GEOGRAPHIC VARIATION IN JAPANESE LARCH-- RESULTS OF A 9-YEAR STUDY IN NORTH CENTRAL UNITED STATES

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ABSTRACT

GEOGRAPHIC VARIATION IN JAPANESE LARCH--
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UNITED STATES

by Dan Henry Farnsworth

A replicated, 7-origin provenance test of Japanese larch, *Larix leptolepis*, was planted in 1958 in the Michigan State University nursery. A second replicated test including those 7 and 15 additional origins was planted in 1959. Seventeen plantations were established in five north central states in 1960 and 1961 using a randomized complete block design with 5 to 12 replicates. An analysis of variance was used to determine if differences occurred among origins, and simple correlations were used to relate characters to each other and to the parental environment.

One source each of *Larix decidua*, *L. gmelini*, and *L. laricina* were included with the 7-origin test. *L. decidua* grew as fast as *L. leptolepis*, *L. laricina* grew slower, and *L. gmelini* grew even slower. *L. laricina* was much more frost hardy than *L. leptolepis*.

Japanese larch can grow in north central United States on sites with well-drained loam soils, light weed competition, and freedom from growing-season frosts.

On such sites growth rate was rapid, height averaging 4.1 meters at age 10. However, growth was poor if these conditions were not met.

There was no geographic variation pattern in height, time of leaf growth, or flower production. A geographic variation pattern existed in spring frost resistance and in preparation for winter dormancy. Preparation for winter dormancy was measured as the date when buds were set, leaves changed color, and the amount of injury resulting from early fall frosts and winter temperatures. The order in which sources prepared for winter dormancy was similar in North Central United States plantations. Small differences in foliage color occurred among sources during the growing season in the nursery, but the differences in the 1958 sowing were not duplicated in the 1959 sowing.

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A THESIS

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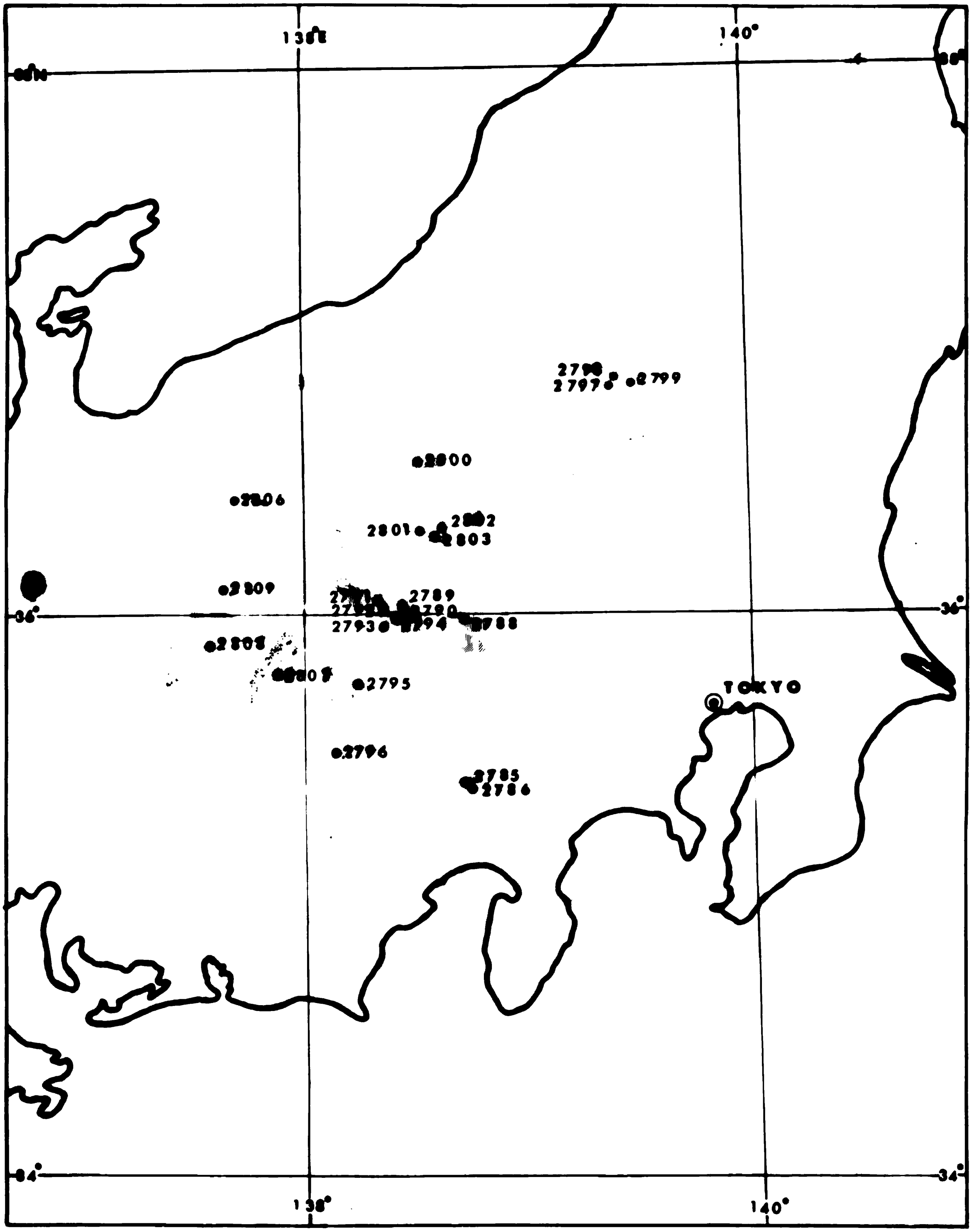
INTRODUCTION

Japanese larch, *Larix leptolepis* (Sieb. and Zucc.) Gord. is an important forest species. In Japan it constituted 28 percent of the planting stock from 1952 to 1954 (Anon., 1957). It is also important as an exotic in England (6 percent of the conifers planted) and other nothern European countries (MacDonald *et al.*, 1957; Wright, 1963). Larch are seldom planted in the United States. The state of New York plants the most; four percent of its planting stock is larch, mostly Japanese (Eliason, 1965).

