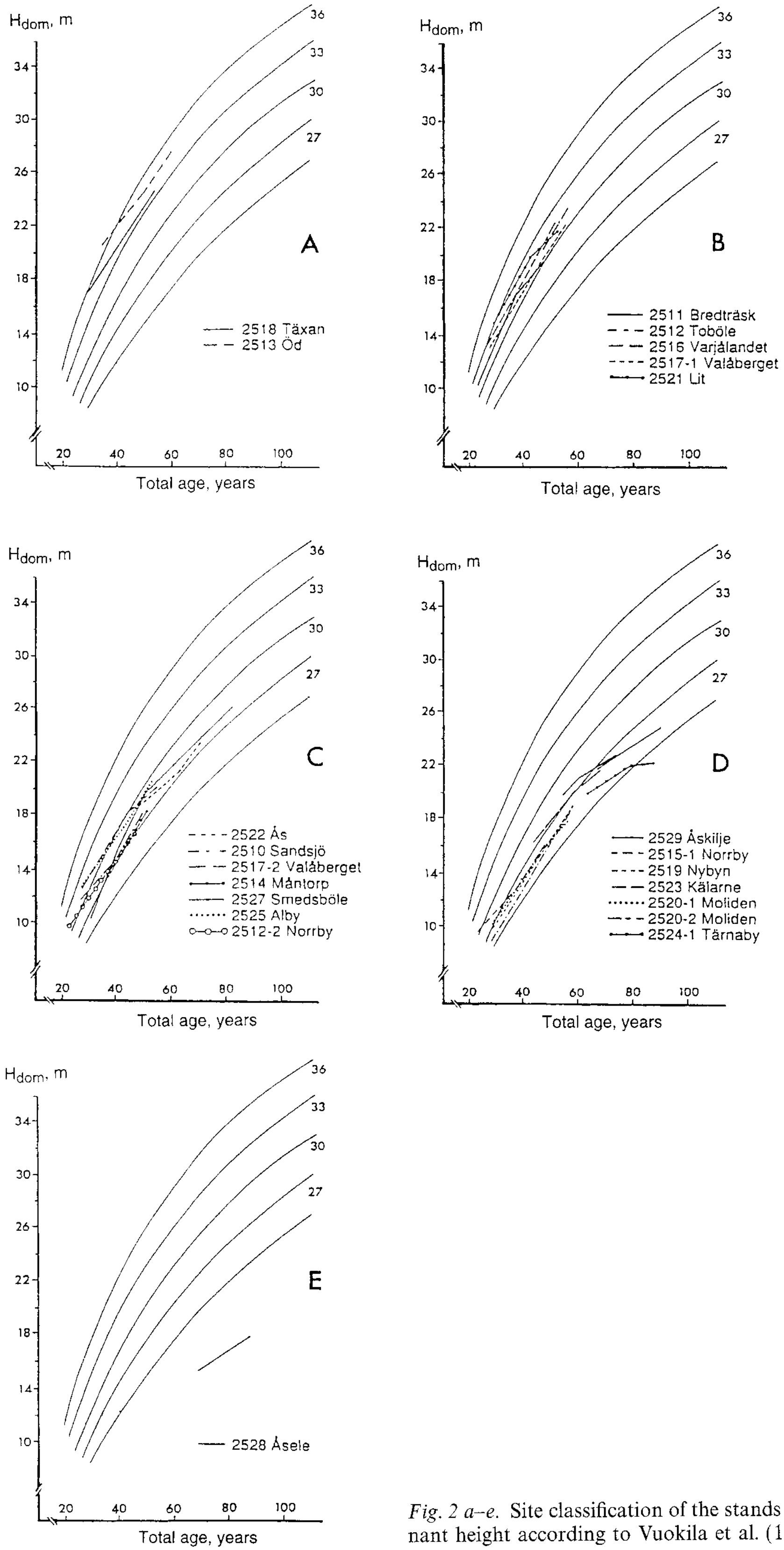

Fig. 2 a–e. Site classification of the stands based on dominant height according to Vuokila et al. (1983).

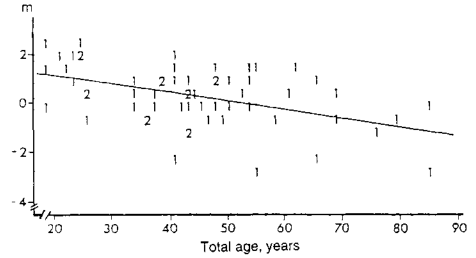

Fig. 3. Deviations between recorded dominant height and dominant height according to Vuokila et al. (1983) in Fig. 2.

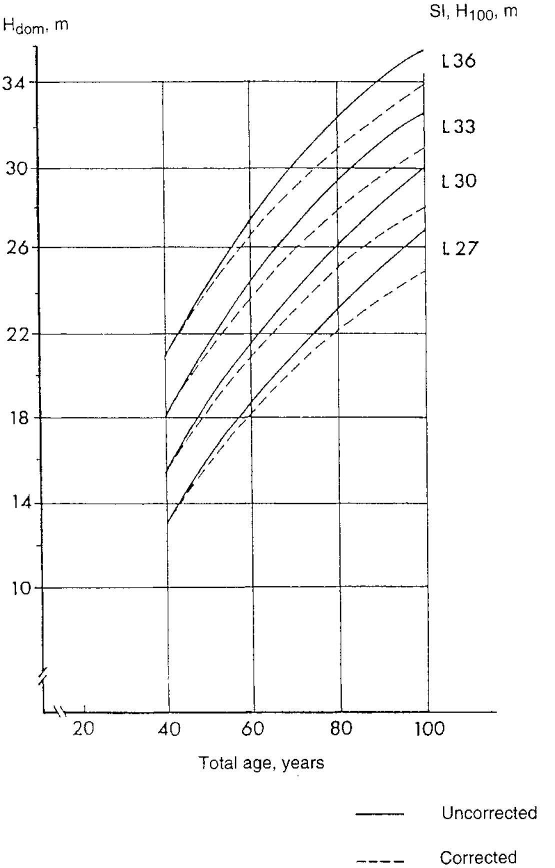

Fig. 4. Dominant height according to Vuokila et al. (1983) after correction to fit to the investigated larch stands.

three occasions, is shown in Fig. 2a–e (see also Appendix 1). The site index of the 19 stands was classified according to Voukila et al. (1983). Two plots were not included in these figures for lack of earlier data.

