GEOGRAPHIC AND STAND VARIATION IN JACK PINE (PINUS BANKSIANA LAMB.)

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ABSTRACT

GEOGRAPHIC AND STAND VARIATION IN JACK PINE

(<u>PINUS</u> <u>BANKSIANA</u> LAMB.)

by David S. Canavera

The objectives of this study were: (1) to determine the geographic variation pattern in jack pine, (2) to determine the amount of variation that exists between - and within - stands of jack pine from Lower Michgan and to establish seed orchards for the production of genetically improved seed for use in Lower Michigan, (3) to determine the effectiveness of mass selection for height growth in natural stands, (4) to determine if there is natural resistance between 2-0 half-sib families from Lower Michigan to ovipositing by the jack pine budworm, and (5) to determine what effect different levels of root pruning has on height growth.

Variation in growth characters was investigated in 95 range-wide sources. The characters were measured on seedlings grown for three years at the Tree Research Center, Michigan State University, East Lansing, Michigan and on 4-year old trees growing in two test plantations located in southwestern Michigan. Analysis of variance, the summation-of-differences technique, and correlations between progeny performance and latitude, length of growing season and growing degree days at the place of seed collection were the principal statistical tools used.

The overall variation pattern in jack pine is continuous. No sharp breaks are evident in the population. The southern sources generally grew taller, remained greener in winter, and produced more flowers and lammas shoots than the northern sources. Height and 1- and 2-year autumn coloration were highly correlated with the previously mentioned climatic variables at the place of seed collection.

Individual-tree selections were made in the summers of 1965 and 1966 in natural stands of jack pine in the Lower Peninsula of Michigan. A total of 382 trees from 61 stands were collected. The trees were selected for height growth, stem straightness and presence of open cones. Average and below-average trees were also selected from each stand. The seedlings were grown in a replicated randomized complete block design at the Tree Research Center. Three-year nursery data for height growth and other characters shows that the variance within-stands is much larger than the variance among-stands. Progeny heights were only slightly correlated with parental heights and it was concluded that mass selection for height growth in natural stands was ineffective.

Six half-sib progeny plantations were established in Lower Michigan with 2-0 stock from the Lower Michigan individual-tree selections in the springs of 1968 and 1969. They consist of replicated randomized complete blocks. The plantations will be converted to seed orchards by the removal of the poorest families and poorest individuals within families. The plantations will be measured at 5-year intervals and the poorest families will be removed after each measurement. The genetic quality of the seed orchards will increase with each thinning.

Twenty-five sources of the individual-tree selections were tested for resistance to ovipositing by the jack pine budworm. Single tree plots of 2-0 trees were planted on a one-foot square spacing at the Tree Research Center. Each source was replicated 12 times in three 100-tree blocks. Larvae and pupae of the insect were collected in July and reared on jack pine foliage until pupation was complete. After the adult moths had mated, they were released on the trees. A 11 x 11 x 3 foot cage covered each block of trees. The female moths oviposited within a week and the egg masses were counted. No significant difference for the number of egg masses per tree was found between sources.

The roots of three hundred and sixty 2-0 seedlings had none, one-quarter or one-half of their lengths removed before spring growth had started. They were transplanted on a one-foot square spacing at the Tree Research Center. First year growth increments did not differ significantly between root pruning levels.

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By

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CHAPTER I

INTRODUCTION

Jack pine (*Pinus banksiana* Lamb.) is now the most prominent pine in the forests of Michigan's Upper Peninsula and the upper half of the Lower Peninsula. Originally it inhabitated a very limited area of the state. Pure stands of jack pine were found only on the poorest sandy soils. On better soils, it grew in mixture with red pine (*P. resinosa* Ait.) and white pine (*P. strobus* L.). Jack pine has been planted extensively in the state and has also spread naturally into burned and deforested areas. The jack pine type now ranks third in acreage among the forest types, occupying about one million acres of forest land.

Jack pine was regarded as an undesirable species in Michigan 100 years ago. Since then, the forests have changed drastically and the demand for pulpwood has increased, so that its present day value is great. Jack pine has been a favorite for reforestation due to its rapid juvenile growth, desirable pulping characteristics, ability to grow on poor sites, and low woods waste. Its least desirable characteristics are extremely poor stem form and coarse branches. The serotinous cones were advantageous when fires ravaged the state. However, the present day fire danger has been greatly reduced, and the early cone opening is now needed to obtain natural regeneration. Many existing plantations have to be considered failures because of slow growth, poor stem form, coarse branches and lack of natural regeneration. Future plantings must produce more value per acre than the present jack pine.

Genetic improvement through selection and selective breeding has been achieved for a number of tree species. The goal of this study was to examine the possibility of obtaining improvement in jack pine. It was conducted as a cooperative effort between the Forestry Division of the Michigan Department of Natural Resources and Michigan State University.

Description of Species

The following information is taken from Silvics of Forest Trees of The United States (P. O. Rudolph, in U. S. Forest Service 1966), Michigan Trees Worth Knowing (Smith 1961), Silvicultural Research in Jack Pine (Cayford 1967), and Natural Variation in Jack Pine (*Pinus banksiana* Lambert) (Schoenike 1962).

Jack pine matures at about age 60, attains heights of 60 to 70 feet and average stem diameters of 12 to 18 inches. The lower branches die rapidly but remain on the tree for many years and give it a ragged appearance. The bark is light brown and only slightly scaly on young trees with new growth, dark gray or black with loose scales on older branches and irregular, scaly ridges on old trunks. Needles are in 2's, dark yellow-green, frequently exceeding 3 inches in young seedlings but only 3/4 to 1 1/2 inches long on mature trees. Staminate flowers are yellow; ovulate flowers are purple. Cones are 1 1/2 to 2 inches long, sessile, oblong-conic, frequently strongly incurved, pointing forward, both serotinous and non-serotinous. Seeds are triangular, black and roughened, 1/2 inch long and 1/3 inch wing.

Jack pine grows under a wide range of habitat conditions. In general, the areas are characterized by warm-to-cool summers, extremely cold winters, moderate rainfall, light sandy soils, and rolling to level topography. The average July temperatures range from 55° to 72° farenheit. Within most of its distribution, precipitation is 15 to 35 inches, the extremes are 10 to 55 inches. Periods of 30 or more days without precipitation occur commonly from Michigan west. It is confined largely to soils of the podzol region: melanized sands, podzolic sands, sandy podzols, and the gley-podzolic sands. Maximum development is reached on well-drained loamy sands. Its altitudinal range is between sea level and a little over 600 meters.

Jack pine is very prolific in seed production and can produce female flowers at age 2. Open-grown trees begin seed production at 5 to 10 years.

Jack pine is a pioneer species. It frequently inhabits burned areas where there is exposed mineral soil, and little plant competition. Extensive even-aged stands are common. In the absence of fire or other catastrophies, jack pine is replaced by more tolerant species. On the poorest, driest sites it forms and edaphic climax. A typical succession on better sandy soils (loamy sands or sandy loams) is from jack pine to red pine, to eastern white pine, to a hardwood type composed of northern red oak (Quercus rubra L.), basswood (Tilia americana L.) and sugar maple (Acer saccharum Marsh.). On loamy soils it is replaced by black spruce (Picea mariana (Mill.) B.S.P.), white spruce (Picea glauca (Moench) Voss) and balsam fir (Abies balsamea (L.) Mill.). Other species commonly growing in mixture with jack pine include trembling aspen (Populus tremuloides Michx.), white birch (Betula papyrifera Marsh.), northern pin oak (Quercus ellipsoidalis E. J. Hill) and bur oak (Quercus macrocarpa Michx.).

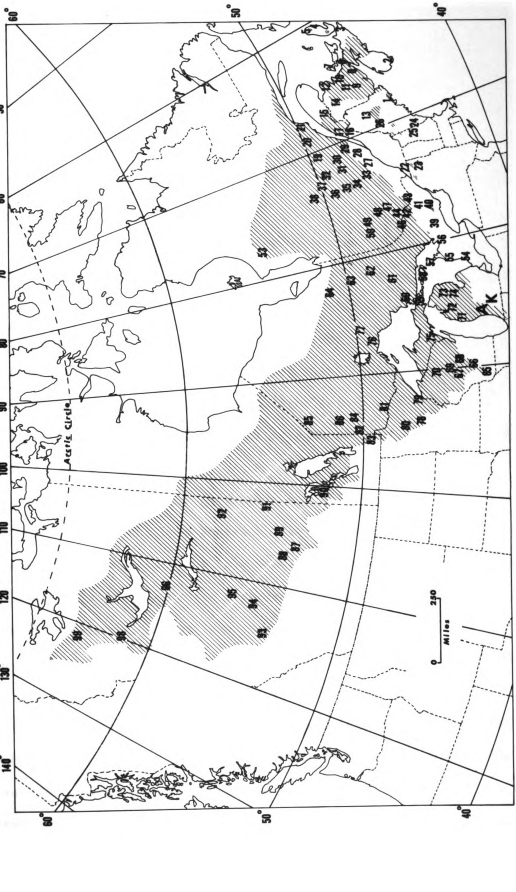
The geographical range of jack pine is shown in figure 1. It extends over 1,000 miles in its greatest north-south direction and about 2,600 miles in a southeast-northwest direction. From its northernmost point along the Mackenzie River in western Canada, it stretches south and east to the Lake States, northern New York and New England, and the Maritime Province of Nova Scotia. The ranges of jack pine and lodgepole pine (P. contorta Dougl.) overlap in Alberta and MacKenzie and natural hybridization occurs.

Previous Genetic Studies in Jack Pine

Provenance research.--The first geographic origin test of jack pine was made by the University of Minnesota in 1940 (Schantz-Hansen and Jensen 1952; Schoenike, T. D. Rudolph and Jensen 1962). It consisted of 32 seedlots collected throughout the range of jack pine, from Maine to Alberta. The trees were grown for two years in the nursery and outplanted in 1943 at the Cloquet Forest Research Center in northern Minnesota. The heights varied from 2 to 8 feet at age 8, and from 6 to 24 feet at age 15. The tallest sources were from Michigan, Minnesota and Ontario. The source from Bar Harbor, Maine was prostrate. The majority of trees from all sources had poor form.

Morphological measurements were made on 23 sources (Schoenike, T. D. Rudolph, and Schantz-Hansen 1959). Trees with closed cones appeared most frequently in sources from northeastern Minnesota and adjacent parts of Ontario and Manitoba, the Upper Peninsula of Michigan, and most of Canada. Contrasted to this, trees with open cones were found with highest frequency in sources from Michigan's Lower Peninsula, southern and western Minnesota, New Brunswick and Maine. Cones on

Figure 1.--Natural distribution of jack pine in North America (shaded area from Critchfield and Little, 1966) and sources included in this experiment (numbers). The two measured plantations are shown as A = Allegan and K = Kellogg.


Arctic Circle
Miles
0
250

sources from the western portion of the range were more curved and had more acute angles (the angle produced between a line connecting the tip and point of attachment of the cone, and the branch upon which the cone was borne) than eastern and Great Lakes sources, which had straight cones and larger cone angles. Branches on trees from eastern sources had larger angles (the upper angle produced by the basal one-foot length of branch and the major axis of the tree) than the Great Lakes and western sources.