More foresters, particularly in northeastern United States, are becoming interested in Japanese larch principly because of rapid juvenile growth. Tests by Cook (1948) showed that it outgrew five other conifers in New York. Chandler (1967) found that Japanese larch outgrew European larch (*Larix decidua* Mill), Tamarack (*L. laricina* Duroi, K. Koch), and Western larch (*L. occidentalis* Nutt.). Japanese larch has been planted only in arboretums and test plantations in north central United States.

The natural range of Japanese larch is about 200 km. square on the central portion of the Japanese island of Honshu (Figure 1). There it is found on mountains at

Figure 1. Map of the central portion of Honshu Island, Japan showing the range of Japanese larch and location of seed sources used in this experiment.


140°
2797
2799
2800
2806
2801
2802
2803
2809
2789
2793
2788
2795
TOKYO
2796
2785
2786
36°
34°
138°
140°

elevations from 900 to 2,500 meters. It usually grows interspersed among other species or in pure stands where the original vegetation has been destroyed through land slippage or fire.

The most characteristic features of Japanese larch are its light, green, flattened leaves with two white bands below, cones ranging from 1.5 to 3.5 cm. with recurved tips, and reddish brown branchlets. It grows to a maximum height of 35 m. and a maximum diameter of 1.5 m.

European larch, tamarack, *L. gmelini* Rupr., and Japanese larch were present in the 1960 test plantations. Tamarack could be identified by its light brown branchlets, small cones about 1.5 cm. long with 12 to 15 lustrous, concave cone scales. European larch was easy to distinguish because of its dark green foliage and dull cones with straight scales. The distinguishing characteristics of *L. gmelini* were its slow growth and lustrous cones with straight scales.

In the native range of Japanese larch, mean annual precipitation ranges from 1330 to 2840 mm. and the mean annual temperature ranges from 3.2° to 6.5°C. In the United States equivalent temperatures would be found in Philadelphia, Pennsylvania and similar amounts of precipitation would be found on the Olympia Peninsula in Washington.

Japanese larch is a very intolerant tree which attains its best growth on moderately drained, limestone soils (Anon., 1957). Aird and Stone (1953) found that survival and growth were very poor on dry or poorly drained sites.

Japanese larch is an excellent source of poles and pilings because its wood is very strong, dense, hard, and decay resistant, but it is not quite as desirable for lumber due to its tendency to split when nailed. It is as satisfactory as Douglas-Fir for pulp production.

Genetics of larch.--European larch is the only larch species in which substantial provenance tests have been conducted. The Japanese larch provenance tests conducted before Langner's test have been small and unreplicated.

The major range wide provenance test is the 1944 IUFRO European larch provenance study. The sources are 51 European larch, 2 Siberian larch, 1 Japanese larch, and 1 European x Japanese larch hybrid. Seventeen plantations were established in 9 countries. The major drawback of this test is that the plantations lacked replication.

Genys (1960) reported results from two plantations growing in the United States, one in New Hampshire, and one in New York. He found that Polish, Sudeten, and Slovakian origins grew the fastest; low elevation sources from Austria had a medium growth rate; and high alpine sources grew the slowest with the best form. The Japanese larch source and the European x Japanese larch source grew as well as or better than the best European larch.

Schober (1958) summarized the results of six 1944 IUFRO plantations and nine other species and provenance trials of European larch in Europe. He concluded that Japanese larch and Polish, Sudeten, and Slovakian sources of European larch grew the fastest. Also Japanese larch was resistant to larch canker, Dasyscypha willkommii (Hartig) Rehm.

Another range-wide European larch provenance test was initiated in 1958 by Schober to substantiate the findings of previous tests. This test includes 69 provenances most of which are European larch, but also includes a few Japanese and European x Japanese larch hybrids. Also progenies from a total of 264 individual trees in 29 localities will be tested separately. Twenty plantations are located in 9 countries in northern Europe, and North and South America. Two plantations are located near Ann Arbor, Michigan.

Early results from a German nursery show that European larch provenances from Slovakia and Sudeten are the tallest, and that high alpine sources are the shortest (Schober, 1961).

Plus tree selection does not hold much promise in improving larch. Matthews (1960) conducted a diallele cross of nine Japanese larch and three European larch clones. The progenies from selfed plants expressed strong inbreeding depression, the heritability was low, and the interspecies hybrids were much superior to either parent.

Hybridization appears to be the most promising method of improving Japanese larch. The following hybrids have been made (Wright, 1963):

1. Natural hybrids occurring where ranges overlap
   - *L. lyallii* x *L. occidentalis*
   - *L. potaninii* x *L. mastersiana*
   - *L. gmelini* x *L. sibirica*.
2. Natural hybrids from cultivated plants
   - *L. decidua* x *L. leptolepis*
   - *L. leptolepis* x *L. sibirica*
   - *L. laricina* x *L. decidua*.
3. Artificial hybrids
   - *L. decidua* x *L. occidentalis*
   - *L. decidua* x *L. leptolepis*
   - *L. decidua* x *L. gmelini*
   - *L. decidua* x *L. sibirica*
   - *L. leptolepis* x *L. gmelini*.

The other combinations have not been tried.

The most promising hybrids are those produced by crossing Japanese and European larch. These are the parents of the famed Dunkeld larch (*L. decidua* x *L. leptolepis*). Hybrids involving Japanese and European larch have been produced by 27 different individuals. The hybrids of Japanese and European larch always perform better than the parent species.

OBJECTIVES

The objectives of this experiment are as follows:

1. Determine where Japanese larch will grow in north central United States.
2. Determine the amount of genetic variability in growth characters.
3. Determine possible relations of those characters to the parental habitats.
4. Determine the relationship of these characters to each other.
5. Determine if the same results are obtained when the same materials are planted in different locations and in different years.

MATERIALS AND METHODS

Seed procurement.--The Japanese Forest Service procured seed for Dr. Wolfgang Langner at the Institute of Forest Genetics, Schmalenbeck, Germany. The seeds were collected from 10 or more trees in each of 25 native stands (Figure 1, Table 1). Two sets of seed were received by Michigan State University. The first consisted of 7 origins shipped directly from Japan. The second shipment of 22 sources, including the original 7, was received from Germany through State University of New York, College of Forestry.

