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A provenance test of Japanese larch in eastern Canada, including comparative data on European larch and tamarack

By Y. S. PARK and D. P. FOWLER
Maritimes Forest Research Centre,
Canadian Forestry Service,
Department of the Environment,
P. O. Box 4000, Fredericton, N. B. E3B 5P7, Canada

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Summary

Japanese larch (*Larix leptolepis* (SIEB. et ZUCC.) GORD.) of 20 provenances, European larch (*L. decidua* MILL.) of 3 provenances and tamarack (*L. laricina* (DU ROI) K. KOCH of 2 provenances were tested in central New Brunswick, Canada. Geographic variation among the Japanese larch was high for most characters studied i.e., height and diameter at ages 4, 8, 12, and 19, stem straightness, damaging agents, survival, volume, and flower production. Geographic variables of the provenances, e.g., latitude, longitude, altitude, temperature, and precipitation were not related to phenotypic variables, i.e., the genetic variation pattern appears to be random.

Although tamarack had a height advantage over the other species up to age 8, Japanese larch was clearly superior in both diameter and height growth by age 12 and increased its superiority through age 19. In general, Japanese larch was straighter and less damaged by porcupines (*Erethizon dorsatum* L.) than the other species at age 19. Despite somewhat poorer survival than tamarack, volume of Japanese larch for the best five provenances averaged 156 m³/ha and was more than double that of tamarack. It is suggested that Japanese larch of good provenance could be used as a short rotation species for fibre production in eastern Canada.

Key words: Provenance test, *Larix leptolepis*, *L. decidua*, *L. laricina*, random genetic variation.

Zusammenfassung

Es wurden 20 Provenienzen von *Larix leptolepis* (SIEB. et ZUCC.) GORD., 3 Provenienzen von *L. decidua* MILL. und 2 Provenienzen von *Larix laricina* (DU ROI) K. KOCH in Zentral-New Brunswick (Kanada) untersucht. Die geographische Variation zwischen den Japanlärchen war für die meisten untersuchten Merkmale hoch, beispielsweise für Höhe und Durchmesser im Alter 4, 8, 12 und 19, für Geradschäftigkeit, Krankheitsursachen, Überlebensprozent, Volumen und Blütenproduktion. Geographische Variablen der Herkünfte, wie Längengrad, Breitengrad, Höhenlage, Temperatur und Niederschlagsmenge standen nicht mit phänotypischen Variablen in Beziehung. So war z. B. das genetische Variationsmuster zufällig. Obwohl *Larix laricina* bis zum Alter 8 einen Höhenvorteil gegenüber den anderen beiden Arten hatte, war *Larix leptolepis* im Höhen- und Durchmesserwachstum im Alter 12 klar überlegen. Die Überlegenheit nahm im Alter 12 noch zu. Im allgemeinen war Japanlärche geradschäftiger und im Alter 19 weniger durch *Erethizon dorsatum* L. geschädigt als die anderen Arten. Trotz eines etwas geringeren Überlebensprozents betrug das Volumen der Japanlärche für die 5 besten Provenienzen 156 m³/ha und war mehr als doppelt so hoch wie das von *Larix laricina*. Es wird vorgeschlagen, daß Japanlärchen guter Herkunft als Art für den Kurzumtrieb zur Faserholzproduktion in Ostkanada in Frage kommen.

Introduction

Japanese larch (*Larix leptolepis* (SIEB. et ZUCC.) GORD.) is edemic to the central part of the island of Honshu, Japan, where it is found as geographically isolated populations at elevations of 900 to 2500 m. All natural stands of the species are located in an area of about 200 km square (FARNSWORTH *et al.* 1972). Japanese larch is of economic importance within its natural range and as an exotic elsewhere.

COOK (1971) expounds the virtues of *Larix* species, emphasizing such things as ease of vegetative propagation, early flowering, stem and branch characteristics as they relate to harvesting, rapid growth and a large amount of genetic variation. In eastern North America, Japanese larch is considered to be the fastest growing of the larches (LITTLEFIELD and ELIASON 1956, SCHOBER 1958, ELIASON and CARLSON 1963, STAIRS 1965, MACGILLIVRAY 1969). COOK (1971) considers that Japanese larch of good provenance will outgrow other conifers commonly planted in the Northeast by more than two to one.

Most provenance studies of Japanese larch have reported highly significant differences among populations and that these differences are not closely associated with altitude, latitude, or any other recognized environmental characteristic of the seed source (LANGNER 1961, WRIGHT 1962, LESTER 1964, PAULEY *et al.* 1965, FARNSWORTH *et al.* 1972). In contrast, KRUSCHE and RECK (1982) found that nearly half of the variation between provenances, grown at 11 locations in Germany, could be explained by climatic differences at the place of origin. In addition LANGNER (1961) reported a relationship between elevation and fall needle color, and GENYS (1971) suggested that stem quality and susceptibility to larch sawfly *Pristophora erichsonnii* (HARTIG) were correlated with longitude.