During the winter of 1947-48, severe winter injury occurred. There was no consistent geographical pattern in the degree of injury. The most severely damaged sources were from Baldwin and Manistee in the Lower Peninsula of Michigan. A few trees were killed, and in some plots as high as 93 percent of the trees showed injury. Eleven other scattered sources showed moderate to light injury. No injury was found in 12 sources. Natural stands of jack pine in the Cloquet area suffered little damage.

The second large scale geographic origin test was started in 1951 by P. O. Rudolf of the Lake States Forest Experiment Station. It consists of 29 seedlots from the Lake States. Each seedlot is made up of seed from several dominant and codominant trees in a single native stand. Seventeen permanent outplantings were established in the Lake States with 2-0 stock. Each test plantation also had one "local" seed source supplied by a commercial nursery in the area of the plantation.

Several reports on this experiment have been published (Stoeckler and P. O. Rudolf 1956; Jensen, Schantz-Hansen and P. O. Rudolf 1960; Batzer 1961; Arend et al. 1961; T. D. Rudolph 1964; King 1964; Alm and Jensen 1969). Height measurements were made in three Lower Michigan plantations at age 5; in 11 of 17 plantations scattered throughout the Lake States at age 10; and in one Minnesota plantation at age 13. The results were consistent. The group of sources from Michigan's Lower Peninsula performed best in the Upper and Lower Peninsula of Michigan and Wisconsin. Sources from north central Minnesota did best in the northern Minnesota plantation.

Winter color differences were evident in 1-0 nursery stock, but disappeared with age. Trees from northern sources turned purple, whereas those from southern sources remained green.

Height growth in northern conifers usually occurs in a single flush without any intermittent rest periods. At the end of the growth period, buds are set and primordia are laid down for next seasons growth. A current season's growth is largely determined by what was formed the previous year. Some trees or individual shoots on a tree may have more than one flush in a single growing season. After initial growth in the spring, intermittent periods of rest and growth follow. The later flushes are developed from primordia formed the same year. These late growth flushes occur frequently in jack pine. They are called lammas shoots when formed on the terminal shoots and prolepsis shoots if formed on the lateral shoots located at the base of the terminal shoot.

In the 1951 Lake States study, lammas growth and prolepsis varied significantly between seed sources in the four Minnesota and two Wisconsin plantations. Southern sources had a higher frequency of these late shoots than northern sources.

Differences among sources in white pine weevil incidence occurred on two plantations in northern Minnesota and three plantations in Lower

Michigan. Seed source differences also occurred in needle cast infection in a southern Wisconsin plantation and a western Upper Michigan plantation.

The most recent provenance test was started by Mark Holst of the Petawawa Forest Experiment Station, Chalk River, Ontario. The genetic information received from earlier provenance studies were limited because they contained a small number of seed lots. In the Petawawa experiment, 95 stands were sampled throughout the range of jack pine. The collections were later subdivided so that nursery and field tests could be performed in the United States, Canada, Denmark, Finland, Scotland, Czechoslovakia, Holland, New Zealand and Germany.

Yeatman, (1967) reported on growth chamger, greenhouse and nursery performance. The average response over all of the environments tested provided the best discrimination between provenances. The interaction of provenance and photoperiod was the second best discriminator. Northern sources were hardier than southern. The degree of hardiness was positively correlated with amount of foliar sugar content, needle coloration and time of bud formation. Following germination, 76 percent of the variation in seedling size was explained equally by seed weight and growing degree-days at the place of seed origin. Temperature was more important than photoperiod in initiating spring growth.

Individual-tree inheritance.--An open-pollinated progeny test, made up of individual-tree collections from 10 closed-cone and 18 open-cone trees, was started in 1939 in northern Minnesota. In 1957, 52 percent of the offspring of the open-coned mother trees produced cones which opened soon after ripening, contrasted to only 13 percent from the closed-cone mother trees (T. D. Rudolph, Schoenike, Schantz-Hansen, 1959).

CHAPTER II

DESIGN OF THE PROVENANCE EXPERIMENT

Earlier jack pine provenance studies do not provide adequate information on the performance of seed sources from outside of the Lake States when planted in Michigan. In experiments at Michigan State University, origins of eastern white pine and white spruce from outside of Michigan grow 20 to 30 percent faster than native sources when planted in southern Michigan (Wright el al. 1963). The Petawawa range-wide test, which I studied, was planted in Lower Michigan in order to study the performance of jack pine seed sources from the entire range of the species when planted in Lower Michigan.

Materials and Methods

Seed procurement.--Seeds from 95 origins of the Petawawa range-wide collections were used. Each seedlot was collected from 3 to 100 trees in a native stand. Seed collection areas are shown in figure 1, and origin data is presented in table 1.

Handling in nursery.--On October 30 and 31, 1963 the seeds were sown in a 4-replicated, randomized complete block design at the Tree Research Center, Michigan State University. Each replicate contained one 4-foot row of each seedlot. The rows were one foot apart. Seeds were sown at eight spots in each row, with three to ten seeds planted per spot. Germination in the spring of 1964 averaged 85 percent for the experiment as a whole. The spots were thinned to two seedlings per spot.

A fifth replicate was broadcast sown to provide stock for outplanting. Enough seed was sown to give a density of 40 seedlings per square foot. The seedlings in these beds grew very fast. In June of 1965, they were mowed back to a height of one foot in order to produce a more favorable root/shoot ratio for outplanting.

All of the seedbeds were treated with methyl bromide prior to seeding. After germination, the seedbeds were watered, kept weed free, fertilized, and mulched with one-half inch of sawdust in the autumn.

Parallel strips running lengthwise in the seedbeds showed areas of poor and good growth on July 14, 1964. Soil analysis showed a nutrient deficiency in the poor growth areas and adequate fertility in the good growth areas. Corrective measures were taken on July 17 by a foliar application of fertilizer to the poor growth areas. Broadcast fertilizer application on the entire seedbeds were made on July 20 and August 3. The seedlings responded rapidly and no strips of differential growth were visible by August 13.

No edge effects were observed either within-rows or over the seedbeds as a whole. There was little within-row competition. However, the position of a seedlot in a replicate did affect growth rate because of differential watering. Some areas in the seedbeds produced taller seedlings than other areas, irrespective of which seed sources were present. Because of this, I adjusted source heights according to their position in the replicates. I accomplished this by first dividing each replicate into eight parts and recording in which of the eight a source was located. Then I calculated the difference between the plot means and the overall average for the same sources. Then the differences for all sources in each of the eight parts were added and the average difference for each part was calculated. Then an amount equal to the average difference, but opposite in sign, was added to the mean for each plot in each of the eight parts. For example, if the average difference for an octile was -2, then +2 was added to the mean of each plot.

Nursery measurements.--Altogether 22 complete sets of measurements were made on different characters or the same character measured at various times. First year measurements were made by Fan Kung, and I made all subsequent measurements. Metric traits were measured to an accuracy of approximately 1/20 of the range between extremes. Non-metric characters were evaluated in terms of the smallest recognizable difference between units. Color was defined in terms of live-tree standards, and was scored by comparing the average color of a plot with a certain color standard set in the observer's mind. Crookedness was measured along the main stem on the tallest tree in each row. A crook was defined as a bend in the main stem of the tree. The deviation of this bend was measured as the perpendicular distance between an imaginary straight line drawn along the main stem of the tree and the greatest point of departure of the bend.

Outplanting procedure.--Experimental plantations were established in Michigan in the spring of 1966 at the Allegan State Game Area and W. K. Kellogg Forest (figure 1). Both plantations contain 92 sources and follow a randomized complete block design, with 4 trees per plot. There are ten replicates at Allegan, two at Kellogg. Spacing between trees is 8 feet. Survival was 82 percent at Allegan and 90 percent at Kellogg.

The Allegan plantation is situated on a uniform level site. Competing vegetation is sparse; no chemical weed control was used. The soil type is Plainfield sand.

The plantation at Kellogg Forest is located on a southwest facing slope that has a 5 to 20 percent grade. The area had previously been planted with Scotch pine (*P. sylvestris* L.), which was removed in 1963 and 1964. The site was sprayed with amino-triazole in the fall of 1965 to control the heavy sod and weeds that invaded after clearing. The soil type is Oshtemo sandy loam. Seventy-five percent of the top soil had eroded prior to 1940.

Plantation Measurements.--Height, cone production and number of trees with lammas shoots were measured in July 1968 at Kellogg and August 1968 at Allegan.

Analysis.--An analysis of variance was calculated for each character studied. Plot means were used as items. A typical analysis of variance table follows:

Source of Variation	Degrees of Freedom	Expected Mean Squares
Source	S-1	$\sigma_e^2 + R\sigma_s^2$
Replication	R-1	$\sigma_e^2 + S\sigma_r^2$
Replication x source	(S-1)(R-1)	σ_e^2
Total	(S x R)-1	

R and S are the number of replicates and sources respectively. Differences between sources were tested with replication x source mean square.

Least Significant Differences (L.S.D.) were computed for each character at the 1 percent and 5 percent levels. This technique is used to determine which sources differ from each other. I used Tukey's method for multiple comparisons.

I divided the sources into natural regions using geographic features, climatic data and similarity of growth traits of the progeny and determined the amount of variation that exists between- and within-regions. A typical analysis of variance table follows:

Source of Variation	Degrees of Freedom	Expected Mean Squares
Sources		
Between regions	4	$\sigma_e^2 + 4\sigma_w^2 + 74\sigma_b^2$
Within regions	90	$\sigma_e^2 \quad 4\sigma_w^2$
Total	94	

Simple correlations, using progeny means as items, were calculated to determine the amount of variation in height, autumn color and cone production that could be explained by length of growing season, growing-degree days and latitude at the place of seed collection. Correlations were also calculated between nursery and field heights and between other characters of possible biological significance. The correlations and analyses of variance were done on Michigan State University's CDC 3600 digital computer.

CHAPTER III

THE GEOGRAPHIC VARIATION PATTERN

Results from the provenance test show the major geographic trend in jack pine is north-south. The correlations between latitude, length of growing season and growing degree-days (sum of positive values of $\left(\frac{\text{daily maximum in } ^{\circ}\text{F} + \text{daily minimum in } ^{\circ}\text{F}}{2}\right) - 42$) at the place of seed and the progenies' characteristics were very high. The origins from the western part of the range fit the climatic data better than those from the east. Over its entire range, jack pine has adapted to the climate where it is growing.

The data were analyzed in a variety of ways in order to obtain the maximum amount of information about the geographic variation pattern. Traits were analyzed individually over the entire range, individually by regions, and collectively over the entire range.

Individual Traits

Height.--Origin and 3-year nursery growth data are given in table 1. Average 3-year height in the nursery was 101 cm. In the plantations, the average 4-year height was 63 cm. at Allegan and 86 cm. at Kellogg Forest. The source x plantation interaction was significant between the nursery and both plantations. It was not significant between

Table 1.-- Origin and 3-year growth data for provenance test sown in 1964, summarized by stand progeny.