Dominant height according to Vuokila et al.

The recorded dominant height did not always correspond to the expected dominant height. Based on the deviations between expected and recorded values (Fig. 3), corrected courses for dominant height development were calculated (Fig. 4) according to the following model:

$$H_{\text{dom}} = V + Corr,$$

where
H_{dom} = Dominant height of the stands
V = Dominant height according to Vuokila et al. (1983)
$Corr$ = 1.7937–0.03465* (age of stand, years).

Dominant height according to Tveite

The courses of dominant height development based on Tveite's method (Fig. 5) resembled those calculated according to Vuokila et al. (1983) including the correction (Fig. 4). Tveite's method for expressing dominant height development is used in the following text and in calculations of stand volume, mainly because no correction is necessary. The dominant height based on Tveite's method is mathematically described in Table 3. The dominant heights of Table 4 were calculated according to the functions of Table 3. The dominant height development as expressed

Table 3. *Functions for the development of dominant height at four different site indices. The graphs of Fig. 5 are based on these functions*

Dominant height, m, at site index	Function	Mean error in regr. coeff.	r^2
L27 = 12.48029*	ln(t)-32.54287	0.24441	0.99542 (F4)
L30 = 13.10348*	ln(t)-32.39733	0.25004	0.99565 (F5)
L33 = 13.95411*	ln(t)-32.91034	0.31419	0.99395 (F6)
L36 = 14.89322*	ln(t)-33.46500	0.41662	0.99070 (F7)

t = age of stand, years.

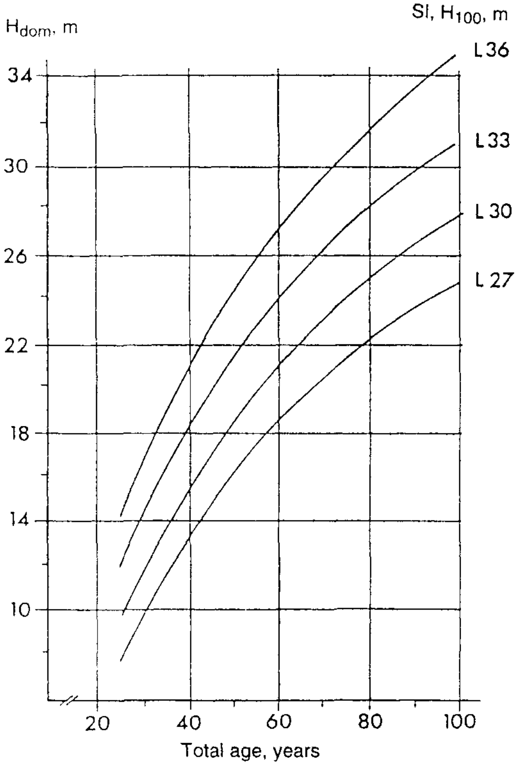

Fig. 5. Dominant height of the investigated larch stands according to 'the deviation method' (Tveite 1968).

in Fig. 5 and Table 4 was used for forecasting volume yield.

Stem volume

The stem volume yield was determined by the relation between the dominant height and the total stem volume yield per hectare (Fig. 6). This relationship is also expressed in Table 5.

For calculating function (8) in Table 5, three stands were excluded, viz. 2513 Öd, 2524 Tärnaby and 2527 Smedsböle. These stands have very large stem volumes calculated on a per hectare basis, and cover small areas. Significant marginal effects can be expected.

If the function for total volume yield is calculated for dominant height reduced by 2.0 or 0.0 m instead of 1.0 m as in function (8), slightly different functions result, viz. functions (9) and (10):

$$Vob = e^{(2.0187 * \ln(H_{dom} - 2) - 0.1320)}$$

$$r^2 = 0.987 \qquad (9)$$

$$Vob = e^{(2.3525 * \ln(H_{dom}) - 1.3616)}$$

$$r^2 = 0.987 \qquad (10)$$

Table 4. *Dominant height, m, of* Larix sukaczewii *in northern Sweden*

Total age, yr	Site index, H100, m			
	L27	L30	L33	L36
25	7.63	9.78	12.01	14.47
30	9.91	12.17	14.55	17.19
35	11.83	14.19	16.70	19.49
40	13.50	15.94	18.56	21.47
45	14.97	17.48	20.21	23.23
50	16.28	18.86	21.68	24.80
55	17.47	20.11	23.01	26.21
60	18.56	21.25	24.22	27.51
65	19.55	22.30	25.34	28.71
70	20.48	23.27	26.37	29.81
75	21.34	24.17	27.34	30.84
80	22.15	25.02	28.24	31.80
85	22.90	25.82	29.08	32.70
90	23.62	26.57	29.88	33.55
95	24.29	27.27	30.63	34.36
100	24.93	27.95	31.35	35.12

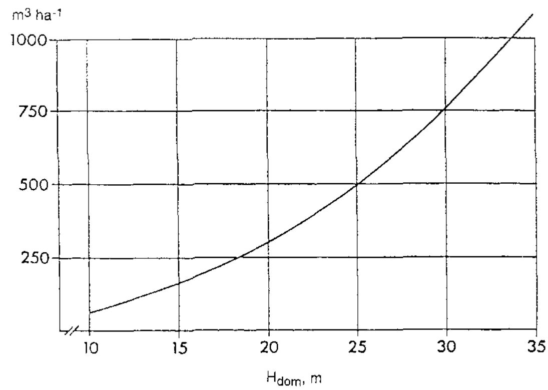

Fig. 6. The relation between the total yield of stem volume and dominant height.