Populations differ with respect to survival (LESTER 1964, PAULEY *et al.* 1965, STAIRS 1965, HATTEMER 1969, GENYS 1971, FARNSWORTH *et al.* 1972, LEE 1975), stem form and quality (LESTER 1964, GENYS 1971, TODA and MIKAMI 1976), phenology (LESTER 1964, HATTEMER 1969, TODA and MIKAMI 1976), susceptibility to larch sawfly (GENYS 1971), wood characteristics (LEE 1965, LOO *et al.* 1982), fall needle color (LANGNER 1961); and disease resistance (TODA and MIKAMI 1976). Many studies have revealed high provenance × environment interactions (PAULEY et al. 1965, STAIRS 1965, HATTEMER 1969, FARNSWORTH *et al.* 1972). On the other hand, KRUSCHE and RECK (1982) reported genotype × environment interactions to be of no practical significance in 11 tests in Germany.

Much of the information on genetic variation in Japanese larch is derived from a rangewide provenance trial organized by LANGNER (1961). In 1956, seeds were collected from 25 natural stands, and distributed throughout the world, so that trials could be established over a wide range of environments. In this paper we report on one of these trials established in eastern Canada by Mr. H. G. MACGILLIVRAY, Canadian Forestry Service (retired).

Materials and Methods

Seeds from 20 seed lots of Japanese larch, two seed lots of native tamarack (*Larix laricina* (DU ROI) K. KOCH) and three seed lots of European larch (*L. decidua* MILL.) were sown in unreplicated nursery beds at the Acadia Forest Experiment Station (AFES) near Fredericton, New Brunswick in the spring of 1959. The seedlings were raised as 2 + 1 stock. In May 1962, a provenance test was established at AFES. Pertinent data on these seed sources are presented in *Table 1.*

The field test was established on a fresh, moderately rich site with a 5—8% north slope. The site, which had recently been clear-cut and the logging debris removed, formerly supported an intolerant mixed wood cover. The experimental layout was randomized blocks with 7 × 7-tree square plot design, replicated three times and planted at 3 × 3 m spacing. A single row of tamarack was planted as a surround around each plot, and an additional row was planted around each of the three replications. Observations and measurements were made in the plantation during the period 1963 to 1980.

Table 1. — Provenance data for Japanese larch, tamarack and European larch.

Schmalenbeck no. (MS no.)	Latitude °N	Longitude °E	Elevation m	Temperature mean annual °C	Precipitation mean annual mm
Japanese larch					
Mt. Fuji					
2 (386)	35.4	138.7	1760	5.0	1760
Mt. Azusa					
4 (388)	36.0	138.7	1500	6.5	1360
Yatsuga Mts.					
5 (389)	36.0	138.4	1780	6.1	1550
6 (390)	36.0	138.4	1750	5.4	1480
7 (391)	36.1	138.3	1600	5.1	1430
8 (392)	36.0	138.3	1700	5.4	1700
9 (393)	35.9	138.3	1450	6.8	1560
10 (394)	35.9	138.3	1750	6.1	1330
Akaishi Mts.					
12 (396)	35.4	138.1	2000	4.0	2840
Mt. Nantai					
13 (397)	36.8	139.4	1360	5.5	2250
14 (398)	36.8	139.4	1490	6.8	2470
15 (399)	36.8	139.5	1700	5.3	2590
Mt. Shirane					
16 (400)	36.6	138.5	1750	4.3	1800
Mt. Asama					
17 (401)	36.4	138.5	1900	3.2	1890
18 (402)	36.4	138.6	1420	6.2	1400
19 (403)	36.4	138.5	1700	4.3	1570
Mt. Komaga					
23 (407)	35.8	137.9	1820	3.2	2380
Hida Mts.					
22 (406)	36.4	137.7	1380	5.6	1670
24 (408)	35.9	137.6	1380	6.9	2130
25 (409)	36.1	137.7	1920	3.3	2300
Tamarack					
Prince Edward Is. - (379)	46.3	62.8°W	-	-	-
Adirondack Mt. N.Y. - (380)	44	74.0°W	-	-	-
European larch					
Sudetan Mts., Poland - (381)	50	19	-	-	-
Eastern Alps, Aust. - (382)	48	16	-	-	-
Eastern Alps, Aust. - (383)	47	12	-	-	-

For all observed variables, including rating scores, one-way analyses of variance and mean separation by cluster analysis were performed (SCOTT and KNOTT 1974, GATES and BILBRO 1978). Volume tables are not available for tamarack; however, volume of each tree at the end of the 19th growing season was estimated by using HONER's (1967) equations for black spruce (*Picea mariana* (MILL.) B.S.P.); i.e., $V = D^2/(1.588 + 333.364/H)$, where V, D, and H are the volume (cu ft), diameter (in.), and height (ft), respectively, and then converted to cubic metres.