Ont. Number and Place of Origin		North Lat.	West Long.	Growing Season(a)	Degree-Days (b)	Height Age 3	Autumn Color Age 1	Trees With Buds Sept. 22 1964	Crookedness: Crooks Per Tree Age 3	Crookedness: Size of Crooks Age 3
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
3200 +		°	°	days	hundreds	cm.	grade	per 16 trees	no.	mm.
Sources west of 80° west longitude										
99	NWT	63.2	123.5	136	17	46	1	3	0	0
98	NWT	61.8	121.3	136	18	48	2	3	1	6
96	NWT	60.1	112.0	136	14	62	2	1	1	6
92	Sas	57.1	102.0	150	15	66	1	3	0	0
91	Man	54.8	101.9	153	18	66	2	2	0	0
89	Sas	54.2	105.0	156	20	64	2	2	1	6
95	Alb	56.6	111.9	156	20	70	3	4	1	13
85	Ont	53.0	93.3	147	18	79	3	4	1	13
94	Alb	55.2	111.9	164	21	79	3	1	1	13
90	Man	52.1	100.4	165	24	83	3	5	1	13
87	Sas	53.1	106.1	168	23	85	4	4	1	13
93	Alb	54.1	115.7	160	20	76	4	4	1	6
64	Ont	50.1	82.2	152	20	76	4	4	1	32
76	Ont	48.8	87.4	156	21	90	4	4	1	32
77	Ont	49.6	86.0	154	20	90	4	6	1	19
88	Sas	53.8	107.7	160	22	75	4	3	1	19
86	Ont	51.0	94.1	166	24	99	5	5	1	19
59	Mic	46.4	84.3	171	27	103	5	5	1	38
83	Man	49.5	95.8	172	28	114	5	6	1	25
84	Ont	49.8	93.3	168	25	105	7	5	1	25
82	Ont	49.8	94.5	171	27	121	9	4	1	32
81	Ont	48.8	93.5	177	26	114	7	5	2	32
63	Ont	48.8	80.8	157	22	117	8	6	2	32
62	Ont	47.7	80.7	164	24	104	7	4	1	25
61	Ont	46.8	81.6	169	26	105	8	4	1	32
60	Ont	46.8	84.0	171	24	107	7	5	1	45
58	Ont	45.8	82.9	184	28	108	7	2	2	45
57	Ont	45.0	81.5	195	29	110	8	5	1	32
80	Min	47.3	94.6	189	30	118	8	5	1	45
79	Min	46.7	92.6	182	29	121	9	3	1	38

Table 1.--Continued

Ont. Number and Place of Origin		North Lat.	West Long.	Growing Season(a)	Degree-Days(b)	Height Age 3	Autumn Color Age 1	Trees With Buds Sept. 22 1964	Crookedness: Crooks Per Tree Age 3	Crookedness: Size of Crooks Age 3
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
3200 +		°	°	days	hundreds	cm.	grade	per 16 trees	no.	mm.
78	Min	46.3	94.2	192	31	134	8	5	2	32
70	Wis	45.6	89.9	188	28	127	8	4	3	76
55	Ont	44.0	81.8	193	33	108	9	5	1	25
69	Wis	44.8	89.7	202	32	127	7	5	2	38
68	Wis	44.3	89.0	205	33	124	8	6	3	51
75	Mic	46.0	86.5	186	28	131	7	7	2	64
74	Mic	44.5	84.8	191	32	124	8	3	2	51
73	Mic	44.5	84.8	191	32	135	8	6	3	57
72	Mic	44.5	85.4	195	33	136	7	7	2	57
56	Ont	44.5	80.0	199	31	137	8	7	2	70
65	Wis	43.6	90.2	217	37	128	8	7	2	32
66	Wis	43.8	89.8	207	36	132	7	5	2	45
67	Wis	44.3	89.7	193	34	132	8	7	2	51
71	Mic	44.1	86.1	210	35	124	9	3	2	45
54	Ont	43.2	81.9	207	36	124	8	4	2	57
Sources east of 80° west longitude										
53	Que	54.0	76.5	111	10	50	3	4	0	0
55	NS	46.9	60.3	191	24	76	3	0	1	13
44	NS	46.8	60.4	191	24	80	6	1	0	0
38	Que	50.4	73.9	141	14	79	4	7	1	6
21	Que	49.7	67.3	159	16	79	7	4	0	0
20	Que	49.7	68.4	159	16	90	7	5	1	19
19	Que	49.3	69.9	152	17	73	6	2	1	13
3	NS	45.3	61.0	182	26	78	7	1	1	13
1	Mai	44.3	68.1	208	27	85	8	2	1	19
15	Que	48.1	67.5	160	24	92	5	5	1	25
37	Que	49.6	72.2	154	18	90	5	5	1	19
32	Que	48.9	71.8	163	22	92	6	2	1	19
13	Mai	45.9	69.6	176	27	84	6	2	1	19
36	Que	49.4	74.0	147	18	95	6	3	1	6
35	Que	48.0	74.3	156	21	96	6	6	1	32

Table 1.--Continued

Ont.Number and Place of Origin		North Lat.	West Long.	Growing Season(a)	Degree-Days(b)	Height Age 3	Autumn Color Age 1	Trees With Buds Sept. 22 1964	Crookedness: Crooks Per Tree Age 3	Crookedness: Size of Crooks Age 3
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
3200 +		°	°	days	hundreds	cm.	grade	per 16 trees	no.	mm.
34	Que	47.7	74.0	159	23	108	6	2	1	38
50	Que	47.9	77.4	166	23	99	6	4	1	25
29	Que	47.6	70.2	169	25	97	5	4	1	13
14	NB	47.4	66.5	166	26	100	6	6	1	32
6	NS	45.7	63.8	182	28	94	8	4	1	45
2	NS	43.8	65.4	205	27	93	8	2	1	25
16	Que	47.6	69.6	167	26	106	6	5	2	32
18	Que	47.7	69.7	170	25	100	6	5	2	45
30	Que	48.3	70.9	167	24	97	8	4	1	32
31	Que	48.7	72.0	163	23	105	7	4	1	13
51	Que	48.0	75.4	165	21	102	6	5	1	19
28	Que	46.9	71.4	176	29	105	7	3	1	19
22	Que	45.0	73.8	190	36	90	9	0	1	25
24	NH	43.9	71.3	180	27	96	7	2	1	32
33	Aue	47.3	73.9	163	25	107	7	3	1	32
49	Que	47.8	76.7	165	23	102	7	5	1	13
48	Que	46.8	76.1	175	25	111	8	4	1	32
9	NB	46.0	66.1	178	27	100	8	3	1	13
8	NB	46.0	65.0	182	29	125	8	7	2	51
7	PEI	46.6	63.9	183	28	107	8	2	1	32
11	NB	46.5	65.9	179	27	107	8	4	2	32
10	NB	46.7	65.6	180	27	105	7	4	1	19
12	NB	47.5	65.4	172	25	100	8	5	1	13
47	Que	46.4	76.2	184	27	113	8	4	2	45
25	NH	43.9	71.6	180	27	106	8	1	1	38
26	Mai	45.5	70.2	176	27	119	7	5	1	32
23	NY	44.3	73.8	187	36	119	8	3	2	51
27	Que	46.4	72.6	184	28	116	8	4	2	45
40	Ont.	44.6	77.0	198	30	109	7	4	1	32
39	Ont.	44.7	77.9	187	31	107	9	2	1	45

Table 1.--Continued

Ont. Number and Place of Origin		North Lat.	West Long.	Growing Season(a)	Degree-Days (b)	Height Age 3	Autumn Color Age 1	Trees With Buds Sept. 22 1964	Crookedness: Crooks Per Tree Age 3	Crookedness: Size of Crooks Age 3
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
3200 +		°	°	days	hundreds	cm.	grade	per 16 trees	no.	mm.
41	Ont	44.7	77.1	187	30	107	7	1	2	51
42	Ont	45.5	77.0	188	30	123	8	2	2	32
43	Ont	45.5	76.1	190	32	122	7	5	2	45
44	Que	45.9	76.7	192	29	127	9	5	2	45
46	Ont	45.8	77.4	183	29	133	7	4	2	38
Std. deviation of a source mean						5.05	0.80	1.23	0.37	10.9
L.S.D.(.05) of a source mean						30.48	4.8	7.4	2.2	66.0
F value						17.5***	6.5***	1.9***	3.1***	2.4***
Percent of variance due to source						81	58	18	34	25

Color grades: 0-3 purple, 4-6 intermediate, 7-10 green

*** Significant at 0.1 percent level.

(a) Number of days on which mean temperature exceeds 42°F.

(b) Sum of positive values of $\frac{(\text{daily maximum }^{\circ}\text{F.} - \text{daily minimum in }^{\circ}\text{F.})}{2} - 42$

(c) Measured from a straight line along the stem for the tallest tree in each plot.

Allegan and Kellogg. Correlations between nursery and field heights are given in table 2. The correlation (r) between Allegan and Kellogg was .74.

At all test locations, the fastest growing sources were from southern Quebec, and southern Ontario. Height growth did not differ significantly among these regions. The next fastest growing sources were from eastern Quebec, New Brunswick, northern Maine, northern New York and southwestern Ontario. The fast growing sources from the eastern part of the range (26-Mai, 11-NB, 8-NS, 10-NB, 23-NY), rank much higher in the plantations than in the nursery. Sources 88-Sas and 93-Alt also rank higher in the plantations than in the nursery. These results explain at least part of the reason for the interaction between the nursery and plantations. Sources from the Northwest Territory were the slowest growing at all test sites.

Most of the genetic variation was explained by latitude, length of growing season and growing degree-days at the place of seed collection. Trees that grew fastest came from areas that were most favorable for growth. The highest correlations were with the number of degree-days and latitude. The lowest correlation was with length of growing season. Correlations were highest in the nursery and smallest at Allegan (table 3). From these results, it is apparent that growth is governed more by temperature than photoperiod.

In the provenance test started by the University of Minnesota in 1940, the source from Bar Harbor, Maine was prostrate. The three sources from Maine in this study are straight growing.

Sources 59 and 75 from the Upper Peninsula of Michigan grew better than expected. Arend et al. (1961) reported that sources from this

Table 2.--Correlations (r) between nursery and plantation heights, based on 92 source means.

Height in Nursery At Age	Four-Year Height At Allegan	Four-Year Height At Kellogg
	----------- r -----------	
1	.79***	.71***
2	.82***	.77***
3	.83***	.74***

*** Correlation significant at 0.1 percent level.

Table 3.--Correlations (r) between height and autumn color and climatic data at place of seed collection, based on 95 source means.

Place	Character	Age When Measured	Climatic Data: Latitude	Climatic Data: Length Growing Season(a)	Climatic Data: Degree-Days(b)
		years	r	r	r
Nursery	Height	3	-.77***	.73***	.80***
Nursery	Autumn color	1	-.85***	.71***	.72***
Allegan	Height	4	-.57***	.24***	.74***
Kellogg	Height	4	-.63***	.58***	.79***

(a) Number of days on which daily mean temperature exceeds 42°F.