Nursery methods.--The 7-origin test was sown in the Michigan State University nursery May 2, 1958, and the 22-origin test was sown May 14, 1959.

The nursery experimental design consisted of five randomized replicates in the 1958 sowing and 4 randomized replicates in the 1959 sowing. Plots within the replicates consisted of 124 cm.-long rows apced 15 cm. apart. The remaining seed of each origin was sown in a large rectangular block with the blocks being separated by 50-cm. strips.

The trees received intensive nursery care. They were kept weed free by hand weeding and watered as needed. The average height of the 2-0 stock was 45 cm. The trees in the large rectangular blocks in the 1958 sowing were not

Table 1.--Location, climate, and characteritics of the 22 parental stands of *Larix leptolepis*.[a]

Schmalenbeck No. (MSFG No.)	North Lat. (degrees)	East Long. (degrees)	Elev. (meters)	Mean annual temp. (°C.)	Mean annual prec. (mm.)	Age (yrs.)	Ht. (m.)	Diam. (cm.)
Mt. Fuji								
2785(111)	35.4	138.7	1320	6.2	1820	75	17	39
2786(112	35.4	138.7	1760	5.0	1760	75	19	34
Mt. Azusa								
2788(3, 114)	36.0	138.7	1500	6.5	1360	40	16	27
Yatsu-ga Mountain Range								
2789(115)	36.0	138.4	1780	6.1	1550	75	19	41
2790(116)	36.0	138.4	1750	5.4	1480	70	21	42
2791(117)	36.1	138.3	1600	5.1	1430	--	23	42
2792(118)	36.0	138.3	1700	5.4	1700	60	20	35
2793(4, 119)	35.9	138.3	1450	6.8	1560	55	20	42
2794(120)	35.9	138.3	1750	6.1	1330	55	21	36
Akaishi Mountain Range								
2795(121)	35.8	138.2	1500	6.5	1720	65	18	31
2796(5, 122)	35.4	138.1	2000	4.0	2840	130	20	41
Mt. Nantai								
2797(123)	36.8	139.4	1360	5.5	2250	60	20	44
2798(124)	36.8	139.4	1490	6.8	2470	60	27	57
2799(1, 125)	36.8	139.5	1700	5.3	2590	65	15	42

Table 1.--Continued.

Schmalenbeck No. (MSFG No.)	North Lat. (degrees)	East Long. (degrees)	Elev. (meters)	Mean annual temp. (°C.)	Mean annual prec. (mm.)	Age (yrs.)	Ht. (m.)	Diam. (cm.)
Mt. Shirane								
2800(2,126)	36.6	138.5	1750	4.3	1800	70	21	46
Mt. Asama								
2801(127)	36.4	138.5	1900	3.2	1890	70	14	35
2802(128)	36.4	138.6	1420	6.2	1400	60	23	39
2803(129)	36.4	138.5	1700	4.3	1570	50	13	29
Mt. Koma-ga								
2807(133)	35.8	137.9	1820	3.2	2380	120	28	54
Hida Mountain Range								
2806(6, 132)	36.4	137.7	1380	5.6	1670	50	12	25
2808(7, 134)	35.9	137.6	1380	6.9	2130	60	27	79
2809(135)	36.1	137.7	1920	3.3	2300	120	19	50

[a]Additional seedlots included in some test plantations were MSFG 8 (L. decidua), MSFG 9 (L. gmelini), MSFG 10 (L. leptolepis) collected from Morton Arboretum, Lisle, Illinois; and MSFG 11 (L. laricina) collected from a native stand near Rhinelander, Wisconsin.

as good planting stock as the 1959 material due to the effects of overcrowded beds.

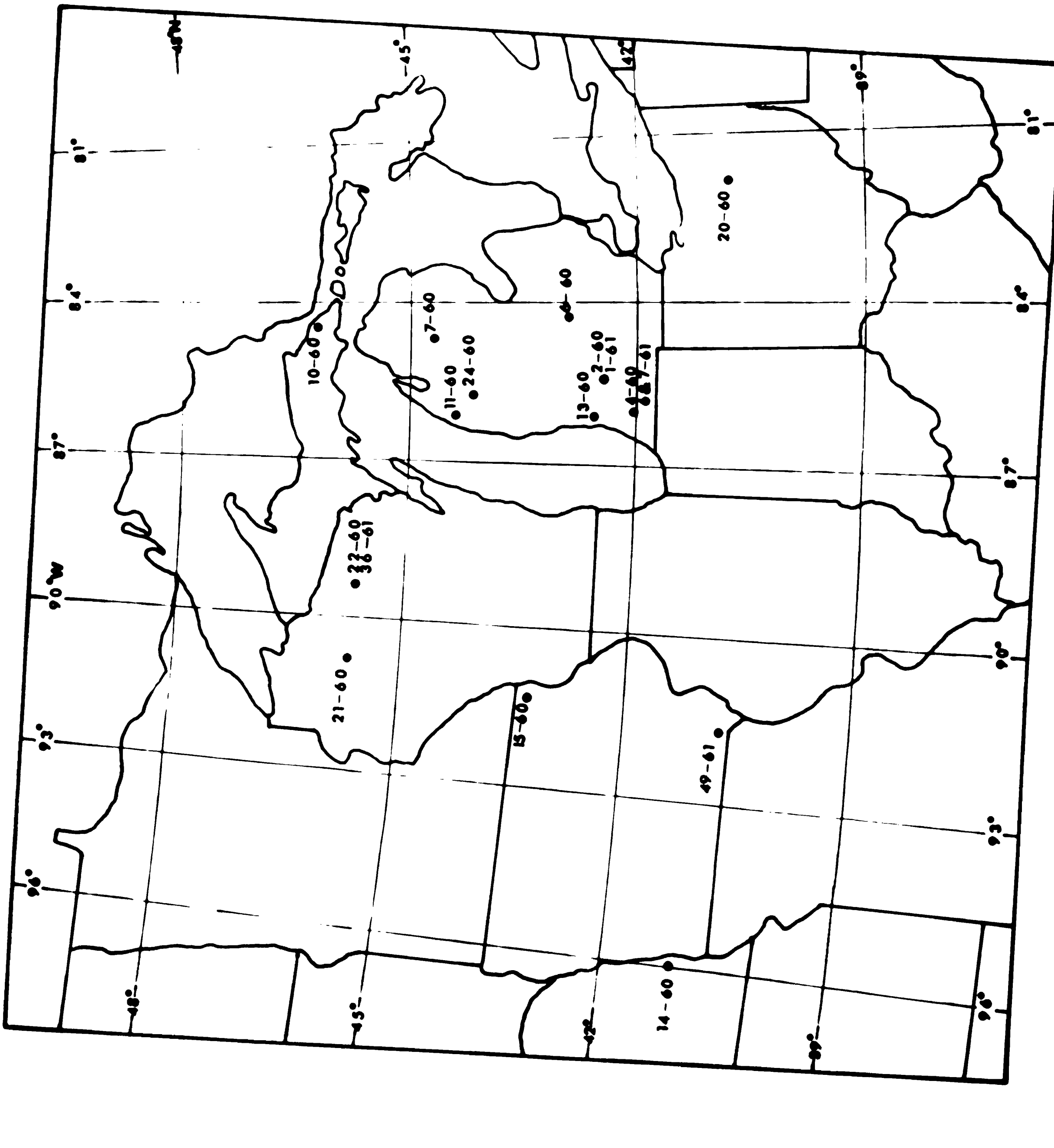
The 22 origins included in the 1959 sowing were also grown near Hamburg, Germany, in a design similar to the one used in Michigan. Growth data for those trees, as published by Langner and Stern (1965), have been used where necessary in this paper. I have also used nursery and plantation data for 20 origins identical with mine as tested in New York (Stairs, 1965).