Table 5. *Functional relationship between total stem volume, m^3 ha^{-1}, and dominant height*

Volume Function	Mean error in regress. coeff.	r^2
$Vob = e^{(2.1868 * \ln(H_{dom} - 1) - 0.7360)}$	0.0526	0.987 (F8)

Vob = Stem volume in m^3 ha^{-1} including bark and top.
H_{dom} = Dominant height, m.

At a dominant height of 35 m, these functions predict a total yield which is 5 per cent lower or 5 per cent higher, respectively, than that predicted by function (8).

In Fig. 7, the recorded stem volumes of individual stands are grouped according to site class and shown together with the calculated relation

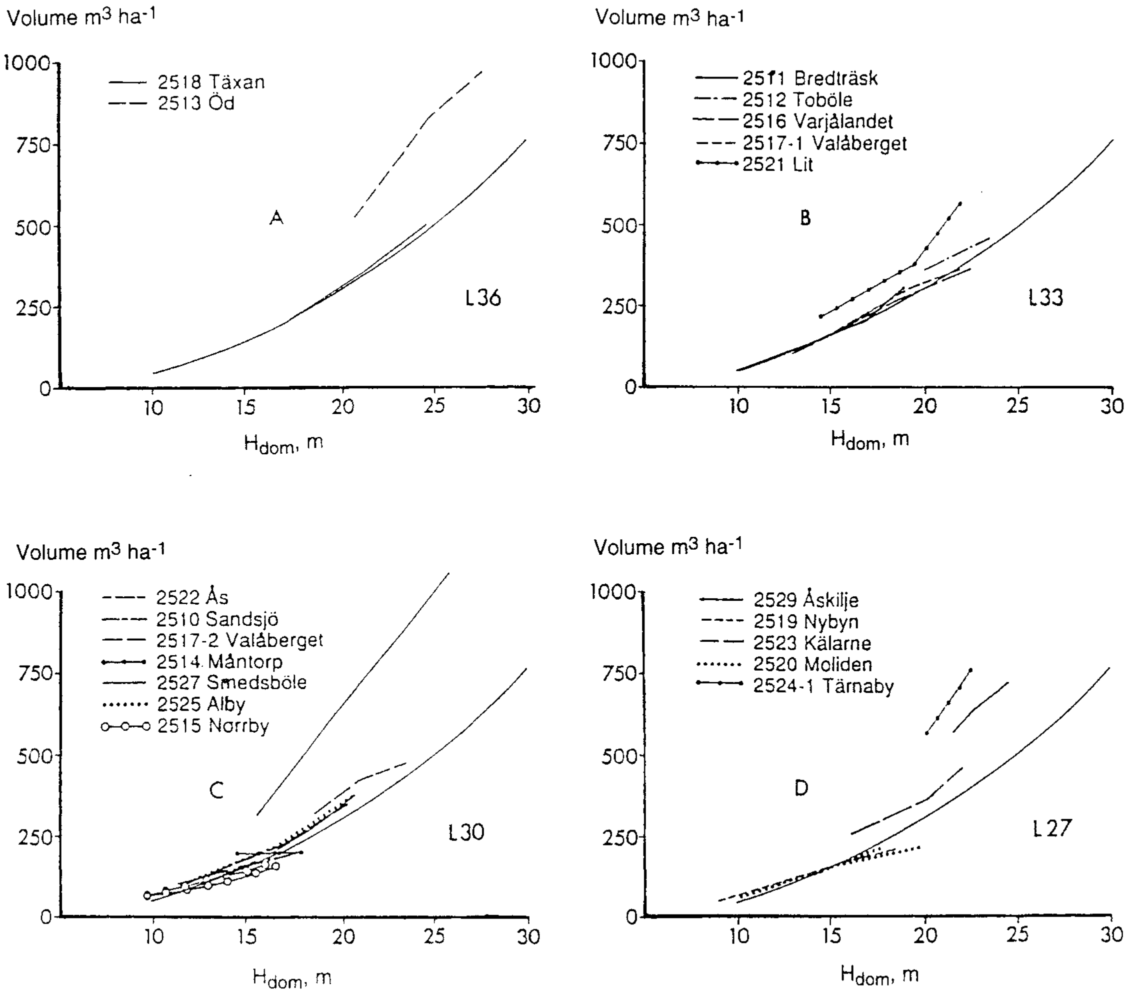

Fig. 7 a–d. Recorded stem volumes of the stands and calculated stem volume related to dominant heights between 10 and 30 m. The stands are grouped according to site class.

between dominant height and stem volume according to function (8). In Table 6, the stem volumes are calculated according to function (8) for four site classes and stand ages between 25 to 100 years.

Damage

The three most frequent types of damage recorded were snow break, forked stem and crooked stem (Table 7). No incidence of disease or insect attack was found.

Bark volume

On the average, the bark volume represents 26 per cent of the stem volume (Table 8), which is approximately twice as large as the proportion of bark in the volume of Scots pine. The mean annual increment of *L. sukaczewii* therefore differs considerably, depending on whether it is calculated over or under bark (Fig. 8).

However, the share of bark in the volume varied between 12 and 35 per cent in the investigated larch stands (Table 8). The cause of this wide variation could not be identified. Bark thickness was correlated neither with stem diameter nor with the age of the tree, but might be explained by genetic factors or site factors.