Estimates of total volume production for each provenance were obtained by multiplying tree volume (V) × total number of trees planted (= 147) × percent survival at the end of the 19th year. Volume production for each provenance is based on a 1323 m² plantation with a spacing of 3 × 3 m, and can be converted to a per hectare basis by multiplying by 7.56.

Correlation coefficients among 23 variables, including five geographic variables, were computed using mean values.

Results

The mean performances for Japanese larch, European larch, and tamarack for 20 observed and derived characters are summarized in *Table 2.* Although provenance variation in the Japanese larch was the main interest in the experiment, the results were also used to compare differences among the three species.

Precocious flowering and cone bearing

In June 1969, current flowering and past cone bearings were recorded in the plantation. In general, tamarack flowered more heavily than either Japanese or European larch, and female flowering was heavier than male flowering *(Table 2).*

Among Japanese larch provenances, there were no significant differences for number of cones up to and including age 7. Significant variation in number of male flowers at age 8 was found and resulted in three different abundance groups or clusters. Differences in the number of female flowers, with the exception of MS 402, were not significant. Provenances MS 386 and 402 produced the most male flowers and MS 402 produced the most female flowers.

Heights

All the sources of variation in height, i.e., replicates (R), combined species and provenances (P) and R × P interactions, at all ages were statistically significant *(Table 2).* At age 4, heights of species and provenances ranged from 0.95 m to 1.52 m with six nonoverlapping groups. European larch was the slowest growing of the three species. Tamarack grew fastest with a mean differential of 17 cm when compared with Japanese larch; however, trees of some Japanese larch provenances were as tall as the tallest tamarack. Among the Japanese larch provenances, five significantly different clusters were found. From ages 4 to 8,

Table 2. — Performance for Japanese larch, European larch and tamarack.