(b) Sum of positive values of

$$\frac{(\text{daily maximum in }^{\circ}\text{F.} + \text{daily minimum in }^{\circ}\text{F.})}{2} - 42.$$

* Correlation significant at 5 percent level.

*** Correlation significant at 0.1 percent level.

area were much slower growing than those from the Lower Peninsula of Michigan; the two populations could be separated into distinct groups. In my study, no significant difference was found between these two regions. In fact, source 75 was among the fastest growing sources at all three test sites. This source is from Gladstone, which is on Lake Michigan in the southwestern part of the Upper Peninsula and has a warmer climate than most of the Upper Peninsula.

Autumn color.--The north-south trend was also evident in first and second year autumn coloration. Northern sources turned purple, whereas southern sources remained green. The differences were most pronounced the first year and disappeared with age. The trend was most clearly defined in the western part of the range and more variable in the eastern part. Sources 4-NS, 21-Que, 20-Que, 19-Que, 3-NS, and 1-Mai were much greener than expected. The correlation (r) between latitude and first year autumn coloration was .85. There were no summer color differences.

Bud set.--The number of buds set by September 22, 1966 was quite variable but significant among sources. The correlations between bud set with latitude and growing degree-days at the place of seed collection were both r = .22. No adaptive features are evident from these low correlations. In addition to this, no regional differences were found. Apparently, the time of bud formation in jack pine is not controlled by photoperiod or temperature.

Number of crooks.--The number of crooks for the tallest tree in each row was highly correlated with source heights (r = .72). Only the slow growing sources 99-NWT, 92-Sas, 91-Man, 53-Que, 4-NS, and 21-Que had straight central stems. None of the fast growing sources were straight stemmed. The tall sources also had the largest crooks (table 1).

Lammas growth.--The number of trees per source with lammas and prolepsis growth were counted at Allegan and Kellogg. Seventeen percent of the trees at both plantations had these late growth shoots. The source X plantation interaction was significant. This relationship is also apparent from the correlation (r = .46) between plantations. When planted at Allegan, the correlation (r) between trees per source with secondary growth and latitude was .57; and the same character correlated with both length of growing season and growing degree-days at the place of seed collection was .74. The correlation with height was (r = .66). The correlations at Kellogg for the same characters ranged between r = .36 for length of growing season, and 4 = .39 for height. At Allegan, sources 6-NS, 8-NS, 29-Que and 98-NWT produced more trees with secondary growth than expected. But, 72-Mich and 25-NH had fewer trees than expected with secondary growth. The following sources did not produce any trees with secondary growth at Kellogg: 54-Ont, 55-Ont, 59-Mic, 23-NY, 26-Mai, and 9-Mai. Sources 64-Ont and 84-Ont produced more trees than expected with secondary growth.

The lammas growth data from Allegan discriminates seed sources better than the data from Kellogg. Thirty-nine percent of the variance at Allegan can be explained by sources, compared to only 27 percent at Kellogg. The data at both plantations shows a north-south trend. However, the trend is more clearly defined at Allegan than Kellogg. Perhaps growing conditions make this so. The plantation at Kellogg is on a sandy loam, and Allegan is on a deep course sand. The plantation at Allegan grew only 73 percent as fast as the plantation at Kellogg.

Male flower production.--Male flowers were present in the nursery on 89 percent of the sources at age three (table 5). All of the sources

Table 4.--Analyses of variance for 4-year growth data at Kellogg and Allegan.

Allegan		Kellogg	
Height 1968	Trees With Lammas Shoots 1968	Height 1968	Trees With Lammas Shoots 1968
cm.	percent	cm.	percent
Range of source means			
20 to 95	0 to 68	27 to 141	0 to 100
F value			
14.9***	7.5***	3.7***	1.7***
Percent of variance source explains			
58	39	58	27

** Significant at 1 percent level.

*** Significant at 0.1 percent level.

Table 5.--Analyses of variance for flower production at nursery, Allegan and Kellogg.

Nursery			Allegan		Kellogg	
Trees With Flowers: Male 1967	Trees With Flowers: Female 1968	Female Fls. For Trees With Fls. 1966	Trees With Female Flowers 1968	Female Fls. For Trees With Fls. 1968	Trees With Female Flowers 1968	Female Fls. For Trees With Fls. 1968
--percent---		number	percent	number	percent	number
Range of source means						
0 to 68	2 to 73	1 to 5	0 to 34	0 to 9	0 to 88	0 to 8
F value						
3.9***	3.2***	3.06***	2.14***	2.09***	1.54*	1.44*
Percent of variance source explains						
43	35	34	11	10	21	18

* Significant at 5 percent level.

*** Significant at 0.1 percent level.

that did not produce male flowers were from the northern part of the range except for 13-Mai and 53-Que from the southern part of the range. Sources 58-Ont, 55-Ont, 19-Que, and 4-NS produced very few male flowers.

The correlation (r) between male flower production and height was .55, and correspondingly with latitude at the place of seed collection -.56 (table 6). Somewhat lower were the correlations with length of growing season (r = .36), and growing degree-days (r = .35).

Regional patterns of male flower production also existed. Sources east of 80^{o} west longitude flowered more heavily than sources west of that line. The differences between these two regions was significant. Within the eastern region, sources that produced the most flowers were from New Brunswick and central to southeastern Quebec (table 5). In the western region, sources from Wisconsin, Michigan and southeastern Ontario flowered heaviest. As a group, they differed significantly from the remaining northern and western sources.

Female flower production.--Female flower production began in the nursery at age 2. At this time, all sources had flowers (table 5). Seventy-seven percent of the sources at Allegan and 83 percent at Kellogg had female flowers by age 4. Total flower production was heaviest in the nursery, where 26 percent of the trees had flowers, and each flowering tree produced an average of 2.8 flowers. Trees flowered more heavily at Kellogg than at Allegan. Twenty-six percent of the trees flowered at Kellogg, with 2.0 flowers produced per flowering tree. At Allegan, only eight percent of the trees flowered; each flowering tree produced an average of 2.8 flowers. From these results, it is apparent that growing conditions contributed to toal flower production. The growing conditions were best in the nursery and worst at Allegan.

Table 6.--Correlations (r) between flower production and climatic data at place of seed collection, based on source means.

Flower Production			Climatic Data		
Character	Place	Age When Measured	Latitude	Length Growing Season(a)	Degree-Days(b)
		years	r		
No. female fls.	Nursery	2	-.43***	.39***	.40***
	Allegan	4	-.41***	.34***	.43***
	Kellogg	4	-.38***	.29**	.39***
Percent of trees with female fls.	Nursery	2	-.55***	.46***	.45***
	Allegan	4	-.40***	.41***	.42***
	Kellogg	4	-.22*	.12	.11
No. male fls.	Nursery	3	-.56***	.36***	.35***

(a) Number of days on which daily mean temperature exceeds 42°F.

(b) Sum of positive values of

$$\frac{(\text{daily maximum in } ^{\circ}\text{F.} + \text{daily minimum in } ^{\circ}\text{F.})}{2} - 42.$$

* Correlation significant at 5 percent level.

** Correlation significant at 1 percent level.

*** Correlation significant at 0.1 percent level.

Female flower production was correlated with height at all test sites. The correlations were r = .62 at Allegan, r = .61 in the nursery and r = .39 at Kellogg.

The correlations for female flower production between test sites were r = .40 between the nursery and Allegan, r = .26 between the nursery and Kellogg, and r = .37 between Allegan and Kellogg. Source X plantation interaction was significant between the nursery and both plantations and also between Allegan and Kellogg. The heaviest flowering sources were 44-Que, 79-Min, 55-Ont, 27-Que, 40-Ont, 46-Ont in the nursery; 73-Mic, 54-Que, 26-Mai, 75-Mic, 79-Min, 50-Que, 69-Wis at Allegan; 75-Mic, 30-Que, 62-Ont, 73-Mic, and 50-Que at Kellogg. The least flowering sources at all test sites were usually from the Northwest Territory, Saskatchewan, Alberta, Manitoba and northern Quebec. With the exception of these sources, most of the remaining sources generally flowered heavily at one or more of the test sites.

The correlations between female flower production and latitude, length of growing season, and growing degree-days at the place of seed collection are shown in table 6. The correlations with latitude were highest in the nursery and Allegan, r = -.56 and r = -.40 respectively, and lowest at Kellogg r = .22. This same general relationship between plantations holds true when female flower production is correlated with length of growing season and growing degree-days at the place of seed collection.

<u>AOV's Compared to Correlations</u>

Variation patterns can also be recognized by properly comparing the results of analyses of variance and correlations between growth characters and a feature of the habitat at the place of seed collection,

Table 7.--Comparison of the amount of variance explained by correlation (r^2) and analysis of variance.

Character	Analysis of Variance Percent of Variance Between Regions	Correlation Percent of Variance Latitude Explains
		-------- r^2 --------
Height	55	58
Autumn color	44	72
Percent of trees with male flowers	17	31
Percent of trees with female flowers	10	30
Number of female flowers	11	19
Number of crooks	28	49
Size of crooks	24	45
Percent of trees with lammas growth	24	32

such as latitude. The analysis of variance was performed on sources grouped by natural geographic regions and whose progeny had similar patterns of variation. It is designed to show differences between groups. The correlations calculated over the entire range, show the deviations from perfect correlation. The amount of variance between groups is then compared to the variance explained by the correlations. Provided there is an adequate sample size, it can be concluded that if more variance is explained by the correlations than by groups, the variation pattern is continuous. But if groups explain more variance than the correlations, the variation is discontinuous.

I performed this type of analysis on growth characters that best differentiated seed sources. I divided the range of the species into nine regions that most logically grouped sources geographically, climatically and by similarity of growth traits. The results of the different analyses are presented in table 7 . From this table, it is apparent that more of the variance is explained by straight line relationships of the correlations than by regions. Consequently, it is best to consider the variation pattern continuous.

Summation-Of-Differences Analysis

The third technique that I used to study the variation pattern was a summation-of-differences analysis. This is a multivariate analysis that combines data from several characters simultaneously. The eight characters used were: 2-year height, 1-year autumn color, percent of trees with secondary growth, percent of trees with male flowers, percent of trees with female flowers, number of female flowers for trees with flowers, amount of deviation of a crook, and date of bud set. The formula used to calculate the summation-of-differences is as follows:

Table 8.--Summation-of-differences table for sources east of 80° longitude.

Ont. number and place of origin — Total difference in summation units between sources listed below and source on the left(a). The gradual increase in numbers is illustrative of clinal variation. Small numbers between the sources being compared denotes similarity, large numbers dissimilarity.