Plantation establishment.--The 7-origin test was outplanted in 1960, and the 22-origin test in 1961. 2-0 seedlings were used in both studies. The trees which died the first year were replaced with 3-0 stock in Michigan, while 2-1 transplants were planted by the out-of-state co-operators. Plantations were established throughout north central United States (Figure 2, Table 2).

The plantation design was a randomized complete block with each plantation consisting of 5 to 12 replicates of 4-tree plots. The trees were planted using a 2.44 meter spacing. Border rows were planted on all sides of the plantation.

Plantation care was not very intensive. In most plantations, trees were planted in furrows and then left to grow. Intensive care occurred at the following plantations: (1) at Russ trees bent by snow were straightened, (2) 2,4,5-T was applied to control brush at 2-60 Kellogg

Figure 2. Map of north central United States showing the location of the test plantations used in this experiment.



45°
42°
39°
81°
84°
87°
90°W
93°
96°
90°
20-60
6-60
7-60
10-60
2-60
1-61
24-60
11-60
13-60
32-60
36-61
21-60
15-60
49-61
14-60

Table 2.--Location and mortality of Japanese larch test plantations.

Plantation number and year of establishment		Name	County, State	Percent mortality in 1961 or 1962	Percent mortality in 1967
10	1960	Dunbar Forest	Chippewa, Michigan	11	49
7	1960	Higgins Lake	Crawford, Michigan	23	90
11	1960	Manistee	Manistee, Michigan	4	8
24	1960	Wexford	Wexford, Michigan	--	94
13	1960	Allegan	Allegan, Michigan	23	90
6	1960	Rose Lake	Shiawassee, Michigan	34	47
2	1960	Kellogg Forest	Kalamazoo, Michigan	48	62
1	1961	Kellogg Forest	Kalamazoo, Michigan	12	26
4	1960	Russ Forest	Cass, Michigan	38	63
6	1961	Russ Forest	Cass, Michigan	55	74
7	1961	Russ Forest	Cass, Michigan	24	40
21	1960	Flambeau	Sawyer, Wisconsin	48	90
22	1960	Oneida	Oneida, Wisconsin	17	42
36	1961	Oneida	Oneida, Wisconsin	10	66
15	1960	Paint Creek	Allamakee, Iowa	8	16
49	1961	Soaper Creek	Davis, Iowa	30	30
20	1960	Ohio	Wayne, Ohio	48	50
14	1960	Nebraska	Cass, Nebraska	38	--

(3) Amitrol-T was applied for weed control at 1-61 Kellogg and 6-61 and 7-61 Russ, (4) at Rose Lake 3 oz. of an equal mixture of 40 percent urea and 5-20-20 fertilizer was applied around each tree plus rototilling was done around each tree.

Measurement methods.--I measured the southern Michigan plantations in 1966, 1967, and 1968. Dr. Wright and Michigan State staff made the previous measurements. The plantations outside of Michigan were measured by N.C.-51 co-operators in those states. The Kellogg, Russ, and Rose Lake plantations were measured much more intensely due to their proximity to the university.

Metric traits were measured as the means of 4-tree plots. Presence-absence traits were measured as the number of occurrences per plot. Leaf color change and leaf fall was measured as the percent of the needles remaining on the tree that had changed color plus the percent of fallen needles.

Statistical methods.--I used plot means as items when calculating analysis of variance, for which the degrees of freedom and expected mean squares are as follows:

Source of variance	Degree of freedom	Expected mean squares
Source	S-1	$\sigma^2 + R\sigma^2_{sxp} + RP\sigma^2_s$
Plantation	P-1	$\sigma^2 + R\sigma^2_{sxp} + RS\sigma^2_p$
Source x plantation	(S-1)(P-1)	$\sigma^2 + R\sigma^2_{sxp}$
Replicate (within plantation)	(R-1)(P)	$\sigma^2 + S\sigma^2_{r(p)}$
Source x replicate (within plantation)	(S-1)(R-1)(P)	σ^2
Total	SXPXR-1	

I used the source x plantation mean square to test significance of the source mean square.