Schmalenbeck Number	MS Number	Cones by age 7 (No.)	Males by age[1] 8 (Scale)[2]	Females by age 8 (Scale)[3]	Height at age 4 (m)	Height at age 8 (m)	Height at age 12 (m)	Height at age 19 (m)	Diameter at age 8 (cm)	Diameter at age 12 (cm)	Diameter at age 19 (cm)	Stem straightness (Score)[4]	Damage by Porcupine (Score)[5]	Damage by Casebearer (Score)[6]	Survival by age 4 (%)[7]	Survival by age 8 (%)[7]	Survival by age 12 (%)[7]	Survival by age 19 (%)[8]	Specific gravity[9]	Volume by age 19 per Tree (m³)	Volume by age 19 per Plantation[11] (m³/ha)	Rank
Larix leptolepis																						
2	386	1.07A[12]	1.31C	1.11A	1.24C	3.69C	7.72C	10.98E	3.53B	9.61A	14.72B	3.21E	3.45C	1.68D	100.0	88.4B	80.3	62.7A	.414A	.094B	65.5	24
4	388	1.03A	1.08B	1.01A	1.30D	4.15E	8.63E	13.56H	4.45D	11.62C	18.02D	3.32E	4.30E	1.57D	100.0	81.6A	76.2	74.7A	.399B	.166D	137.8	5
5	389	1.00A	1.08B	1.05A	1.52F	4.30E	8.71E	13.00G	4.55D	11.65C	16.10C	3.23E	4.29E	1.73D	98.0	86.4B	87.8	84.0B	.390C	.131C	122.3	9
6	390	1.02A	1.10B	1.07A	1.20C	3.90D	7.87D	12.67G	4.06C	10.53B	17.21D	3.06D	3.96D	1.79D	100.0	76.9A	76.2	64.0A	.399B	.148D	105.2	17
7	391	1.04A	1.01A	1.03A	1.29D	4.12E	8.43E	12.09F	4.29D	11.00B	15.76C	3.17D	4.38E	1.45C	100.0	89.8B	87.8	88.0B	.402A	.123C	120.3	11
8	392	1.03A	1.13B	1.07A	1.44E	4.02D	8.10D	12.19F	4.32D	10.90B	16.05C	2.88C	4.38E	1.79D	99.3	83.7B	86.4	90.7B	.405A	.121C	121.9	10
9	393	1.02A	1.09B	1.04A	1.20C	3.71C	7.65C	11.39E	3.58B	10.21B	16.46C	2.76C	3.60D	1.28B	98.0	76.9A	77.6	77.3A	.396B	.125C	107.4	15
10	394	1.04A	1.13B	1.01A	1.22C	3.76C	8.25D	12.14F	3.66B	10.77B	15.67C	2.91C	4.36E	1.81D	100.0	82.3A	77.6	89.3B	.399B	.119C	118.1	12
12	396	1.01A	1.09B	1.02A	1.33D	3.89D	8.11D	12.51G	3.96C	10.92B	16.73C	3.16D	4.66E	1.71D	100.0	72.8A	73.5	82.7B	.385C	.137C	125.9	8
13	397	1.01A	1.03A	1.00A	1.38D	3.84D	7.88D	11.47E	4.04C	10.88B	16.60C	2.72C	3.87D	1.61D	100.0	91.8B	81.6	81.3B	.398B	.127C	114.8	13
14	398	1.00A	1.11B	1.01A	1.26C	3.72C	7.97D	12.32F	3.81B	10.88B	16.91D	2.92C	3.87D	1.70D	100.0	87.1B	79.6	84.0B	.403A	.136C	126.9	7
15	399	1.01A	1.08B	1.06A	1.16C	3.66C	7.98D	11.47E	3.56B	10.52B	17.03D	3.17D	3.80D	1.76D	100.0	78.9A	74.1	72.0A	.409A	.134C	107.2	16
16	400	1.01A	1.06B	1.01A	1.44E	4.22E	8.67E	13.67H	4.88E	12.55D	18.35D	3.37E	4.51E	1.49C	100.0	91.8B	89.8	89.3B	.408A	.170D	168.7	1
17	401	1.00A	1.01A	1.01A	1.42E	4.31E	8.71E	13.30H	5.51E	12.35D	17.29D	3.36E	4.55E	1.53C	100.0	87.8B	87.1	97.3B	.403A	.153D	165.4	2
18	402	1.09A	1.28C	1.23B	1.20C	3.60C	7.56C	11.22E	3.71B	10.34B	15.64C	2.83C	3.83D	1.75D	99.3	81.0A	78.2	80.0B	.402A	.107B	95.1	18
19	403	1.01A	1.08B	1.08A	0.94A	3.03A	6.21A	9.29B	2.77A	8.77A	13.50A	3.03D	4.17E	2.02E	99.3	73.5A	78.2	84.0B	.395B	.073A	68.1	21
22	406	1.00A	1.08B	1.03A	1.22C	3.69C	7.96D	11.82F	3.38B	10.31B	16.00C	3.38E	4.46E	1.63D	100.0	83.0B	83.0	84.0B	.417B	.117C	150.4	14
23	407	1.01A	1.03A	1.02A	1.37D	4.23E	8.74E	12.51G	4.29D	11.18B	17.01D	3.08D	4.61E	1.46C	99.3	90.5B	92.5	96.0B	.394A	.141C	109.2	4
24	408	1.01A	1.01A	1.04A	1.39D	4.08E	8.68E	13.28H	4.37D	12.17D	18.11D	3.02D	4.58E	1.26B	100.0	85.0B	86.4	88.0B	.386C	.161D	157.5	3
25	409	1.04A	1.14B	1.06A	1.51F	4.33E	8.80E	12.57G	4.57D	12.10D	17.34D	3.02D	4.34E	1.88D	99.3	88.4B	87.8	85.3B	.409A	.141C	133.7	6
Species mean		1.02	1.10	1.05	1.30	3.91	8.13	12.17	4.04	10.96	16.53	3.08	4.20	1.65	99.6	83.9	82.1	82.7	.401	.131	120.4	-
Larix decidua																						
	381	1.02A	1.02A	1.02A	1.10B	3.43B	6.99B	9.05B	3.38B	8.95A	13.99B	2.20A	1.92A	1.00A	100.0	70.1A	82.3	65.3A	.399	.074A	53.7	25
	382	1.00A	1.02A	1.02A	1.02A	3.21A	6.82B	8.16A	3.02A	8.78A	14.78B	2.59B	2.57B	7.17E	100.0	81.6A	82.3	65.3A	.391	.094B	68.2	20
	383	1.01A	1.01A	1.01A	1.00A	3.20A	6.85B	8.73B	3.10A	8.95A	14.20B	2.62B	2.82B	1.18B	100.0	84.4B	88.4	81.3B	.401	.075A	67.7	22
Species mean		1.01	1.02	1.02	1.04	3.28	6.88	8.65	3.17	8.89	14.32	2.47	2.43	1.45	100.0	78.7	84.4	70.7	.397	.081	63.7	-
Larix laricina																						
	379	1.60B	1.57D	2.50C	1.44E	3.85D	7.11B	9.75C	3.43B	8.30A	13.02A	2.48B	3.38C	1.52C	100.0	90.5B	93.9	88.0B	.411	.069A	67.5	23
	380	1.55B	1.47D	2.79D	1.51F	4.13E	7.72C	10.61D	3.56B	8.91A	12.81A	2.85C	3.69D	1.62D	100.0	90.5B	90.5	90.7B	.410	.070A	70.5	19
Species mean		1.58	1.52	2.65	1.47	4.00	7.42	10.18	3.49	8.60	12.91	2.67	3.54	1.57	100.0	90.5	92.2	89.3	.411	.070	69.3	-
Overall mean		1.07	1.12	1.17	1.29	3.84	7.92	11.59	3.89	10.53	5.97	2.97	3.93	1.62	99.7	83.88	83.26	81.8	.401	.121	110.0	-
Significant clusters		2	4	4	6	5	5	8	5	4	4	5	5	5	0	2	0	2	-	4	-	-
Range: from		1.00	1.01	1.00	0.95	3.03	6.21	8.16	2.77	8.30	12.81	2.20	1.92	1.00	98.0	70.07	73.47	62.67	.385	.069	53.7	-
to		1.60	1.57	2.79	1.52	4.33	8.80	13.67	5.11	12.55	18.35	3.38	4.66	2.17	100.0	91.84	93.88	97.33	.417	.170	168.7	-