3200 +

Ont. number and place of origin	53	5	4	38	21	20	19	3	1	15	37	32	13	36	35	34	50	29	14	6	2	16	18	30	31	51	28	22	24	33	49	48	9	8	7	11	10	12	47	25	26	23	27	40	39	41	42	43	44	46
53 Que																																																		
5 NS	0																																																	
4 NS	2	1																																																
38 Que	1	0	1																																															
21 Que	1	0	0	0																																														
20 Que	6	0	1	0	0																																													
19 Que	0	0	0	0	0	0																																												
3 NS	3	1	0	1	0	0	0																																											
1 NS	3	0	0	0	0	0	0	0																																										
15 Que	3	0	0	0	0	0	0	0	0																																									
37 Que	3	0	0	0	0	0	0	0	0	0																																								
32 Que	3	0	0	0	0	0	0	0	0	0	0																																							
13 Mai	2	0	0	0	0	0	0	0	0	0	0	0																																						
36 Que	3	0	0	0	0	0	0	0	0	0	0	0	0																																					
35 Que	4	1	1	0	0	0	0	0	0	0	0	0	0	0																																				
34 Que	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0																																			
50 Que	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																		
29 Que	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																	
14 NB	4	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0																																
6 NS	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																															
2 NS	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																														
16 Que	6	3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0																													
18 Que	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																												
30 Que	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																											
31 Que	5	2	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																										
51 Que	6	3	2	1	1	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0																									
28 Que	7	3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																								
22 Que	6	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																							
24 NH	7	3	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																						
33 Que	6	2	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																					
49 Que	4	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
48 Que	9	6	4	3	2	3	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																			
9 NB	6	4	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																		
8 NB	9	7	4	5	4	4	4	3	2	2	1	3	1	1	0	0	1	0	2	1	2	0	0	1	0	0	0	2	1	0	0	0	0																	
7 NB	6	3	3	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
11 NB	9	6	4	4	3	4	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
10 NB	6	3	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0														
12 NB	5	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0													
47 Que	7	4	3	3	2	3	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0												
25 NH	6	3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
26 Mai	8	5	5	3	4	4	3	2	1	1	1	2	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0										
23 NY	10	8	6	5	4	4	3	2	2	1	2	2	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0									
27 Que	10	7	4	4	3	5	1	0	1	2	1	0	2	2	2	2	2	2	1	0	0	1	1	0	1	1	0	0	0	1	1	1	1	0	0	0	0	1	0	0	1	0								
40 Ont	12	9	6	5	5	6	3	2	2	0	2	1	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0							
39 Ont	12	8	5	6	4	5	3	2	2	3	1	2	2	2	2	2	2	2	2	0	1	1	1	0	1	1	1	1	0	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0						
41 Ont	11	8	6	6	5	6	1	2	3	4	5	2	4	3	3	3	3	3	3	0	0	2	2	1	2	3	2	2	0	3	1	3	3	0	2	2	1	3	2	2	3	1	0	0	0					
42 Ont	13	11	7	7	6	7	3	2	3	4	3	3	3	3	2	2	2	2	3	1	1	2	2	0	1	2	1	2	1	2	1	2	2	0	1	1	0	1	1	1	2	0	0	0	0	0				
43 Ont	13	9	9	7	8	9	6	5	5	3	5	5	4	2	3	2	2	2	2	4	4	1	2	2	2	0	1	2	1	3	2	0	2	2	1	2	1	2	1	1	0	0	1	2	1	0	0			
44 Ont	16	9	8	7	7	5	4	4	3	2	2	3	1	1	0	1	1	2	2	1	2	0	0	0	0	0	0	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0		
46 Ont	16	10	9	8	8	7	5	5	4	4	5	2	4	3	3	3	3	3	3	0	0	2	2	1	2	3	2	2	2	3	1	3	3	0	2	1	3	2	2	3	0	0	0	0	1	0	0	0	0	

(a) Summation unit = $\frac{\sum 4(\text{actual difference between sources} - \text{LSD}(.05))}{\text{LSD}(.05)}$

Table 9.--Summation-of-differences table for sources west of 80° longitude.

Total difference in summation units between sources listed below and source on the left(a). The gradual increase in numbers is illustrative of clinal variation. Small numbers between the sources being compared denotes similarity, large numbers dissimilarity.

Ont. number and place of origin	99	98	96	92	91	89	95	85	94	90	87	93	64	76	77	88	86	59	83	84	82	81	63	62	61	60	58	57	80	79	78	70	55	69	68	75	74	72	56	65	66	67	71	73	54
3200 +																																													
99 NWT																																													
98 NWT	0																																												
96 NWT	0	0																																											
92 Sas	0	0	0																																										
91 Man	1	0	0	0																																									
89 Sas	2	0	0	0	0																																								
95 Alb	2	0	0	0	0	0																																							
85 Ont	4	1	0	0	0	0	0																																						
94 Alb	3	0	0	0	0	0	0	0																																					
90 Man	6	2	2	2	0	0	0	0	0																																				
87 Sas	5	1	1	0	0	0	0	0	0	0																																			
93 Alb	4	1	1	1	1	1	0	1	0	0	0																																		
64 Ont	6	2	3	3	0	1	0	0	0	0	0	0																																	
76 Ont	5	2	1	1	0	0	0	0	0	0	0	0	0																																
77 Ont	8	4	3	3	0	1	0	0	0	0	1	0	0	0																															
88 Sas	7	3	4	4	1	2	0	1	0	0	0	0	0	0	0																														
86 Ont	9	4	3	3	1	2	0	2	0	0	0	0	0	0	0	0																													
59 Mic	16	12	11	10	7	8	7	1	1	2	2	1	2	1	0	0	0																												
83 Man	15	10	9	8	6	6	5	1	2	4	1	2	3	0	0	3	0	0																											
84 Ont	14	9	8	8	7	7	5	1	1	3	1	0	0	0	0	1	0	0	0																										
82 Ont	18	14	13	12	12	11	9	4	6	14	4	2	4	0	0	5	0	0	0	0																									
81 Ont	17	12	12	11	9	8	6	3	2	4	1	2	2	0	0	2	0	0	0	0	0																								
63 Ont	18	12	12	11	10	11	9	4	5	6	4	2	5	0	0	3	0	0	0	0	0	0																							
62 Ont	14	11	10	10	7	8	6	1	3	4	2	0	2	0	0	1	0	0	0	0	0	0	0																						
61 Ont	20	15	13	13	12	11	9	2	4	4	3	0	2	0	0	2	0	0	0	0	0	0	0	0																					
60 Ont	18	13	13	12	10	10	8	3	4	4	2	1	2	0	0	2	0	0	0	0	0	0	0	0	0																				
58 Ont	17	14	12	11	10	9	8	2	3	4	3	1	3	0	0	2	0	0	0	0	0	0	0	0	0	0																			
57 Ont	20	15	14	14	11	11	9	6	5	5	3	2	2	2	0	3	0	0	0	0	0	0	1	0	0	0	0																		
80 Min	20	17	15	14	12	13	10	7	6	4	4	3	5	2	0	3	0	0	0	1	0	0	1	0	0	0	0	0																	
79 Min	28	23	23	22	18	13	14	12	11	8	7	7	8	4	2	6	4	1	2	3	0	0	3	0	0	0	0	0	0																
78 Min	24	19	18	19	16	15	13	10	8	8	7	5	5	3	2	6	1	1	0	0	0	0	1	1	0	0	0	0	0	0															
70 Wis	30	24	22	24	21	18	15	12	10	9	9	8	7	3	3	6	0	1	0	0	1	0	1	1	0	1	0	0	0	1	0														
55 Ont	23	20	18	18	14	12	11	8	6	7	4	3	5	1	1	4	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0													
69 Wis	24	20	19	19	16	17	14	9	9	7	8	5	5	3	2	4	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0												
68 Wis	24	18	17	14	16	15	12	8	8	7	6	3	5	1	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
75 Mic	27	22	22	22	19	18	15	11	11	8	10	7	7	5	4	6	3	1	1	3	1	1	3	1	1	1	0	0	0	1	0	0	0	0	0										
74 Mic	25	19	19	18	16	16	13	9	9	7	8	5	4	3	2	4	1	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0									
73 Mic	27	18	18	20	18	15	13	10	8	8	7	7	5	5	4	6	2	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0								
72 Mic	27	20	22	21	20	17	15	11	11	11	8	7	7	4	4	7	3	2	0	2	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0							
56 Ont	22	20	20	20	19	18	16	11	11	9	9	8	6	5	4	6	3	1	1	3	1	1	3	1	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0						
65 Wis	27	21	21	21	18	19	16	12	11	10	10	8	6	6	5	7	3	2	1	3	1	2	3	2	2	2	1	1	0	2	1	0	0	0	0	0	0	0	0	0					
66 Wis	28	23	22	22	19	20	18	14	12	12	11	9	7	7	5	7	4	1	2	3	1	0	4	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0				
67 Wis	28	22	23	22	19	20	18	14	13	11	11	9	8	6	5	7	5	2	3	4	1	1	3	1	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0			
71 Mic	31	25	23	25	22	20	18	15	12	14	11	9	8	7	5	8	5	1	3	5	0	0	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
54 Ont	34	27	27	27	24	22	20	17	16	14	15	11	11	9	6	9	6	3	4	6	3	2	8	3	2	3	3	2	1	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	

(a) Summation unit = $\frac{\sum 4(\text{actual difference between sources} - \text{LSD}(.05))}{\text{LSD}(.05)}$

$$\text{summation-of-difference} = \frac{\sum 4(\text{actual difference between sources} - \text{LSD}(.05))}{\text{LSD}(.05)}.$$

Four was used as a multiplier to eliminate the use of decimals.

This analysis was done individually for each trait and then all of the summation units for each source were totaled. A total value of zero means that the sources being compared do not differ significantly in any of the eight traits. Increased values above zero indicate increased significant differences between sources for several traits. The tables give a visual presentation of the variation pattern.

Sources from the same latitude in the eastern and western parts of the jack pine range differed. For this reason, I divided the sources into east (of 80° longitude) and west (of 80° longitude) sectors and prepared two separate summation-of-differences tables (tables 8 and 9). The sources for both tables were arranged by latitude, length of growing season and number of growing degree-days at the place of seed collection.

The results of the summation-of-differences analysis show that the variation pattern is continuous. The summation units for all eight characters in both the east and west sectors increase gradually from north to south. No sharp breaks in the tables are evident. It must also be pointed out that there is no sharp break between the southwestern Ontario and southern Michigan sources. Yeatman (1967), working with seed from the same sources, also concluded from nursery, greenhouse and experimental plantations in Ontario, that the variation was continuous.

There are two logical reasons for the continuous variation pattern. The first is that there are no sharp breaks in the range of jack pine and consequently there is a free interchange of genes. The second reason is that there is a gradual environmental gradient from south to north within the range of jack pine which has caused a gradual change in characters over the entire range.

CHAPTER IV

EVOLUTION AND MIGRATORY HISTORY

Jack pine is now growing on an area that was almost completely ice covered during the Wisconsin glaciation of the Pleistocene. The Driftless Area in southwestern Wisconsin was the only part of the present range of jack pine not glaciated during this period. Prior to the Pleistocene, jack pine was generally believed to have been widely distributed in Canada and the Great Lakes region (Mirov 1967, Yeatman (1967).