Volume yield of larch: comparison with other tree species

Table 9 shows the recorded total volume yield of larch together with expected yield of Scots

Table 6. *Forecast of stem volume yield per hectare of* Larix sukaczewii *in northern Sweden*

	Site index, H100, m			
	L27	L30	L33	L36
Total age, years	m^3 stem volume per hectare, excluding bark			
25	22	41	67	104
30	42	70	106	156
35	65	100	146	209
40	89	131	186	261
45	113	163	227	313
50	138	194	267	363
55	162	225	306	411
60	186	255	344	459
65	210	285	381	506
70	234	314	417	551
75	258	343	453	595
80	280	370	488	638
85	301	398	521	679
90	325	425	554	720
95	346	451	586	759
100	367	476	618	798
Total age, yr	m^3 stem volume per hectare, including bark			
25	30	55	91	141
30	57	94	143	211
35	88	135	197	282
40	120	177	252	353
45	153	220	307	423
50	186	262	361	491
55	219	304	413	556
60	252	345	465	621
65	284	385	515	684
70	316	424	564	745
75	348	463	612	804
80	379	500	659	862
85	409	538	704	918
90	439	574	749	973
95	467	609	792	1 026
100	496	643	835	1 078

pine (P) or Norway spruce (S) in adjacent stands. The yield of pine or spruce is based on yield tables by Ekö (1985), and corresponds to the yield in closed stands with one or two thinnings during a rotation.

This comparison indicates a wide amplitude in the productivity of larch. On some of the sites investigated, larch produced far more than the indigenous tree species, on other sites less. On the average, the yield of larch was 25–40 per cent superior to that of the indigenous conifers, depending on site index (Table 9).

These figures include the volume of bark. Calculated under bark, the volume yield of larch on the sites studied was 10–25 per cent superior to that of indigenous conifers.

The difference between the yield of larch and that of Scots pine or Norway spruce varies greatly between sites, probably depending on local site conditions and on the tending of the stand, e.g. on the genetic origin of seed, on spac-

Table 7. *Frequency of damage in the larch stands. The figures indicate the number of larch trees on the plot*

Plot No.	Site	Total	Dead	Living	1	2	3
2510	Sandsjö	57	18	39	12	9	–
2511	Bredträsk	73	1	72	3	4	–
2512	Toböle	52	1	51	–	–	–
2513	Öd	20	–	20	1	–	–
2514	Måntorp	37	3	34	–	4	2
2515-1	Norrby	70	13	57	4	6	3
2515-2	Norrby	91	23	68	13	15	3
2516	Vargålandet	164	13	151	–	2	3
2517-1	Valåberget	88	13	75	–	11	1
2517-2	Valåberget	202	70	132	–	12	6
2518	Täxan	30	–	30	1	1	2
2519	Nybyn	73	3	70	10	–	6
2520-1	Moliden	59	16	43	10	–	1
2520-2	Moliden	50	6	44	4	–	–
2521	Lit	49	–	49	–	1	–
2522	Ås	27	–	27	–	–	–
2523	Kälarne	46	–	46	–	3	–
2524-1	Tärnaby	21	–	21	1	2	5
2524-2	Tärnaby	29	–	29	3	–	6
2525	Alby	51	–	51	1	5	–
2527	Smedsböle	36	–	36	–	11	–
2528	Åsele	53	1	52	–	–	–
2529	Åskilje	33	–	33	–	–	–
2530	Sarvisvaara	45	–	45	–	2	1

1 = Top broken. 2 = Crooked. 3 = Double top.

Table 8. *Bark volume in per cent of the total larch stem volume*

Plot No.	Site	Dbh of mean tree basal area, mm	% bark of stem volume
2510	Sandsjö	207	27
2511	Bredträsk	204	12
2512	Toböle	191	27
2513	Öd	351	21
2414	Måntorp	201	26
2515-1	Norrby	181	27
2515-2	Norrby	184	27
2516	Vargålandet	185	24
2517-1	Valåberget	218	28
2517-2	Valåberget	172	28
2518	Täxan	276	27
2519	Nybyn	161	20
2520-1	Moliden	178	31
2520-2	Moliden	192	31
2521	Lit	216	27
2522	Ås	279	28
2523	Kälarne	232	29
2524-1	Tärnaby	289	16
2525	Alby	187	27
2527	Smedsböle	351	35
2528	Åsele	163	28
2529	Åskilje	328	26
2530	Sarvisvaara	188	28

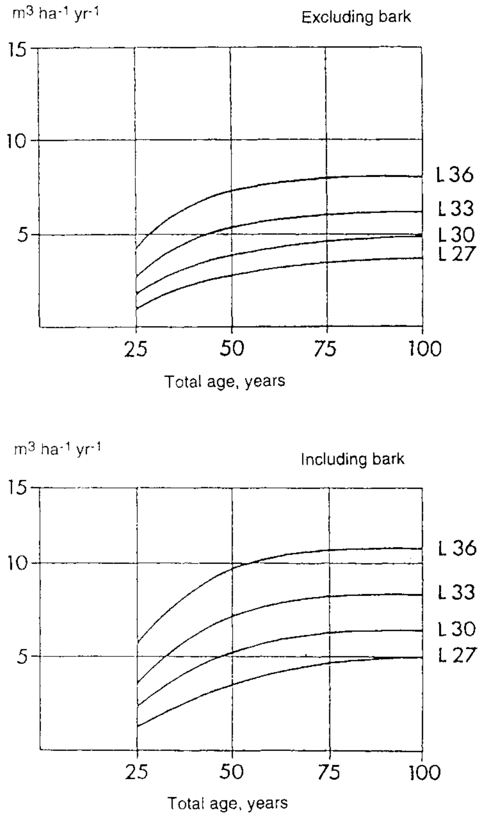

Fig. 8. Mean annual increment of four different site qualities including or excluding bark volume.

ing and thinnings. In general, the difference increased with increasing site index. In 13 cases, larch was compared to Scots pine and in nine cases to Norway spruce. Compared to Scots pine, larch usually was superior in stem volume yield, and this superiority increased with site index. Comparison with Norway spruce is more difficult, because of the difficulty of finding properly managed Norway spruce stands.