1 All ages from planting.
2 Number in scale: 1 = 0, 2 = 1-25.
3 Number in scale: 1= 0, 2 = 1-50, 3 = 51-100, and 4 = 100+.
4 1 = very crooked, 3 = average, and 4 = straight.
5 1 = severe damage (dead), and 5 = no damage.
6 1 = little defoliation and 3 = heavy defoliation.
7 Based on 147 trees.
8 Based on 75 trees.
9 From Loo *et al.* (1981).
10 Based on Honer's (1967) black spruce volume calculation.
11 Per tree volume × percent survival.
12 Mean separation by cluster analysis [Gates and Bilbro (1978)]; means with different letters belong to different clusters.

overall plantation height increased from 1.3 to 3.8 m. The means of the combined species and provenances at age 8 ranged from 3.0 to 4.3 m. The rankings in mean performance of species were the same as at age 4: tamarack was the tallest, followed by Japanese and European larches. However, the height advantage of tamarack over Japanese larch was only 10 cm after 8 years from planting and Japanese larch of several provenances was taller than tamarack. Japanese larch was highly variable as indicated by four different clusters.

At age 12, the rankings of species changed. The mean of Japanese larch exceeded that of tamarack by 71 cm (9.6%) and that of European larch by 125 cm (18.2%). Mean for all seed sources and species ranged from 6.2 to 8.8 m with a plantation mean of 7.9 m. Five different clusters were found when all the seed sources were considered. With the exception of MS 403, which was the slowest growing seed source, Japanese larch of all provenances performed as well as or better than European larch and tamarack provenances.

By age 19, height superiority of the Japanese larch was well established in that they had a 19.5% height advantage over tamarack, and an even greater advantage over European larch (46.8%). Mean for all seed sources ranged from 8.2 to 13.7 m with an overall mean of 11.6 m. Again, variability among the Japanese larch provenances was exhibited by five significant clusters. With the exception of MS 403, the Japanese larch provenances were taller than any of the tamarack or European larch provenances. The species difference in height was clearly demonstrated by exclusiveness of the clusters.

Provenance differences among the Japanese larch are evident for heights at any age. An unusually slow-growing provenance (MS 403) was shorter than European larch until age 12. In addition, performances of the two tamarack populations are consistently different. Similarly, MS 381 (Sudeten Mts.) is different from the other two European larch populations (Alps).

Diameters

Replicates, species and provenances, and the interactions were significant sources of variation at 8, 12, and 19 years from planting. At age 8, mean diameter ranged from 2.8 to 5.1 cm with five distinct clusters *(Table 2)*. Japanese larch provenances were represented in all five clusters indicating large provenance variation. On average, Japanese larch ranked first in diameter growth, followed by tamarack and European larch, respectively. Twelve of the 20 Japanese larch provenances had greater mean diameter than any of the tamarack or European larch provenances.

At age 12, the superiority of Japanese larch in respect to diameter growth was maintained. Changes, although not significant, occurred in ranking between tamarack and European larch. The means for all species and provenances ranged from 8.3 to 12.6 cm with a plantation mean of 10.5 and five significant clusters. By age 19, Japanese larch of all provenances were larger in diameter than tamarack and except for MS 386 and 403 all were larger than European larch. Differences in diameter between tamarack and European larch were clearly evident as the species fell into different clusters. The plantation mean was 16.0 cm with provenance means ranging from 12.8 to 18.4 cm.