Six mountains were represented by two or more sources and were tested for between-mountain differences. I used the within-mountain mean square to test significance of differences among mountains. Degrees of freedom and expected mean squares were as follows:

Source of variation	Degrees of freedom	Expected mean squares
Sources	18	
Between mountains	5	$\sigma^2_e + R\sigma^2_{pxs} + R\sigma^2_w + RW\sigma^2_b$
Within mountains	13	$\sigma^2_e + R\sigma^2_{pxs} + R\sigma^2_w$

I used simple correlations or rank correlations when so specified to test whether characters were related to each other and to factors of the parental environment. Seedlot means were used as items.

PERFORMANCE IN NORTH CENTRAL UNITED STATES

Mortality.--The site requirements of Japanese larch must be closely met or high mortality will result. Those plantations planted on sites with sandy loam to clay loam soils, with light weed competition, and mild frost damage had low mortality, but mortality rapidly increased whenever even one of these conditions was not met (Table 2).

Mortality in the 1960 plantations was sometimes high because of the use of spindly stock grown in dense stands in the nursery. Less mortality was obtained in an European larch plantation than in the Japanese larch plantations using 1-1 stock instead of 2-0 stock. At Rose Lake the stock dried out and some dead trees were planted. Mortality was almost total in plantations on sites with sandy soils, heavy weed competition, and repeated frosts, or a combination of these factors. At Dunbar, 89 percent of the Japanese larch died which were planted on a poorly drained site and suffered a secondary canker attack by Valsa sp. Woodchucks caused much mortality in Ohio by nipping off the tree stems.

Sites which would be suitable to plant to pine are not always suitable for planting to Japanese larch. Scotch pine planted near the Japanese larch plantations at Allegan and Higgins Lake have survived and grown well while most of the Japanese larch have died. The climax vegetation of a site may predict the performance of Japanese larch. In Michigan plantations on sites growing northern hardwoods or a hardwood mixture containing red, black, and white oaks, beech, and sugar maple had low mortality, while almost all the Japanese larch died on scrub oak, jack pine, or tamarack sites.

Another important part of the mortality story in Japanese larch is that trees will continue to die after the plantation appears to be established and is growing well (Table 2).

Comparison of mortality in plantations containing 280 Japanese larch and 40 tamarack showed that more tamarack remained than Japanese larch in plantations on sandy soils with repeated frost damage and on the poorly drained site. The average mortality was 55 percent for Japanese larch and 79 percent for tamarack at Russ, Kellogg, and Rose Lake plantations.

Height.--Japanese larch has exhibited rapid juvenile growth in the test plantations (Tables 3 and 4). At Kellogg Forest Scotch pine, spruce and Japanese larch provenance test plantations of the same age are adjacent to each other. The tallest Japanese larch trees are about 25 percent taller than the tallest Scotch pine and almost twice as tall as the tallest spruce. Japanese larch has an indeterminate growth pattern in that trees begin growth in May and continue to grow throughout the summer until buds are set in September. Height growth can be strongly influenced by the hot, dry summers that are common in north central United States. Differences in summer climate may explain why 9-year-old plantations in north central United States are the same height as a 7-year-old one in New York or why 5-year-old trees are only half as tall in Michigan as in Germany.

The average plantation height at 10 years of age was 5.9 meters in Nebraska and 4.1 meters at Manistee,

Table 3.--Height at age 10 of seven geographic origins of Japanese larch and comparison with seedlots of other species, as measured in the 1960 plantations.

Origin Number and Species[a]	Height in meters at Kellogg Mich. 2-60	Rose Lake Mich. 6-60	Manistee Mich. 11-60	Dunbar Mich. 10-60	Neb. 14-60	Wisc. 22-60	Ohio 20-60	Mean
2788 JAP	3.4	4.1	4.1	3.2	6.1	3.2	3.7	4.1
2793 JAP	3.6	4.0	4.3	3.3	6.3	3.5	4.0	4.0
2796 JAP	3.7	3.6	4.6	3.4	6.3	3.9	3.5	4.1
2799 JAP	3.4	4.0	4.0	3.4	5.6	4.2	3.1	4.2
2800 JAP	3.9	4.2	4.6	4.1	5.0	--	2.4	4.3
2806 JAP	3.9	3.1	3.4	2.6	6.2	3.2	3.3	3.8
2808 JAP	4.0	3.3	3.9	2.9	6.0	3.3	3.3	3.9
Average	3.7	3.8	4.1	3.9	5.9	3.5	3.3	4.1
8 EUR	4.2	--	4.7	3.9	--	--	--	4.3
9 GME	1.7	--	1.7	--	--	--	--	1.7
10 JAP	--	--	--	4.2	--	--	--	4.2
11 TAM	2.0	--	2.7	3.2	--	--	--	2.6

F values showing significance of between-origin differences for seven Japanese larch sources.

	.5	1.7	2.6*	1.1	25.0**	4.2**	4.6**	1.1
Including sources 8-11.								
All species	7.5**	--	16.7**	3.7**	--	--	--	16.7**

[a]JAPanese larch, EURopean larch, L. GMElini, TAMarack.

*Significant at .05 level.

**Significant at .01 level.

Table 4.--Height at age 9, bole form, and flowering of Japanese larch origins planted in 1961 at Kellogg and Russ Forests in southwestern Michigan.

Mountain of origin	Origin number	Mean height (meters)	Mean number of crooks (per tree)		Trees with flowers[a] (percent)	
			stem	leader	female	male
Fuji	2785	3.2	3.1	2.8	10	18
Fuji	2786	3.3	2.7	2.2	13	24
Azusa	2788	3.1	3.1	2.2	1	1
Yatsu-ga	2789	3.3	3.5	2.3	3	9
Yatsu-ga	2790	3.2	3.7	2.5	3	4
Yatsu-ga	2791	3.2	3.5	2.6	1	1
Yatsu-ga	2792	2.7	2.9	2.3	4	5
Yatsu-ga	2793	3.0	3.6	2.1	2	4
Yatsu-ga	2794	3.0	3.3	2.2	1	1
Akaishi	2795	2.9	3.0	2.3	10	16
Akaishi	2796	2.6	3.6	2.2	0	1
Nantai	2797	3.0	3.1	2.3	2	6
Nantai	2798	3.1	2.6	2.1	3	4
Nantai	2799	3.3	2.5	2.4	5	7
Shirane	2800	2.6	2.5	2.1	0	5
Asama	2801	3.0	3.4	2.2	3	8
Asama	2802	2.6	3.4	2.0	19	27
Asama	2803	2.2	2.9	1.7	12	13
Koma-ga	2807	2.8	3.6	2.4	0	4
Hida	2806	3.0	2.5	2.6	0	1
Hida	2808	3.2	3.5	2.5	0	3
Hida	2809	3.2	4.0	2.6	2	5
F value		1.66	1.00	1.08	2.20*	3.64**

[a]Produced in 1966, 1967, and 1968 at Kellogg and 1966 at Russ.