A direct relationship between the estimated site index of Scots pine and that of larch is shown in Fig. 9. This relationship is also expressed in function (11).

$$SI(P) = 0.822 * SI(L) - 1.531$$
$$r^2 = 0.746 \qquad (11)$$

where
$SI(P)$ = Site index for Scots pine, H_{100}, m
$SI(L)$ = Site index for larch, H_{100}, m

For stem volume yield, site index L27 is equal to P20.8, L30 is equal to P23.2, L33 equal to P25.7 and L36 equal to P28. Table 10 shows the mean annual increment of Scots pine and larch between ages 30 and 100 years, for equivalent sites. Here the expected yield of larch is compared with the expected yield of Scots pine. For both species bark is included. At age 100 years, the yield of larch exceeded that of Scots pine by 2 per cent for site index L27/P20.8, and by 64 per cent for site index L36/P28. The corresponding figures for stem volume under bark were −12 per cent and +38 per cent, respectively. The difference in productivity of Scots pine growing on a rich as compared to a poor site is relatively small, while the productivity of larch is more than twice as great on L36 as compared to L27.

Site index for Norway spruce and larch was similarly compared. However, no significant correlation could be found. A high site index for larch sometimes corresponded to a high, sometimes to a low, site index for spruce.

Four of the larch stands are situated close to contemporarily established stands of Lodgepole pine. These stands are 2510 Sandsjö, 2512 Toböle, 2511 Bredträsk and 2513 Öd. At Öd there is also a small stand of Douglas fir, established in the same year as the larch and Lodgepole pine. Table 11 shows the total yield of all tree species present on the four sites.

More detailed information concerning the 20 larch stands reported here, and the processing of data, is given by Martinsson (1990).

Discussion

Increment of dominant height

The most remarkable difference between the results of this investigation, and those of earlier investigations of the same larch stands, is the course of dominant height increment over time (Fig. 10). The dominant height development described by Remröd & Strömberg (1977) is considerably more curved, resulting in lower values of dominant height at the end of the rotation. Remröd & Strömberg (1977) give no detailed description of their mathematical methods, other than the statement that 'H_{dom} is set to predetermined levels at age 50 years at breast height'.

Wiksten (1962) explained the mathematical function he used for calculating dominant

Table 9. *Mean annual increment of larch at latest revision or at growth culmination, and expected mean annual increment of Scots pine or Norway spruce on the same site at total age 80 years, according to Ekö (1985)*

Plot No.		Larch		Pine/spruce		
		o b	u b	o b	u b	Species*
Site index L24						
2528	Åsele	1.9	1.4	3.4	3.0	(P)
Site index L27						
2524	Tärnaby	8.7	7.3	4.5	3.8	(S)
2515-1	Norrby	3.2	2.7	5.1	4.4	(P)
2523	Kälarne	6.3	4.5	5.0	4.3	(S)
2520	Moliden	3.9	2.7	4.8	4.1	(S)
2519	Nybyn	3.2	2.6	5.0	4.4	(S)
2529	Åskilje	8.5	6.3	3.8	3.3	(P)
2530	Sarvisvaara	4.7	3.4	3.5	3.1	(P)
Site index L30						
2515-2	Norrby	3.7	2.7	5.1	4.5	(P)
2514	Måntorp	5.1	3.8	5.1	5.3	(P)
2510	Sandsjö	4.5	3.3	2.7	2.4	(P)
2517-2	Valåberget	6.3	4.6	5.4	4.7	(S)
2522	Ås	6.7	4.9	5.2	4.5	(P)
2527	Smedsböle	(12.4)	(8.0)	2.3	2.1	(S)
2525	Alby	6.5	4.7	5.3	4.6	(P)
Site index L33						
2511	Bredträsk	6.2	5.5	5.8	5.1	(P)
2521	Lit	10.1	7.4	5.2	4.5	(P)
2517-1	Valåberget	6.6	4.7	5.4	4.7	(S)
2512	Toböle	7.8	5.7	6.9	6.0	(P)
2616	Vargålandet	7.2	5.5	3.7	3.3	(S)
Site index L36						
2513	Öd	(16.0)	(12.6)	8.4	7.2	(P)
2518	Täxan	9.42	6.9	7.3	6.4	(S)

*Native alternative tree species for site classification. P = Scots pine. S = Norway spruce.

height:

$$H_{dom} = (x/(a + bx))^3$$

where
H_{dom} = The dominant height of the stand
x = Total age of the stand
a, b = Constants determined for the dominant height at stand age 50 years.

Thus, the only point at which the calculated course of dominant height definitely corresponds to the values recorded in the field, is at stand age 50 years. Wiksten refers to Peterson (1955), who used this and similar functions to describe the development of dominant height for naturally regenerated coniferous stands, mainly Scots pine.

Edlund (1966) refers to Wiksten's method of calculation of the dominant height, and used the same method.

Tveite's method for describing the development of dominant height is similar to those used by Wiksten (1962), Edlund (1966) and Remröd & Strömberg (1977) in one respect: the starting point of the course is set to a predetermined level. The main difference between Tveite's

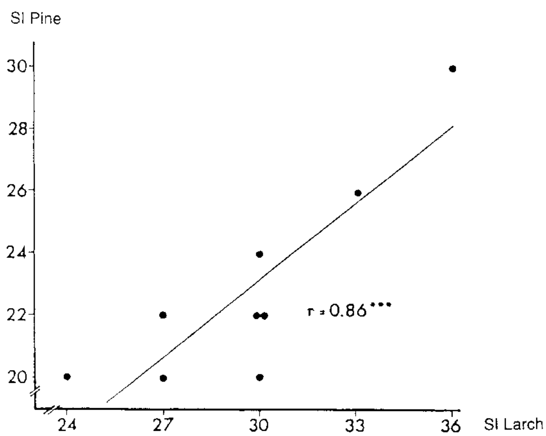

Fig. 9. The relation regarding stem volume yield between site index of larch and Scots pine on the same site.