Stem straightness

Average rating scores for the species and provenances ranged from 2.20 to 3.38 with a plantation average of 2.97 *(Table 2)*. In general, Japanese larch was straighter than either tamarack or European larch. Provenance variation within the Japanese larch was confined to the three upper clusters. Of the Japanese larch 13 of the 20 provenances exhibited above-average stem straightness, i.e., average score greater than 3.0.

Damaging agents

The plantation was damaged by porcupines *(Erethizon dorsatum* L.) and larch casebearer *(Coleophora laricella* (HBN)).

Damage by porcupine often resulted in mortality. The damage was rated in 1980 and included damage occurring up to that time. Mean rating scores for provenances and species ranged from 1.92 to 4.66 with a plantation mean of 3.93 and five clusters *(Table 2)*. Japanese larch was the least damaged ($\bar{x}$ = 4.20), followed by tamarack ($\bar{x}$ = 3.54). European larch was clearly most susceptible to porcupine damage as the three provenances tested fell exclusively into the two lowest clusters. The rating within Japanese larch ranged from 3.45 to 4.66, and except for MS 386 the variability was characterized by two significant clusters.

Larch casebearer populations were high in the test plantation in 1979 and 1980. Average rating for provenances and species in 1980 ranged from 1.00 and 2.17 with a plantation average of 1.62 and five significant clusters, indicating considerable variation *(Table 2)*. Japanese larch was more susceptible than the other species; however the differences were not clear, because of the high variability within each species.

Survival

Differences in survival of species and provenances were significant at ages 8 and 19 but not at ages 4 and 12 *(Table 2)*. For ages 8 and 19 the differences were categorized into two clusters. At age 8, mean survival ranged from 70.1 to 91.8% with a plantation mean of 83.8%. At age 19, based on 25 trees per plot, mean survival ranged from 62.7 to 97.3% with a plantation mean of 81.8%. Tamarack had better survival than either other species; however, 13 of the 20 Japanese larch provenances had greater than 80% survival, to age 19.

Volume

Mean volume per tree ranged from 0.069 to 0.170 m^3 with a plantation mean of 0.121 m^3 and four significant clusters *(Table 2)*. With the exception of MS 403, Japanese larch had greater volume than either tamarack or European larch. Total volume production for seed sources per hectare ranged from 53.7 to 168.7 m^3, with a plantation mean of 110.0 m^3. Despite the poorer survival of Japanese larch compared to tamarack, the volume production per unit area of Japanese larch was about 74% greater than that of tamarack and 89% greater than European larch.

Relationship among geographic and phenotypic variables

None of the geographic variables, i.e., latitude, longitude, altitude, and mean annual temperature and precipitation, had any significant relationship with phenotypic variables (Table of correlation coefficients is available from the authors). Sixty-two out of 253 possible correlations were statistically significant at the 5% probability level. The variables relating flowering, i.e., number of cones and male and female flowers, had strong correlations among themselves, and they were inversely correlated with diameter at later ages. Heights at different ages were highly correlated, as were correlations among diameters at different ages. Except for the non-significant correlation between height at age 4 and diameter age 19, all possible correlations between