Refuges for jack pine during the Wisconsin glaciation have been postulated in (1) a general area south of the Great Lakes, (2) the Yukon River valley, and (3) the Atlantic continental shelf (Halliday and Brown 1943). Schoenike (1962) studied morphological variation in natural stands of jack pine throughout its range. He concluded from his data, that the present population of jack pine probably came from one glacial remnant which was located south of the Great Lakes, However, Schoenike points out that an experiment such as his is not designed to determine how many refuges existed, and he did not exclude the possibility of there being several. Yeatman (1967) conducted a literature survey of geological and paleobotanical evidence, and concluded that during the Wisconsin glaciation jack pine survived at a single place in the Appalachian mountains. He excluded the areas south and west of the

Great Lakes, and the Yukon River valley as possible refuges. He also thought that the continuous variation of his growth data was proof that there was only one center of origin for modern jack pine.

The present study also indicates that the variation pattern is continuous. However, from this fact and the small amount of paleobotanical evidence available, it cannot definitely be stated whether the present population of jack pine came from one or several Pleistocene remnants. It is easiest to explain the variation pattern, however, if the present population is considered to have emerged from only one southern population. During its northward migration, the species would have adapted to the environment around it. Some important features of the environment would be length of photoperiod, temperature during the growing season, and length of growing season. Results from my data indicate this to be true. On the other hand, it is also possible that distinct ecotypes in the present population of jack pine could have evolved, even if the entire present population came from trees that existed in only one refuge. More preglacial pollen samples, adequately dated and identified, are needed to resolve this question.

CHAPTER V

DESIGN OF INDIVIDUAL-TREE INHERITANCE STUDY

Recently there has been a great amount of interest in seed orchard establishment and improvement through selective breeding. An individual-tree progeny test was conducted to determine whether there is sufficient genetic variation within jack pine from Lower Michigan to make selective breeding worthwhile and also to develop seed orchards that will provide seed for future plantings in Michigan. This type of study permits an evaluation of the between- and within-stand components of variance. The selections were limited to jack pine from Lower Michigan because the 1951 Lake States provenance study and early results from the all-range provenance study showed that sources from Lower Michigan were fastest growing (Arend *et al.* 1961).

Materials and Methods

Seed procurement.--I made individual-tree selections in the summers of 1965 and 1966 on land owned by the State of Michigan. Selections were made in native stands that appeared to be growing on uniform sites. Ages of individual trees within a stand were determined by increment cores and found to vary by only five years above or below the average age of the stand. Most of the stands were above average for height growth, stem straightness and number of trees with open cones. Several of the stands had been thinned by foresters. The trees they left were tall, straight and many had open cones. I chose the best of these trees. The selection intensity in these areas was higher than my records indicate because it was impossible to determine how many trees were removed from the stand. For example, if a stand had 500 trees before thinning and 50 after thinning and I selected the one best tree remaining, I would say my selection intensity was 1 in 50, when in actuality it was 1 in 500. Many of the stands were heavily attacked by the jack pine budworm (Choristoneura pinus Free.). Most of the trees with budworms did not produce any cones, so my selections were mainly limited to trees that were not attacked.

I selected for height, stem straightness and presence of open cones. Trees with open cones were selected because fire danger has been greatly reduced in the state and cones that shed seeds freely are needed for natural regeneration. The feature of open versus closed cones appears to be under simple genetic control. An open-pollinated progeny test started in Minnesota in 1939 showed that 52 percent of the offspring collected from open-coned parent trees produced open cones, whereas, only 13 percent of the offspring collected from closed-coned parent trees produced open cones (T. D. Rudolph, Schoenike, Schantz-Hansen 1959). It appears to be a relatively easy task to obtain a large portion of trees with open cones in the first generation.

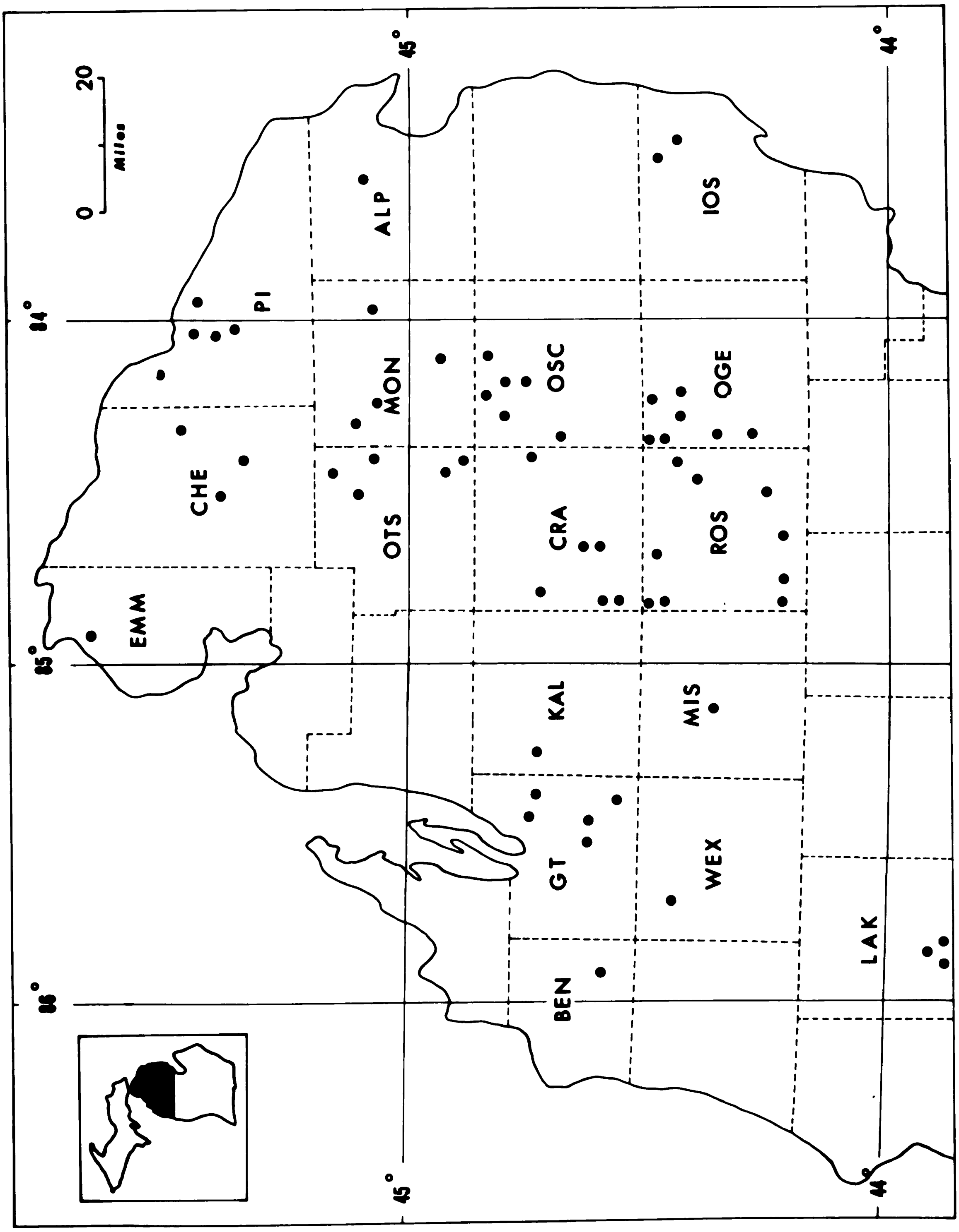
The superiority of each tree was judged in relation to other trees growing within 200 feet. The selection intensity was such that a selected tree was best on about 2 acres for one, two or three traits. Each tree was evaluated separately for each trait. Average- and below-average trees were also chosen from each stand. Cones were collected by felling the trees. I collected seed from 199 trees in 40 stands in the fall of 1965, and 183 trees from 21 stands in the fall of 1966. Seed collection areas are shown in figure 2. Data on stands is presented in tables 10 and 11. Individual parent tree data is available upon request.

Handling in nursery.--Seeds from both years of selection were planted at Michigan State University's Tree Research Center at East Lansing. The first year selections were sown on May 23 and 24, 1966, and those from the second year selections were sown on May 15 and 16, 1967. The design for both experiments consisted of 4 randomized complete blocks. Each block contained one 4-foot row of each seedlot. Twenty sound seeds were evenly spaced in a row. The rows were one foot apart. Germination in both years was over 90 percent. After germination, the seedbeds were watered, kept weed free, fertilized and mulched with one-half inch of sawdust in the autumn.

The seedbeds were relatively uniform except for fifteen feet on both ends. This area did not get watered adequately and consequently height was reduced. I applied a correction factor for height growth, since it was affected by the location of a seed source in the replicate. I accomplished this by first dividing each replicate into 20 equal parts and recording in which of the 20 parts a source was located. Then I calculated the difference between the plot means and the overall average for the same sources. Then the differences for all sources in each of the 20 parts were added and the average difference for the sources in each of the 20 parts was calculated. Then an amount equal to the average difference, but opposite in sign, was added to the mean for each plot in each of the 20 parts.

Seed weights were measured and not found to be significantly correlated with height, so no correction was made for them.

Figure 2.--Distribution of the parental stands (black dots) from which the half-sib progenies were obtained. County names are as follows: EMM = Emmet, CHE = Cheboygan, PI = Presque Isle, OTS = Otsego, MON = Montmorency, ALP = Alpena, BEN = Benzie, GT = Grand Traverse, KAL = Kalkaska, CRA = Crawford, OSC = Oscoda, WEX = Wexford, MIS = Missaukee, ROS = Roscommon, OGE = Ogemaw, IOS = Iosco and LAK = Lake.


0
20
Miles
45°
84°
85°
86°
44°
EMM
CHE
PI
ALP
MON
OTS
OSC
CRA
IOS
OGE
ROS
KAL
MIS
GT
WEX
BEN
LAK

Measurements.--Eight sets of measurements were made on the seedlings sown in 1966 and four sets on the seedlings sown in 1967. Metric traits were measured to an accuracy of approximately 1/20 of the range between extremes. Non-metric traits were evaluated in grades of the smallest recognizable difference between units. Color was defined in terms of live-tree standards, and was scored by comparing the average color of a plot with a certain color standard set in the observer's mind.

Analysis.--An analysis of variance was calculated for each trait studied. A typical analysis of variance table, using progeny means as items, follows:

Source of Variance	Degrees of Freedom	Expected Mean Squares
Source	S-1	$\sigma_e^2 + R\sigma_s^2$
Replication	R-1	$\sigma_e^2 + S\sigma_r^2$
Replication x source	(S-1)(R-1)	σ_e^2
Total	(S x R)-1	

R and S are the number of replicates and sources, respectively. Differences between sources were tested with the replication x source mean square.