*Significant at .05 level.

**Significant at .01 level.

Michigan. These plantations are on sites with loamy soils and light weed competition. Another factor at Manistee is the strong moderating influence of Lake Michigan on the climate. The average height for all plantations except those with very high mortality was 4.1 meters at 10 years of age. Those plantations with high mortality planted on sandy soils and repeated frost damage averaged 2 meters tall at 10 years of age.

Trees grown from seed sown in 1958 averaged 11, 43, and 137 cm. tall at ages 1, 2, and 3; seed sown in 1959 produced trees 9, 48, and 109 cm. tall at the same ages. These differences in height reflect differences in spacing. The 1958-sown trees grew in very dense, uniform rows whereas the 1959-sown trees grew in sparsely stocked and variable rows. Evidently full stocking induced better growth.

There were significant between-source differences in both the 1958 and 1959 nursery experiments. The differences were relatively small and not correlated with latitude, longitude or altitude of origin. The biological meaning of these early differences is very obscure because:

1. Results of the 1958 and 1959 experiments were not correlated with each other.

2. Results obtained with the same 22 origins in Michigan and German nursery tests were not correlated.

3. Nursery height was not correlated with height in the permanent plantations established with either the 1958 or 1959 material.

Therefore the early height data have very limited genetic significance.

Within plantations there was a 25 percent difference in height between the tallest and shortest origins. These differences varied from nonsignificant at the .05 level in three plantations to significant at the .001 level in Nebraska (Table 3 and 4). However, the origins which were tallest in one plantation were not the tallest in another plantation (Table 3). When all plantations were considered as one experiment, differences among seedlots or groups of seedlots from the same mountain were not significant, but plantation x seedlot interaction was (1 percent level) in both the 1960 and 1961 series of plantations. Correlation calculations substantiated this conclusion from analysis of variance. The correlations were only $r = .20$ and $r = .17$ between height of an origin in Michigan (age 10) and Iowa (age 7) or Michigan and New York (age 6).

The height of an origin in the permanent plantations was not related to altitude, precipitation, mean annual temperature, or growth characteristics of the parent stand. Nor did simple correlation indicate that it was related to other measured characteristics such as the amount of spring and fall frost damage or winter injury.

The height variability found in Japanese larch is comparable to the differences found in an area of similar size in a species with a larger range, or even to differences found in a single stand of a more variable species. The significant differences at individual plantations which were not repeatable at other plantations bear the following implication to testing the small differences found in plus tree selections of other species; to test the validity of small differences between trees, the plantations should be repeated in different locations and years to check if the same differences will be repeated.

Three other species of larch were present in the Michigan plantations established in 1960 (Table 3). European larch grew as fast as the Japanese larch. Tamarack grew slower; in relation to Japanese larch it grew slowest in southern Michigan, and fastest farther north. At Dunbar, in Michigan's Upper Peninsula, it outgrew some Japanese larch origins. _L. gmelini_ was slowest growing of all.

Form.--I paid special attention to measurement of form because most literature indicated there was a difference among origins, and because Japanese larch is considered to have poorer form than European larch. I measured form as the number of times the stem of the tree departed from a straight line, and recorded separately the number of crooks in the leader and the older portions of the stem. Crooks were counted whether due to bending of the stem or loss of leader.

Differences in form among origins were not detectable in the field because within a 4-tree plot there was often one very crooked and three straight trees, giving an appearance of more variation within a plot than between plots.

An analysis of variance showed no significant differences among origins in the plantations with 22 origins (Table 4). In the plantations with 7 origins, source 2800 was significantly straighter. It was the second straightest origin in the 22-origin Kellogg plantation, but only average at Russ.

The correlation between number of crooks in the main stem and in the leader was r = .28 for the 7-origin plantations and r = .24 for the 22-origin plantations. Therefore the crookedness or straightness of the stem was not due to some genetic factor controlling the growth of the leader, but due to some environmental factor occurring after the completion of growth.

Differences in form occurred among the four species present at the Manistee plantation. The European larch source averaged 5.8 crooks per tree to 3.5 for Japanese larch. Tamarack and *L. gmelini* had a similar number of crooks in the portion of the stem, one year or older, to Japanese larch. *L. gmelini* averaged only .25 crooks per leader compared to 3.0 crooks per leader in Japanese larch. This difference is probably due to the short leader of *L. gmelini*, averaging .2 meters, compared to the Japanese larch average of 1 meter.

Cone and flower production.--Tamarack produced cones at an earlier age (8 years at Dunbar) than the other three larch species in Michigan plantations 2-60 (Kellogg), 10-60 (Dunbar), and 11-60 (Manistee). Tamarack continued to grow heavier cone crops, producing four times as many cones as all other species combined (Table 5). At Kellogg Forest *L. gmelini* first produced one cone in 1966 (age 9), one more cone in 1967, and none in 1968. European larch produced one cone at age 8 at Dunbar and no other cones until age 10. The first cones appeared on Japanese larch at age 6 in Nebraska, but Japanese larch was the last species to yield cones in plantations with other species present.

Japanese larch flowers appear before leaf development starts. They are easily visible until the leaves are almost fully grown. Spring frosts often kill the flowers but the dead flowers remain visible on the tree. In Japanese larch up to age 11, more trees had male than female flowers, and if a tree had female flowers it also had male flowers. The number of female flowers which matured into cones was often low. For example, 134 trees produced flowers in plantations 1-61 (Kellogg) and 7-61 (Russ), but yielded only 31 cones. Flower production varied from year to year. The number of trees with female flowers declined at Rose Lake from 3 in 1967 to 1 in 1968, at 2-60 (Kellogg) from 16 in 1967 to 2 in 1968, and at 1-61 (Kellogg) from 92 in 1967 to 9 in 1968.