Table 10. *Mean annual increment of stem volume, $m^3\ ha^{-1}\ yr^{-1}$ of* Larix sukaczewii *(larch) and* Pinus sylvestris *(pine) growing under similar site conditions and the yield of* Larix sukaczewii *in per cent of that for* Pinus sylvestris

Age, yr	Site index L27/P20.8 Larch	Pine	%	L30/P23.2 Larch	Pine	%	L33/P25.7 Larch	Pine	%	L36/P28.0 Larch	Pine	%
						Including bark						
30	1.9	2.5	76	3.1	2.8	111	4.8	3.6	133	7.0	4.4	159
40	3.0	3.5	86	4.4	3.9	113	6.3	4.8	131	8.8	5.7	154
50	3.7	4.1	90	5.2	4.5	116	7.2	5.7	126	9.8	6.4	153
60	4.2	4.6	91	5.8	5.0	116	7.8	6.0	130	10.4	6.7	155
70	4.5	4.7	96	6.1	5.1	120	8.1	6.2	131	10.6	6.7	158
80	4.7	4.8	98	6.3	5.2	121	8.2	6.2	132	10.8	6.7	161
90	4.9	4.9	100	6.4	5.2	123	8.3	6.2	134	10.8	6.7	161
100	5.0	4.9	102	6.4	5.2	123	8.4	6.1	138	10.8	6.6	164
						Excluding bark						
30	1.4	2.2	64	2.3	2.5	92	3.5	3.2	109	5.2	3.9	133
40	2.2	3.1	71	3.3	3.4	80	4.7	4.2	112	6.5	5.0	130
50	2.8	3.6	78	3.9	4.0	98	5.3	5.0	106	7.3	5.6	130
60	3.1	4.0	78	4.3	4.4	98	5.7	5.3	108	7.8	5.9	130
70	3.3	4.1	80	4.5	4.5	100	6.0	5.5	109	7.9	5.9	133
80	3.5	4.2	83	4.6	4.6	100	6.1	5.4	113	8.0	5.9	135
90	3.6	4.3	84	4.7	4.6	102	6.2	5.4	115	8.0	5.9	136
100	3.8	4.3	88	4.8	4.6	104	6.2	5.4	115	8.0	5.8	138

Table 11. *Stem volume yield of* Larix sukaczewii *(L s),* Pinus sylvestris *(P s),* Pinus contorta *(P c) and* Pseudotsuga menziesii *(P m) in neighbouring stands*

Plot No.	Site	Species	Age, yr	Tot. prod, $m^3\ ha^{-1}$	Plot area, m^2
	Sandsjö	P s	49	64	*
	Sandsjö	P c	53	211	1 500
2510	Sandsjö	L s	49	220	590
	Bredträsk	P s	47	237	750
	Bredträsk	P c	53	370	1 000
2511	Bredträsk	L s	47	292	750
	Toböle	P s	56	374	*
	Toböle	P c	56	496	900
2512	Toböle	L s	56	434	383
	Öd	P s	58	601	560
	Öd	P c	58	578	740
2513	Öd	L s	58	944	288
	Öd	P m	58	900	230

*From Ekö (1985).

method and that used by the other three authors, lies in Tveite's use of data collected in larch stands to describe the whole course of dominant height development. Of especial importance to the reliability of such calculations is the age of the larch stand on which the course of dominant height development is based. The material used by Wiksten, by Edlund and by Remröd and Strömberg is mainly identical with the stands used in the present study, but at a younger stage. In the present material, no larch stand is older than 89 years. There are four stands aged between 80 and 90 years, but the basis for describing dominant height development between age 90 and 100 years does not exist in the present field data.

The function of Vuokila et al. (1983) for dominant height development is based on 26 permanent plots, some of which have reached the age of 100 years. Most of their stands are in the age interval 60–80 years. The course of dominant height development given by Voukila et al. coincides very well with those described by Tovstoljes (1916), based on the old, well-known larch stands in Raivola, Karelia. Fig. 10 shows the dominant height of Siberian larch calculated by Wiksten (1962), Remröd & Strömberg (1977), Vuokila et al. (1983) and the present author. The dominant height according to Wiksten corresponds fairly well with that described for the highest site index in the present study. On poorer sites, the course of dominant height is more curved, according to Wiksten. However, it should be emphasised that in the present study, material from site indices below H_{100} = L27 has been excluded. The dominant height according to Remröd and Strömberg corresponds fairly well with those up to age 30