The analysis of variance table for the within- and between-stand components of variance for the sources sown in 1966 follows:

Source of Variance	Degrees of Freedom	Expected Mean Squares
Sources		
Between stands	39	$\sigma_e^2 + 4\sigma_w^2 + 20\sigma_b^2$
Within stands	159	$\sigma_e^2 + 4\sigma_w^2$
Total	198	

A similar table, but with different degrees of freedom and exponents for the components of variance, was constructed for the sources sown in 1967.

Simple correlations, using source means as items, were calculated between latitude and length of growing season at the place of seed collection, and height, autumn coloration and flower production. Correlations were also calculated between characters of possible biological significance. The correlations and analyses of variance were done on Michigan State University's CDC 3600 digital computer.

CHAPTER VI

VARIATION AMONG MICHIGAN HALF-SIB PROGENIES

Origin data and the average performance of progenies from each of the 40 stands sown in 1966 and 21 stands sown in 1967, is summarized in tables 10 and 11. The genetic variation pattern within the Lower Michigan population of jack pine is random.

Individual Traits

Trends which were quite evident in the range-wide study are not apparent in the Lower Michigan population. Correlations between progeny performance and climatic data at the place of seed collection are given in table 12. Several of the correlations are reversed from those in the range-wide study. Many characters indicate different trends if correlated with latitude or length of growing season. One possible reason for this is that Lakes Michigan and Huron moderate the climate of areas around them. Consequently, within the natural range of jack pine in Lower Michigan, the areas most favorable for growth are found along the southern, western and eastern parts of the range. The area least favorable for growth is centered in Roscommon, Kalkaska and Missaukee counties.

Height.--Areas which produced the fastest growing progenies appear to be randomly located. The fastest growing sources from the selections sown in 1966 came from Oscoda, Iosco, Roscommon, Missaukee and Grand Traverse counties. Those from the sources sown in 1967 came from Alpena,

Table 10.--Analyses of variance for Michigan 1/2-sib progeny test sown in 1966.

Height 1968	Trees With Lammas Shoots 1967	Trees With Female Flowers 1968	Female Flowers 1968
percent of overall mean	percent	percent	per 40 trees
	Range of source means		
86 to 106	5 to 30	2 to 23	2 to 13
	F value		
0.990	2.061**	0.839	0.928

** Significant at 1 percent level.

Table 11.--Analyses of variance for Michigan 1/2-sib progeny test sown in 1967.

Height 1968	Color 1968	Trees With Lammas Shoots 1968
percent of overall mean	grade	percent
	Range of source means	
84 to 128	4 to 9	4 to 17
	F value	
1.638	1.007	2.739**

** Significant at 1 percent level.

Lake and Grand Traverse counties. Not all of the sources were sampled both years (tables 10 and 11).

Color.--Autumn color in the sources sown in 1967 was correlated with latitude. Sources from two bordering northeastern counties (Alpena and Montmorency) turned the deepest shade of purple, while sources from the southernmost county (Lake) remained greenest (tables 11 and 12).

Lammas shoots and female flowers.--Lammas shoots and female flowers were abundantly produced on sources from all areas. No area produced appreciably more or less amounts of either. The amount of variance explained by source for both characters was small (table 13).

Between- and Within-Stand Variance Components

The individual parent progeny data obtained in this study permits an assessment of the amount of variance that exists between- and within stands. This information is valuable because it gives the breeder a clue as how to proceed in his selection program to achieve maximum genetic gain. The method used for this analysis was given earlier in the 'Analysis' section. The results for the growth data from both years of seed collection are given in table 14. The parent-within-stand variance was significant for height, trees with female flowers, number of female flowers and autumn color.

Improvement by family selection would be an efficient method of improvement for these traits. On the other hand, the variance between stands was appreciable for only trees with lammas growth and autumn color. Stand selection would be a productive way of improving these traits. Autumn color was the only character that had significant amounts of both within- and between-stand variance components and a combination of stand and family selection could be used to improve it.

Table 12.--Correlations (r) between growth characters and climate at place of seed collection for Michigan 1/2-sib progenies, summarized by stand.

Tree Character			Climatic Variable		Was the Trend in the Same Direction as in the Rangewide Study?	
Year Sown	Tree Character	Age When Measured	Latitude	Frost-Free Days		
		years	---r---	----r----	latitude	frost-free days
1966	Height	3	-.52	-.15	Yes	No
	Trees with lammas growth	3	+.21	-.03	No	No
	Trees with female fls.	3	-.13	-.17	Yes	No
	Female fls. per source	3	-.11	-.22	Yes	No
1967	Height	2	-.30	+.50*	Yes	Yes
	Trees with lammas growth	2	-.64**	+.06	Yes	No
	Color	2	-.51**	-.33	Yes	No

* Correlation significant at 5 percent level.

** Correlation significant at 1 percent level.

Table 13.--Analyses of variance for Michigan 1/2-sib progeny tests.

Character	Date Measured	Unit of Measurement	Standard Deviation of Source Mean	F Value	Percent of Variance Explained By Source
Sown in 1966 - Degrees of freedom for source:198, replicate:3, error:594					
(4) Height	9/68	Inches	6.150	1.825***	17
(5) Lammas shoots	6/67	% of trees	0.087	1.319**	7
(6) 1-year cones	6/68	% of trees	0.093	1.249	6
(7) 1-year cones	6/68	No.per tree	0.148	1.281	7
Sown in 1967 - Degrees of freedom for source:182, replicate:3, error:546					
(4) Height	10/68	Inches	2.886	3.304***	37
(5) Color	10/68	Grade	1.254	1.854***	18
(6) Lammas shoots	10/68	% of trees	0.083	1.173	4

** Significant at 1 percent level.

*** Significant at 0.1 percent level.

Table 14.--Within-stand, between-stand, and error variances expressed as a percent of the total variance.

Year Sown	Character	Age When Measured	Percent of Total Variance Due to: Parent Within Stand	Stand	Error
		years			
1966	Height	3	17.1***	0	82.9
	Trees with lammas growth	3	2.1	5.3**	92.6
	Trees with female fls.	3	5.3**	0	94.7
	Female fls. per source	3	6.9**	0	93.1
1967	Height	2	31.9***	7.1	61.0
	Trees with lammas growth	2	3.9	0.5	95.6
	Color	2	10.7***	12.3**	77.0

** Significant at 1 percent level.

*** Significant at 0.1 percent level.

The amount of variation that exists within a typical stand can be seen in table 15. The stand is located on a level site in Crawford County and is growing on Rubicon sand. At the time of seed collection, the average height of the stand was 40 feet and 90 percent of the trees were attacked by the jack pine budworm. The progenies at age 3 varied in height from 19.6 to 26.1 inches. A breeder trying to obtain increased height growth in this population at this age could get substantial improvement by selecting family 4253. He would obtain an increase (over the stand average) of 17 percent.

It was not possible to select a genotypically superior stand for height growth. For example, three similar-aged parent stands, growing on level sites on Rubicon sand in Presque Isle County were 39, 50 and 61 feet. The average 3-year heights of the progeny from each stand were respectively: 23.3, 22.6 and 22.9 inches. In this instance, the shortest parent stand produced the fastest growing offspring.

Effectiveness of Selection for Height

Parent trees were selected for height, stem straightness and non-serotinous cones. Some indication as to the effectiveness of selection for height can be evaluated at this time.

One method that I used to evaluate the effectiveness of selection for height was to divide parent trees into 'control' and 'select' groups, and then I compared progeny performance between the two groups. The 'control' group consisted of parent trees that were either below-average or average, when compared to the average height of trees in the stand. Parents in the 'select' group were at least 10 percent taller than the average height of trees in the stand.

Table 15.--Parental and 3-year progeny growth data for individual-tree selections within a randomly chosen stand.

MSFG	Parent Height	Progeny: Height Sept. 1968	Progeny: Trees With Lammas Shoots Oct. 1967	Progeny: Trees With Female Flowers June 1968	Progeny: Female Flowers June 1968
	(1)	(2)	(3)	(4)	(5)
	feet	percent of stand mean	percent	percent	per 40 trees
4247	50	90	4	4	1
4248	44	108	23	11	4
4249	48	103	32	16	6
4250	50	104	5	15	6
4251	44	89	5	3	2
4252	46	103	11	0	0
4253	40	117	10	16	6
4254	52	88	11	13	5

The results show that selection for height growth in natural stands was only slightly effective in 1966 and nil in 1967. Progenies from 118 parents in the 'select' group in the sources sown in 1966 averaged 23.48 inches at age 3, whereas 81 progenies from the 'control' group averaged 23.38 inches. In the 1967 sown sources, 96 progenies from the 'control' group averaged 7.54 inches and 87 progenies from the 'control' group averaged 7.52 inches. Neither of the differences between the groups was statistically significant.

The second method that I used to evaluate the effectiveness of selection for height was to correlate the height of parent trees with progeny height. For this analysis, I expressed parental heights as a percent of the average height of the stand, and progeny heights as a percent of the average overall progeny height. This permitted a direct comparison of the parental trees, of various ages growing on different sites with progeny performance.

The results from these parent-progeny correlations agree with those received above from analysis of the 'select' and 'control' groups. The correlation between parental height and progeny height in the study sown in 1966 was ($r = .16$). Therefore (r^2) or 2.6 percent of the progenies' height could be explained by parental height. Stated another way, the heritability (ability of a parent to transmit to its offspring) was 2.6 percent for height growth. In the sources sown in 1967, the parent-progeny correlation was 0.0025, and r^2 was negligible.

Results from the within- and between-stand analysis show there is sufficient variation within stands to make individual tree selection worthwhile. The difficulty lies in selecting a genetically superior tree for height growth. Results from the individual tree selections show that mass selection for height growth in natural stands is relatively ineffective when the progenies are three years old. Jack pine is noted for its rapid juvenile growth and possibly the true genetic potential of the families will not be realized until the trees are older. Continued testing of the progenies will show whether or not this is true.

CHAPTER VII

JACK PINE BUDWORM RESISTANCE STUDY

The jack pine budworm has caused much damage in Michigan. It attacks young and old jack pine in both natural stands and plantations. The larvae feed primarily on staminate flowers and newly emerging needles. Several successive years of defoliation can kill large numbers of trees. Certain varieties of Scotch pine have been shown to be resistant to European pine sawfly (*Neodiprion sertifer* (Geoff.)) attack by providing unsuitable sites for ovipositing (Wright *et al*. 1967). This study was undertaken to determine if there is resistance to ovipositing by the jack pine budworm between widely diverse individual-tree selections of jack pine.

Life Cycle of the Jack Pine Budworm

Winter is spent as nonfeeding second-instar caterpillars in silken cases called hibernacula. These cases are spun in old staminate flower bracts, under bark scales on the trunk and larger limbs, or between needles. In spring, the caterpillars emerge and feed for about six weeks. During this time, the larvae go through five additional instars. Pupation begins from late June to late July, depending on locality and weather, and moths issue from early July to early August. A female can lay about 150 eggs. Hatching occurs about two weeks after the eggs are laid. A few days later, without feeding, the first-stage caterpillars spin their hibernacula, molt to the next stage and hibernate (MacAloney and Drooz 1956).