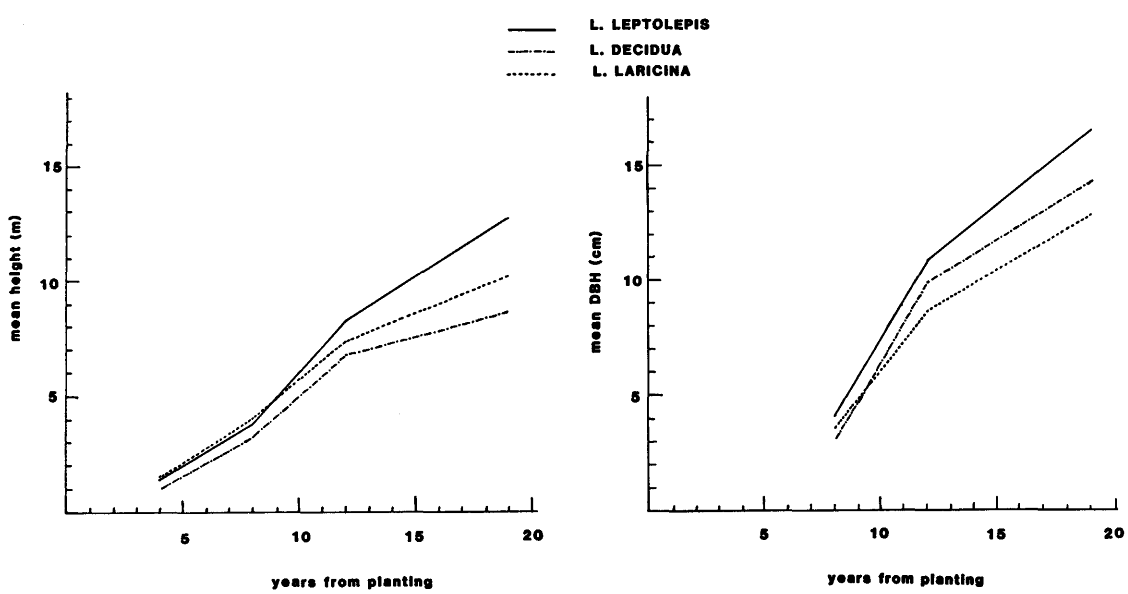

Fig. 1. — Mean height and diameter (DBH) increments of three species of *Larix* at ages up to 19 year in New Brunswick, Canada.

Table 3. — Rankings and regression coefficients for height and diameter (DBH) at different ages.

Provenance Number MS	Rank of height at age 4	8	12	19	Change in rank[1]	Regression for height growth[2]	Rank of DBH at age 8	12	19	Change in rank	Regression for diameter growth
386	8	5	4	2	0	0.901	3	2	2	0	0.895
388	11	15	14	19	1	1.122*	16	15	18	0	1.084
389	20	18	17	16	0	1.055*	17	16	8	1	0.929
390	4	11	5	15	3	1.043	11	7	15	1	1.048
391	10	14	13	8	1	0.994	12	13	5	1	0.920
392	18	12	10	10	1	0.987	14	11	7	1	0.940
393	5	6	3	4	0	0.936*	5	3	9	1	1.028
394	7	8	12	9	0	1.012	6	8	4	0	0.964
396	12	10	11	12	0	1.027	9	12	11	0	1.021
397	14	9	6	6	1	0.931*	10	9	10	0	1.005
398	9	7	8	11	0	1.018	8	10	12	0	1.048
399	2	3	9	5	1	0.956	4	6	14	1	1.076
400	17	16	15	20	1	1.119	19	20	20	0	1.080
401	16	19	18	18	0	1.087*	20	19	16	0	0.945
402	3	2	2	3	0	0.924*	7	5	3	0	0.955*
403	1	1	1	1	0	0.766*	1	1	1	0	0.859*
406	6	4	7	7	0	0.980	2	4	6	0	1.010
407	13	17	19	13	1	1.028	13	14	13	0	1.018
408	15	13	16	17	0	1.095*	15	18	19	0	1.101
409	19	20	20	14	1	1.022	18	17	17	0	1.025

1 Number of change in ranking of more than 5 ranks.
2 Regression of provenance means on overall means of the respective ages.
* Significant at 0.05 for testing $H_0 : \beta = 1$ vs $H_1 : \beta \# 1$.

heights and diameters were highly significant. Stem straightness was highly correlated with heights and diameters at ages 8, 12, and 19. Porcupine damage was also highly correlated with heights and diameters at all ages. Correlation between stem straightness and porcupine damage was highly significant. Survival at ages 8, 12, and 19 was highly correlated. Several significant correlations were found between survival with heights and diameters at different ages. Larch casebearer infestation, survival at age 4, and specific gravity, except for an unexplainable correlation between specific gravity and male flowers, were not correlated with any other characters.

Discussion

The general performance of Japanese larch compares favorably with that of tamarack and European larch *(Fig. 1)*. Early height advantage of tamarack over Japanese larch diminished after age 8. Japanese larch was taller than either tamarack or European larch after age 12. Diameter growth of Japanese larch exceeded that of the other two species at all ages. European larch was the slowest growing species in height but exceeded tamarack in diameter growth after age 8.

Of the 20 characters examined for Japanese larch, 17 were highly variable at the provenance level. The variability, however, was not associated with geographic variables at the seed origin. Such lack of correlations both among characters and locations concurs with results reported elsewhere (Langner 1961, Farnsworth *et al.* 1972, Genys 1971). As expected, there were significant correlations among heights and diameters at different ages, as well as between heights and diameters at the same age. Despite these correlations, ranking of provenances at different ages changed considerably indicating different rates of growth. For height, about one-half (9) of the provenances fell behind or jumped ahead at least once by five or more ranks, while similar changes in diameter ranking occurred with six provenances *(Table 3)*.

Relative growth rates over a 19-year period were estimated by regression analysis. The means of a provenances at the different ages were regressed on the mean of all provenances at the respective ages. Since the abscissa is the means of all provenances at the different ages, the overall regression coefficient is expected to be 1.0. It follows that a provenance whose regression coefficient is lower or higher than 1.0 is interpreted as having below-or above-average growth rate, respectively. The regression coefficients for height ranged from 0.766 to 1.122, with 11 greater than 1.0. Regression coefficients for diameter ranged from 0.859 to 1.101, and 12 were greater than 1.0. These regression coefficients are relative as the X-variables were calculated from means of all provenances. The regression coefficient for height relates closely to the rankings of 19-year heights ($r = 0.93$); however, those for diameter do not necessarily correspond with rankings of 19-year diameter. If the trend continues, the regression coefficients could serve as a long-term predictor of growth.