Table 5.--Numbers of cones produced in 1960 plantations.

Source Number and Species[a]	Kellogg Forest	Rose Lake	Dunbar	Manistee	Neb.	Iowa	Wis.	Total
2788 JAP	0	0	2	0	2	10	0	14
2793 JAP	0	0	126	36	1	15	High[b]	178
2796 JAP	0	0	0	4	0	2	0	6
2799 JAP	0	0	21	0	0	2	0	23
2800 JAP	4	15	575	0	978	2	--	1574
2806 JAP	0	0	9	0	0	15	0	24
2808 JAP	0	6	15	0	3	2	0	26
8 EUR	3	--	11	124	--	--	--	138
9 GME	2	--	--	0	--	--	--	2
10 JAP	--	--	376	--	--	--	--	376
11 TAM	135	--	1700	400	--	--	--	2235
Years of recorded cone production	1966 to 1968	1967 to 1968	1965 1967	1967	1963 1965 to 1967	1964	1967	

[a]JAPanese larch, EURopean larch, L. GMElini, TAMarack.

[b]24 trees were estimated to produce 5 cones per tree.

Heavy cone production occurred in plantations at Dunbar Forest, Michigan and Nebraska for unknown reasons (Table 5). The Dunbar plantation is the slowest growing, wettest, and farthest north; the Nebraska plantation is the fastest growing and most southerly and is planted on a silt loam soil.

Of the seven Japanese larch sources in 1960 plantations, source 2800 produced 84 percent and source 2793 10 percent of the cones (Table 5). Each of those sources yielded cones in five different plantations. The chance of that occurrence is less than 1 in 100. Only in Iowa did another source fruit more heavily than one of these.

Heavy cone production by a particular source was repeated year after year in the same plantation. In Nebraska 25 to 50 percent of the trees of source 2800 produced over 200 cones each year after 1965 but all trees of other sources produced only 6 cones altogether.

The number of cones a source produced was not correlated with height, time of bud set, or other characters measured in the plantations. For example, source 2800, which flowered most heavily, was shortest in Nebraska and second tallest at Dunbar.

In the 22-origin plantations established in 1961 trees of five sources flowered heavily (Table 4). However, sources which produced many female flowers in 1-61 Kellogg did not do so at 7-61 Russ. For example, 10, 10, and 19 percent of the trees in sources 2785, 2795, and 2802 produced female flowers at 1-61 Kellogg whereas no trees in these sources produced female flowers at 7-61 Russ.

Two sources (2793 and 2800) produced most of the female flowers in the plantations established in 1960, but those same two flowered lightly or not at all in the plantations established in 1961. Such an interaction is difficult to explain.

Results of this provenance test have an implication for Japanese larch seed orchard establishment. To guarantee large quantities of seed one would have to plant many different sources at many different places and hope.

Leaf Growth.--Japanese larch is one of the earliest species to begin leaf growth. Near East Lansing, leaves appear three weeks earlier than in most tree species, and up to seven weeks earlier than in some. In a Japanese larch plantation there is a 5-day difference between the day the first tree develops leaves and the day the last tree begins leaf growth.

The order in which trees initiated leaves was measured as the amount of leaf development on one date or on certain dates. Leaf growth was measured in two different years in three plantations. The order in which sources initiated leaves was similar from year to year in the same plantation.

Small differences in order of leaf initiation existed between sources at individual plantations (Table 6). However, the order in which sources initiated leaves at one plantation was not significantly correlated with the order in which sources developed leaves at another plantation. For example, the correlation for amount of leaf growth between 1-61 and 2-60 Kellogg on April 22, 1968 was $r = -.45$.

The order in which species developed leaves at Kellogg Forest and *L. gmelini*, European larch, Japanese larch, and tamarack. *L. gmelini* developed leaves one week earlier than did tamarack.

Spring frost damage.--Spring frost damage occurred once in the 10 years of the study in southern Michigan and in each year that spring measurements were made in Wisconsin.

Japanese larch are much more susceptible to spring frost damage than tamarack. Significant differences in the amount of spring frost damage occurred among sources of Japanese larch. However, the order with which sources suffered damage was not constant from plantation to plantation (Table 7).

The only 22-origin plantations in which spring frost damage was recorded were 6-61 and 7-61. In these plantations, the sources showed a distinct geographic variation pattern. Grouping the origins by mountain of

Table 6.--Order of growth initiation among 7 sources of Japanese larch sources planted at different plantations.

Earliness (=1) or lateness (=7) of leaf growth of trees planted						
Source Number	Nursery	Kellogg 2-60	Kellogg 1-61	Rose Lake 6-60	Russ 7-61	Ohio 20-60
			Rank			
2808	1	2	1	2	3	4
2788	2	4	2	1	2	3
2799	4	3	6	3	5	1
2796	4	1	7	5	7	2
2793	4	6	3.5	4	6	5
2806	6	7	3.5	7	1	6
2800	7	5	5	6	4	7

Table 7.--Damage to new growth by spring frost in 1960 plantations.

		Rose Lake 5/25/63	Russ 5/25/63	Wis. 1964
Species	Source Number	Rank 1 =	large, 8 =	small
JAP	2808	1	1	2
JAP	2806	3	2	3
JAP	2788	6	3	1
JAP	2796	2	5	4
JAP	2793	4	4	6
JAP	2799	5	6	5
JAP	2800	7	7	-
TAM	11	8	8	-
F value		2.85*	1.22	26.3**

JAPanese larch, TAMarack.

*Significant .05 level.

**Significant .01 level.

parental stand explained 72 percent of the variation due source (Table 8).

Spring frost damage was not related to the earliness or lateness of leaf initiation at Rose Lake and 6-61 and 7-61 Russ.

The only plantation in which both spring and fall frost damage occurred was Wisconsin. Those sources which were least damaged by spring frost were also least damaged by fall frosts.