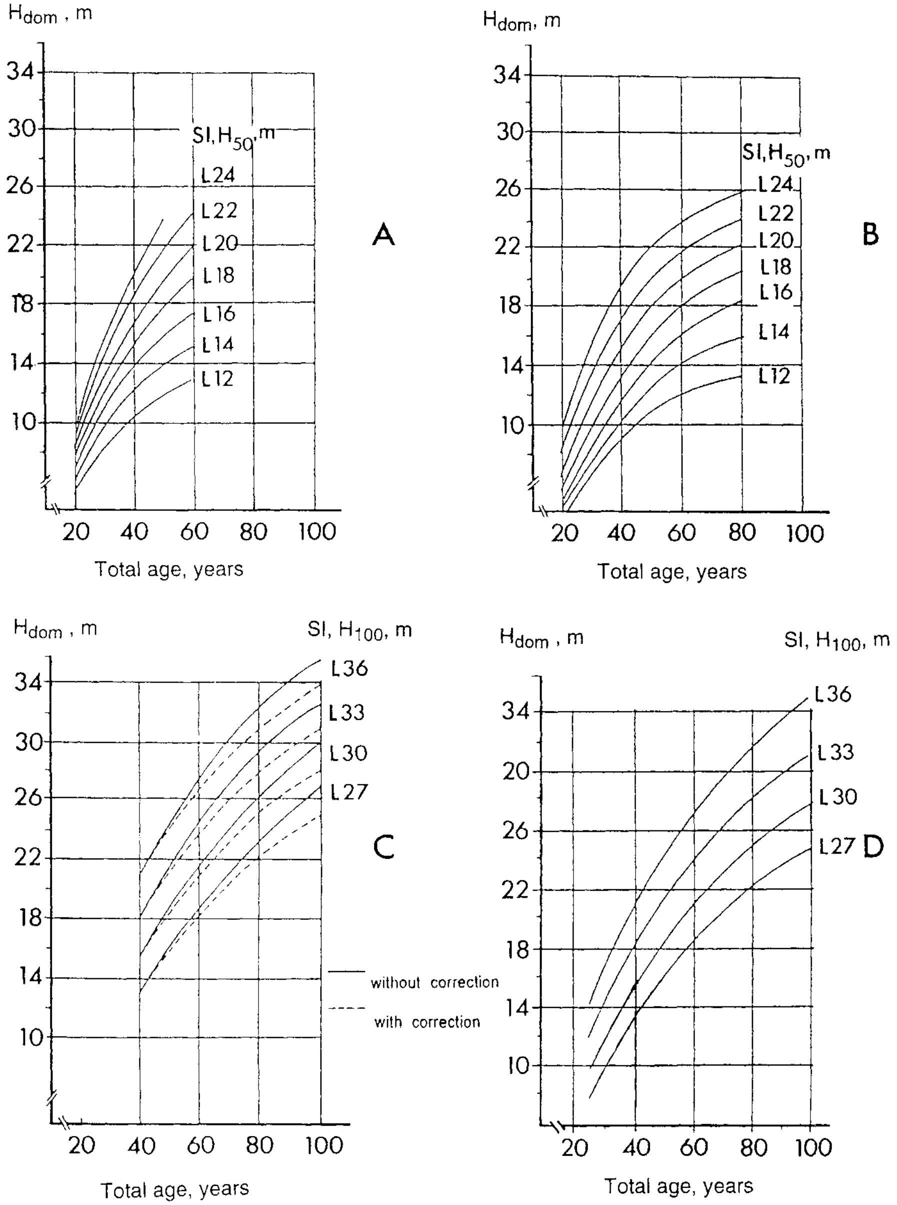

Fig. 10. Development of dominant height of Siberian larch according to four different investigations: A = Wiksten (1962), B = Remröd & Strömberg (1976), C = Vuokila et al. (1983). D = Material in this investigation processed according to Tveite (1968).

in the present study. After that point, the differences are large, since the dominant height according to Remröd and Strömberg more or less levels off at age 70.

Shortcomings in the present material are the small size of the plots, the poor management of the stands (few or no thinnings) and too few data from old stands. The course of dominant height development in the age interval 70–100 years may therefore need to be adjusted when more information becomes available from these and other stands in the future. However, at present the most reliable description of dominant height development for Siberian larch in northern Sweden, is that illustrated in Fig. 10d.

Stem volume increment

The predicted stem volume increment is based upon two relationships:

1. The relationship between stand age and dominant height.
2. The relation between the stem volume of the stand and its dominant height.

The second relationship is independent of site index, according to Eichhorn (1904). In the investigated material, a strong correlation was found between stem volume and dominant height. This relationship is more clearly supported by the data collected, than is the relationship between stand age and dominant height.

The stem volume yield of the investigated stands should be considered as the result of growth under the conditions obtaining. The total material is limited, and the individual plot areas small. Marginal effects, arising from the small size of the plots, may occur in some cases. Factors which could have increased the total volume yield are, e.g., the genetic origin of the seed, the choice of site, the method of stand establishment and the lack of regular thinnings. It is well known that larch is much influenced by site conditions. The soil water regime, soil texture and site exposure probably influence larch more than many other tree species. Siberian larch, as well as the Japanese and the European larches (*Larix kaempferi* (Lamb.) Carr. and *L. decidua*) need rich sites and slopes with mobile soil water to attain a very high yield.

Volume yield of larch: comparison with other tree species

The stem volume yield of larch was compared to that of other tree species in adjacent stands. This comparison was based on a site classification determined by the assessment of dominant height. In two cases, viz. 2511 Bredträsk and 2523 Öd, larch was compared with adjacent, contemporarily planted stands of Scots pine.

In 47 years the Scots pine stand at Bredträsk produced 237 m^3 ha^{-1}, while larch on the same site and during the same period produced 292 m^3 ha^{-1}, i.e. 23% more. At Öd, the Scots pine stand produced 601 m^3 ha^{-1}, larch 944 m^3 ha^{-1}. For both species, bark volume is included. At 2511 Bredträsk, the share of bark was 12 per cent of the total stem volume of larch. This is less than the average for larch, and approximately the same as for Scots pine. At 2523 Öd, the share of bark was 21 per cent of larch stem volume.

At four sites, larch was also compared to Lodgepole pine and at one site to Douglas fir. The comparison indicates that the volume yield of larch is superior to that of Lodgepole pine at high elevations and on hilly sites with mobile soil water.

Examples of very poor volume yield of larch also occur. Many such larch stands have been classified as failures and abandoned. One exception may be 2528 Åsele, where larch, owing to low site quality, is evidently not the best choice of species. On this site, Scots pine produced 114 per cent more stem volume than larch when calculated excluding bark, and 79 per cent more including bark.

The influence of provenance

The genetic origin of the investigated material is unknown in most cases. Except for plot 2520 Moliden, the origin of the seed source is probably the northern part of European Russia or allochthonous stands in Finland.

Provenance research concerning *L. sukaczewii* and other Asiatic larch species is very incomplete in Sweden. However, one 30-year old trial, including 30 provenances of larch mainly from Siberia, indicates that the second generation of Swedish-grown Siberian larch, provenance Visingsö, is very competitive by comparison with directly introduced material (Martinsson, 1992). Most of the successful plantations of Siberian larch in northern Sweden originate from Archangel oblast in northern Russia or from the allochthonous stands at Raivola in Karelia. Other seed sources that have produced good growth are Sverdlovsk (lat. 57°00′N, long. 60°00′E), Sonskij (lat. 54°00′N, long. 90°00′E) and Askitzky (lat. 53°00′N, long. 90°00′E) (Jonsson, 1978).

Conclusions

Regarding the increment of height and stem volume of Siberian larch in northern Sweden, the following conclusions can be drawn: On medium to good sites in central northern

Sweden, a dominant height of 25–27 m can be expected at age 60 years. Dominant height is still increasing at an age of 90 years.