The significant correlation between stem straightness and both height and diameter indicates straightness may be indirectly selected for, while practicing selection for height and diameter. Porcupine damage is positively related to height, diameter, and stem straightness.

Significant differences among replicates and replicate × provenance interactions suggest a strong environmental influence due to microsite differences within the plantation. It may be implied that Japanese larch is exacting in its site requirements. Provenance × location interactions are also large (as reported elsewhere Farnsworth *et al.* 1972, and many others), and therefore, the present results should be used cautiously in making broad recommendations.

Interpretation of the geographic variation pattern in Japanese larch is rather nebulous because of the lack of correspondence between the performance characteristics and environmental variables of the provenances. Neither ecotypic or clinal variation has been established. Farnsworth *et al.* (1972) and Hattemer (1969) discussed some regional trends among provenances; however, the present results are not consistent with their findings. Farnsworth *et al.* (1972) ascribed most of the variation in Japanese larch to genetic drift. Many of the subpopulations are small (Wright 1962), and, at the extreme of the species range, these populations are isolated, dwarfed, and may be lost (Toda and Mikami 1976). Our findings support the suggestion that random genetic drift has played an important role in the development of genetic variation in Japanese larch.

In general, the potential of Japanese larch in eastern North America is high. It is an attractive species for short rotation fiber production because of its rapid growth and productivity. Although specific gravity of Japanese larch is slighly lower than tamarack (Loo *et al.* 1982), the difference is negligible considering the superiority of Japanese larch in volume production. Based on volume production per unit area which is based in turn on height, diameter, and survival, provenances, MS 400 (Mt. Shirane), 401 (Mt. Asama), 407 (Mt. Komaga), 406 (Hida Mts.), and 388 (Mt. Azusa) performed best in central New Brunswick. These are the five most productive provenances with an average volume of 156 m^3/ha at age 19, and 29.6% higher than the average of all the Japanese larch provenances, and more than double that of tamarack.

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Studies of variation in Central American Pines V: a numerical study of variation in the Pseudostrobus group

By J. W. Stead[1])

Commonwealth Forestry Institute, Oxford, England

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Summary

A study of the variation and taxonomy of the *Pseudostrobus* group (*sensu* Martínez) has been carried out at the Commonwealth Forestry Institute, Oxford.

The approach adopted in the investigation was to make site collections of approximately 25 trees each throughout the ranges of the taxa involved, to assess morphological and micromorphological characters of needles and cones on the material collected, and to submit the resulting data to numerical analysis . Principal components analysis was used to reveal patterns of variation in the data and to suggest possible taxonomic groupings. Canonical Discriminant Analysis was used to examine the relationships between the resulting groups, to suggest the best ways of discriminating between them and to measure the success with which groups had been formed. Individual collections made throughout the range, and taken on loan from various herbaria, were used to augment the coverage of the site collections.

It was confirmed that the *Pseudostrobus* group is composed of three species only. *Pinus pseudostrobus* Lindl. was found to be a very variable species with two identifiable infraspecific taxa. *P. tenuifolia* Benth. and *P. douglasiana* Martínez are relatively homogeneous species, more closely related to each other than to *P. pseudostrobus.* The character of hypodermal intrusions, found in the internal needle anatomy, was confirmed to be the most reliable for distinguishing *P. tenuifolia* and *P. douglasiana* from *P. pseudostrobus.*

On the basis of this morphological study a revised classification is proposed. The *Pseudostrobus* group now contains three species *P. pseudostrobus, P. maximinoi* H. E. Moore (the correct name for *P. tenuifolia)* and *P. douglasiana. P. pseudostrobus* has two infraspecific taxa *P. pseudostrobus* subsp. *apulcensis* (Lindl.) Stead and *P. pseudostrobus* var. *oaxacana* (Mirov) Harrison. Details of the taxonomic background and conclusions will be given in a subsequent paper.

Key words: Pinus pseudostrobus, Pinus tenuifolia, Pinus maximinoi, Pinus douglasiana, numerical taxonomy.

Zusammenfassung

Am Commonwealth Forestry Institute in Oxford wurde eine Untersuchung zur Variation und zur Taxonomie der *Pseudostrobus*-Gruppe bei *Pinus* (sensu Martínez durchgeführt.

[1]) NTB2, Shell Centre, London, England.