Growing season foliage color.--Spring and summer foliage colors of Japanese larch were measured in the nursery. The differences in color among origins were so slight they could be distinguished only under the best light conditions and by a person with excellent color perception. The person grading color differences stood 6 meters from the plots and quickly read the color grades to the person recording. Colors measured by a different person ten minutes later agreed with the first color measurements.

Five color grades were distinguishable in spring color, grade-1 being the yellowest. Differences in spring color among origins were significant at the .01 level in both the 7-origin and 22-origin tests. The yellow origins at age 2 were not the yellowest origins at age 3 in the 7-origin test, nor were the yellowest origins in the 7-origin test the yellowest origins in the 22-origin test.

Table 8.--Damage to new growth by spring frosts in 1961 plantations.

6-61 and 7-61 Russ 5/25/63		
Mountain	Number sources	Percent
Akaishi	2	72
Yatsu-ga	6	63
Azusa	1	62
Fuji	2	60
Asama	3	57
Shirane	1	56
Hida	3	56
Koma-ga	1	55
Nantai	3	39
F value		3.4*

*Significant .05 level.

Spring color was related to autumn color and winter dieback in the 7-origin test but no similar relationship was found in the 22-origin test.

Two summer color grades were measured at age 1 in the 22-origin experiment with grade-1 trees having a very slight brown tinge and grade-2 trees lacking a brown tinge. There was no relationship between summer color and any other character measured.

Preparation for winter dormancy.--The earliness with which trees set buds or changed leaf color, the amount of damage done by fall frosts, and winter injury were used as indicators of preparation for winter dormancy. These characters were highly related to each other in all plantations (usually at the .01 level), and appeared to be under uniform genetic control which was not strongly influenced by the local environment. Those origins which entered winter dormancy early in the Michigan State University nursery also did so in a nursery in northern Germany (Langner, 1965). When the trees in the Michigan State University were outplanted, the order in which sources prepared for dormancy was constant from nursery to plantation, plantation to plantation, and from year to year in the same plantation or between plantations. The geographic variation pattern for preparation for winter dormancy is shown in Table 9.

Table 9.--The similarity of the geographic variation pattern of Japanese larch for earliness or lateness of bud set, leaf color change, and amount of winter injury at 1-61 Kellogg, 7-61 Russ Forest, and Michigan State University nursery.

Source	Mountain	Preparation for winter dormancy (1=early, 22=late) Bud set	Leaf color change	Winter injury
			Rank	
2785	Fuji	21	22	10
2786	Fjui	17	21	14
2788	Azusa	20	17	21.5
2789	Yatsu-ga	10	6	19
2790	Yatsu-ga	19	13	11
2791	Yatsu-ga	11.5	11	9
2792	Yatsu-ga	18	14	19
2793	Yatsu-ga	11.5	10	14
2794	Yatsu-ga	15	19	19
2795	Akaishi	22	12	14
2796	Akaishi	13	18	7
2797	Nantai	4	4	8
2798	Nantai	6	3	3
2799	Nantai	3	5	6
2800	Shirane	1.5	9	1.5
2801	Asama	1.5	1	1.5
2802	Asama	7	16	14
2803	Asama	9	20	4
2807	Koma-ga	5	7	17
2806	Hida	14	15	14
2808	Hida	16	8	21.5
2809	Hida	8	2	5

Bud set is the first phase of dormancy. In Michigan trees start to set buds in the first week of September, with the last buds being set the last week of September. The only inconsistency in order of bud set occurred in Wisconsin where source 2796 set its buds early but did not do so in plantations at Kellogg, Rose Lake, and Ohio.

The amount of fall frost damage was recorded only in the 22-60 Wisconsin plantation where fall frost damage was observed in three out of four years of measurement. Fall frost damage was least on trees which set buds early (Table 10).

In Michigan the leaves of Japanese larch began to turn yellow in the middle of September. Leaves nearest the trunk turned yellow first. All leaves turned yellow by the middle of November and dropped by early December. Leaf color change was measured as the combined percentages of the leaves that had changed color and those that had fallen.

Trees from Mt. Fuji averaged 25 to 50 percent more green leaves than other sources during the first six weeks in which leaves changed color.

Winter damage was recorded in the nursery and at Dunbar. Sources 2799 and 2800 were least injured at Dunbar and were also least damaged in the 7-origin test in the nursery. It should also be noted that although the sources from Mt. Fuji set their buds, and their leaves

Table 10.--The amount of damage done by fall frosts to trees with growing buds in Wisconsin.

Schmalenbeck Number	Number of trees with growing buds	Number of trees with fall frost damage
	Percent	
2788	35	85
2793	2	8
2796	48	75
2799	6	6
2800	--	--
2806	17	77
2808	12	56
F value	4.83**	12.7**

**Significant at .01 level.

changed color much later than other sources, they did not suffer as much winter injury as would be expected (Table 9).

Disease and insect resistance.--Larch sawfly, *Pristiphora erichsonii* (Htg.), invading from surrounding tamarack stands, attacked the plantation at Dunbar in 1964. The sawfly attacked tamarack much more than the Japanese or European larch (Table 11). All Japanese larch sources were similar in resistance to larch sawfly damage.

A *Valsa* sp. canker also attacked the Dunbar plantation in 1965 with new cankers appearing each year since 1965. The canker attack is apparently secondary, attacking the trees growing in a very poorly drained portion of the plantation.

Japanese and European larch are much more susceptible to damage by *Valsa* sp. canker than tamarack (Table 11).

Table 11.--The resistance of Japanese larch to larch sawfly attack and susceptibility to *Valsa* sp. canker attack in comparison to tamarack.

Source Number	Species	Trees with *Valsa* sp. canker 9/30/1967	Number of sawfly colonies
		Percent	Per 40 trees
2788	JAP	70	0
2800	JAP	65	7
2793	JAP	55	1
2799	JAP	55	4
8	EUR	52	1
2806	JAP	50	1
2808	JAP	50	3
2796	JAP	35	1
11	TAM	15	107
F value		23.8**	3.58**

JAPanese larch, EURopean larch, and TAMarack.

**Significant at .01 level.

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