On rich sites in northern Sweden, the stem volume yield of larch under bark can reach 800 m^3 ha^{-1} during a 100-year rotation, and may exceed the volume yield of Scots pine by 10–25 per cent on the same site.

Larch is more sensitive to soil conditions than is Scots pine. Dry, flat or waterlogged areas should be avoided. With respect to mineral nutrient status, medium to good sites are to be preferred.

This investigation gives clear examples of larch being superior in productivity to indigenous conifers on some sites in northern Sweden.

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Appendix 1

Compiled data from the investigated stands

Plot Measurement no.	Age, yr tot.	Dbh III	Dbh, mm III[11]	Dom height, m I	II	III	N of stems/ha larch I	II	III	tot. III	Basal area, m²/ha larch II	III	Stem volume, m³/ha ob Larch+other sp. II	III	Larch I	II	III	Larch+other sp. I	II	III	Thinned, m³/ha I-III	Total prod., m³/ha I	II	III
2610	49	43	207	11.6	14.7	18.0	1 136	683	661	2 356	19.6	22.1	22.4	30.2	74	124	175	81	138	202	18	81	138	220
2511	47	38	204	9.8	17.0	19.2	893	960[12]	960	4 907	22.6	31.3	23.6	33.8	35	205	265	37	210	276	17	53	224	292
2512	56	46	191		20.1	23.5	–	1 359	1 333	2 327	34.2	38.1	36.2	43.5		316	407	–	328	433	2	–	328	434
2513	59	53	351	20.3	24.3	27.6	729	694	411	453	58.3	39.6	58.3	40.0	363	640	798	363	640	846	146	521	786	944
2514	50	43	201		14.6	17.8	–	1 139	658	2 553	16.4	20.8	21.3	29.2		103	167	–	124	212	2	–	124	213
2515-1	47	38	181	9.3	12.9	16.0	820	610	570	1 350	12.9	14.6	15.2	20.0	26	71	103	29	82	128	21	44	99	150
2515-2	47	40	184	9.6	13.8	16.5	930	700	680	1 290	15.5	18.1	17.0	23.3	36	91	127	39	100	145	28	53	114	173
2516	51	43	185	12.9	18.4	22.5	1 689	1 311	1 269	1 655	28.4	34.2	28.4	34.8	90	236	346	90	236	346	23	95	257	369
2517-1	55	44	218	12.8	19.3	22.1	1 176	1 086	809	1 197	32.6	30.3	32.6	32.1	75	281	308	75	281	308	21	85	288	330
2517-2	55	44	172	12.2	18.0	20.5	1 924	1 552	1 257	2 124[1]	27.4	29.9	27.4	33.9	86	218	284	86	218	284	58	106	257	342
2518	53	48	276	16.8	21.1	24.7	681	659	666[2]	1 366	33.7	40.0	36.3	45.0	153	317	438	177	334	484	15	196	349	499
2519	57	44	161	8.8	15.1	18.6	918	855	1 108[13]	1 662	19.0	22.5	20.1	25.0	21	123	158	22	128	171	10	32	138	182
2520-1	57	48	178	9.8	15.5	17.7	1 027	704	577	3 543	14.9	14.3	16.7	19.0	29	98	148	32	105	167	30	52	129	221
2520-2	57	48	192	9.8	15.5	19.3	1 027	704	592	2 176	14.9	17.1	16.7	24.0	29	98	181	32	105	214	30	52	129	221
2521	52	48	216	14.5	19.5	21.8	1 136	1 237	1 237	1 923	36.9	45.1	38.7	49.1	112	319	447	122	332	478	41	177	373	519
2522	72	67	279	18.3	21.2	23.6	650	516	450	683	25.7	27.5	27.9	27.9	170	252	293	210	270	294	174	323	404	469
2523	69	63	232	16.1	20.0	21.9	850	724	724	1 574	27.5	30.6	35.5	45.4	181	252	316	216	323	391	43	260	366	434
2524-1	89	75	289	20.0	22.1	22.3	1 340	670	830[3]	830	44.0	54.3	44.0	54.3	341	401	466	341	401	466	284	531	685	750
2524-2	34	20	247	–	–	17.8	–		598	639	–	28.6	–	29.1	–	–	220	–	–	222	16			238
2525	52	43	187	12.6	16.7	20.7	1 077	1 176	1 360[14]	1 600	25.1	37.2	26.2	38.8	91	176	328	96	184	336		97	162	336
2527	83	73	351	15.4[10]	19.9[5]	26.1	1 474[10]	855[5]	550	2 675	43.8[5]	53.4	43.8[5]	54.6	232[10]	371[5]	831	232[10]	371[5]	835	192	296[10]	563[5]	1 027
2528	87	72	163	15.2[6]	15.9[7]	18.0	605[6]	594[7]	582	604	9.3[7]	12.1	10.4[7]	13.2	59[6]	65[7]	91	59[6]	69[7]	96	66	125[6]	135[7]	162
2529	89	81	328	21.5[8]	22.4[9]	24.6	437[8]	437[9]	437	437	26.9[9]	36.9	26.9[9]	36.9	223[8]	268[9]	399	223[8]	268[9]	299	300	560[8]	605[9]	699
2530	38	31	188	–	–	13.6		–	1 000	1 733	–	27.8		28.3	–	–	157	–	–	158	22	–		180

[1] Including 667 larches not included at measurement II. [2] Included in the permanent plot is one tree which probably was not included at measurement II. [3] At measurement II only the 15 largest trees were included. At III all trees were measured. [4] The plots were not thinned between measurements II and III. Thinned volume = mortality + earlier thinnings. [5] Measured in 1955. [6] Measured in 1966. [7] Measured in 1971. [8] Measured in 1963. [9] Measured in 1970. [10] Measured in 1944. [11] Dbh on bark of the tree of mean basal area, larch only. [12] The plot at revision I and II was not identical with the plot at revision III. [13] Some small larch trees not measured at revision II were measured at revision III. [14] The plot area was probably not correct at revision II.