Materials and Methods

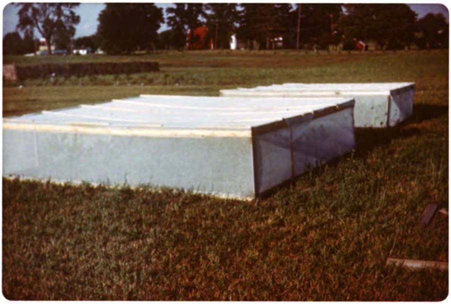
The trees used were 2-0 seedlings from the Michigan individual-tree selections sown in 1966. Twenty-five sources were planted on a one-foot spacing at the Tree Research Center in April 1968. A randomized complete block design was used with single tree plots. The experiment contained three blocks. Each block contained four replicates of the 25 sources. The blocks were 10 feet square. A cage 2 feet high and 11 feet square covered each block (figure 3).

Larvae and pupae were collected in the first week of July from three places near Grayling, Michigan. The larvae were reared on jack pine foliage until pupation was complete. The pupae were then separated by sex. A total of 1,052 female pupae and 826 male pupae were obtained. The male and female pupae were then split into three equal groups. Then one of the three groups of male pupae was placed in a box with one of the three groups of female pupae. The three boxes were kept at 50°F. The moths soon emerged and mated.

The males and gravid females were released in the center of each block of trees on July 27. One box of insects was released in each of the three blocks of trees. The moths dispersed readily throughout the cages. Egg laying started 2 days after the insects were released and was finished within a week.

The easily visible egg masses were counted on each tree when egg laying was completed. Other measurements taken on each tree were height, fresh weight of the foliage, and width of 10 needles.

Figure 3.--The cages pictured here are 2 feet high and 11 feet square. Each cage covers a block of 100 trees.



Results and Discussion

The female moths found the environment suitable for ovipositing and laid 1,030 egg masses, which is almost one egg mass for each released adult female. They laid eggs on 244 of the 300 trees. However, the female moths found no sources which were unsuitable for ovipositing. The 'F' value for the number of egg masses laid on the different sources was 1.007, which was nonsignificant.

I also performed correlations between the number of egg masses and height, amount of foliage, and needle width. All of the correlations were nonsignificant at the 10 percnet level. Height of the sources produced the highest correlation (r = .23), amount of foliage was next with (r = .18), and needle width was lowest (r = .08). From these low correlations, it seems that sources may have been chosen for ovipositing because they were tall and had a large amount of foliage.

Parental trees of 22 of the 25 selections were not attacked by the jack pine budworm. Whether they were not attacked because of genetic reasons or because they were escapes is not known. The results from this study indicates that they were probably escapes. At this early age, however, it cannot be determined whether all of the sources will be susceptible when they reach maturity.

CHAPTER VIII

RESPONSE TO DIFFERENT LEVELS OF ROOT PRUNING

Seedlings are frequently root pruned when transplanted or field planted in order to make planting easier and to produce a dense, fibrous root system. Reduced height growth results whenever seedlings are moved. The fine lateral roots are damaged when the seedlings are lifted and consequently the absorbing area of the roots is reduced. The purpose of this experiment was to determine if different levels of root pruning affect the height growth of transplanted seedlings.

Materials and Methods

The seedlings used were 2-0 stock from the Michigan individual-tree selections sown in 1966. At the end of their second year, the seedlings were about 9 inches tall and had well developed root systems. In March of the following year, a lifter was run under the seedlings that were to be transplanted and cut the roots at 8 inches. The lifter was not run under seedlings that were to remain in the nursery. I applied further root prunings to the seedlings that the lifter had run under. The levels of root pruning were: none, one-fourth, and one-half of the length of the existing roots. The lengths of the roots after the three levels of pruning were respectively: 8, 6 and 4 inches. Each level of root pruning was applied to 30 plots, with four trees per plot. The seedlings were planted on a one foot square spacing on April 15, at the Tree

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the Tree Research Center. Heights were measured immediately after planting and again in September.

I performed an analysis of covariance to adjust for initial height differences. The form for the analysis of covariance follows:

Source of Variation	Degrees of Freedom
Total	89
Between pruning levels	2
Within pruning levels	87
Reduction due to regression	1
Deviations from regression	86

Results and Discussion

The seedlings that remained in their original seedbeds and not undercut by the lifter were 23 inches tall at the end of the growing season. The seedlings that were transplanted had reduced height growth and were only 12 inches tall. However, there was no differential response to the three different levels of root pruning. The seedlings that had one-half of the length of their existing roots removed grew as fast as those that were not pruned beyond what the lifter had removed. First year growth increments for the seedlings that had none, one-quarter, or one-half of the length of their existing root systems removed were respectively: 2.66, 2.64 and 2.68 inches. The 'F' value between the different levels of root pruning, after adjusting for initial height, was 0.0046.

There are several possible reasons why the seedlings did not have different heights as a result of the various levels of root pruning.

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Jack pine is noted for its rapid juvenile growth and it is likely that the root systems grew rapidly and soon attained maximum absorption area. The roots were pruned before growth started in the spring, and they probably elongated very rapidly with initiation of growth.

The roots were pruned according to their length and not actually to the amount of absorbing area. Thus to say that one-half of the length of the roots was removed does not mean that one-half of the absorbing area was removed. The roots were much more developed near the surface and tapered down to a point. Therefore, removing one-half of the length of the root system actually only removed about one-third of the absorbing area.

Another possible reason why there was no difference in growth between the different levels of root pruning is that the seedlings were given good growing condtions. They were not subject to environmental stress. In the nursery environment, they had ample room to grow and received no competition for water or nutrients. Perhaps a difference in height growth would have resulted if they were grown under stress conditions of inadequate water and growing space, or if they received further competition from competing vegetation.

It is probable that transplant 'shock' is not so much a function of degree of pruning or surface area, but simply the fact that reestablishment of root contact with soil and renewed absorption capabilities takes time and results in net growth loss.

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CHAPTER IX

POSSIBILITIES FOR FUTURE IMPROVEMENT

The results obtained to date from the Petawawa range-wide provenance test and the Lower Michigan individual-tree inheritance study give some insight as how to proceed in genetically improving jack pine for height growth. The number and distribution of samples in the Petawawa provenance test was large enough to clearly show the geographic variation pattern. No further provenance tests are needed. The permanent plantations of this study will continue to be measured every three to five years in order to calculate correlations between progeny performance at various ages.

Six plantations of the Lower Michigan individual-tree inheritance study were established in the spring of 1968 with 2-0 stock from the sources selected in 1965 and the remaining three plantations were established in the spring of 1969 with 2-0 stock from the sources selected in 1966. The plantations have replicated randomized complete blocks with 5 and 10 tree plots. There are 40 trees per family in each plantation. The spacing between trees is 6 by 6 feet and the rows are straight in both directions.

No significant difference was found between stands for height growth in the nursery, so in the future each family will be evaluated on its own performance. The plantations will be measured when flowering starts.

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Additional measurements taken at this time besides height growth include branch diameter, stem straightness and other traits such as resistance to disease and insects. Later sets of measurements will be made and analyzed at 5-year intervals.

The plantings will be thinned by removal of the poorest families after each set of measurements. This type of thinning is termed 'family' selection by plant breeders and is the process which leads to improved seed quality. There are approximately 30,000 trees growing in the six plantations. After the first thinning, this number can be reduced to 10,000. The subsequent thinnings will continue to remove the poorest families and also the poorest individuals within the best families; this will give a combined 'family and mass' selection gain. After these thinnings, there will be approximately 4,000, 2,500 and 1,000 trees remaining at ages 10, 15 and 20. The genetic quality of the seed produced will increase with each thinning.

Removal of the poorest families from the progeny tests marks the conversion of the plantations to seed orchards. Cultural treatments may be undertaken in the seed orchards to promote seed production and ease of cone collection. Some of the cultural treatments that can be applied include complete weed control, fertilization, and pruning of the lower branches.

The 1-parent progeny test-seed orchards are the first step in a several-generation improvement program. They will be outmoded at about age 20 by 2-parent progeny test-seed orchards capable of producing seed of higher genetic quality. A 2-parent progeny test is produced by artificial pollination so that both parents are known. The identity of each tree x tree combination is maintained separately. The 2-parent progeny tests give twice as much gain as 1-parent progeny tests of the same size.

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The controlled pollinations will be made as soon as there is adequate flower production in the 1-parent progeny test plantations already established. This will be when the trees are about 8 years old. The crossing scheme will consist of making as many biparental crosses as possible with the 5 best trees in the 25 best families. Each cross will be made in sufficient quantity to produce about 10 cones (300 + seeds) per tree x tree combination. This type of crossing scheme will give maximum gain.

All control-pollinated cones will be collected 16 months after pollination and the seeds will be extracted immediately. Each seedlot's identity will be maintained by seed and pollen parent. Nursery handling will be as was previously described for the Lower Michigan individual-tree selections. Permanent progeny test-seed orchards will be established in the spring with 2-0 stock. The data from the 1-parent progeny test may permit some culling of undesirable progenies in the nursery. However, most of the thinnings and subsequent conversion to seed orchards will follow the procedure previously described for the 1-parent progeny test.

The process of selecting superior families and making crosses between them can be continued into the third and fourth generations. The progress obtained in the first two generations will indicate what gain can be expected if the breeding program is continued into these later generations.

The present information also shows that it is best to leave trees with open cones in areas that are to be thinned and natural regeneration is the only way to obtain reproduction. Most of the trees in the area will have open cones if the procedure is carried on two or three rotation periods and fire will not be needed for seed dispersal.

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APPENDIX

Table 16—Four-year growth data at Allegan and Kellogg, planted 1966.

Ont. number and place of origin		Allegan Height Age 4 1968	Allegan Trees with lammas shoots 1968	Kellogg Height age 4 1968	Kellogg Trees with lammas shoots 1968
3200 +		cm.	percent	cm.	percent
		Sources west of 80° west longitude.			
99	NWT	20	0	27	0
98	NWT	39	8	38	0
96	NWT	33	0	65	8
92	Sas	34	0	47	0
91	Man	41	0	68	0
89	Sas	45	0	65	0
95	Alb	45	3	65	9
85	Ont	50	3	78	8
94	Alb	52	0	41	0
90	Man	59	6	59	0
87	Sas	54	0	82	0
93	Alb	55	3	88	8
64	Ont	65	10	87	33
76	Ont	55	5	73	0
77	Ont	65	0	71	0
88	Sas	70	10	96	0
86	Ont	58	13	76	13
59	Mic	76	7	62	0
83	Man	63	20	93	13
84	Ont	56	10	94	28
82	Ont	61	6	85	17
81	Ont	65	10	96	25
63	Ont	53	14	79	13
62	Ont	59	8	109	17
61	Ont	72	10	99	0
60	Ont	72	8	114	0
58	Ont	63	19	87	17
57	Ont	76	13	137	17
80	Min	76	8	109	8
79	Min	84	27	84	25
78	Min	75	16	104	25
70	Wis	76	55	123	28
55	Ont	70	20	105	17
69	Wis	82	48	106	36
68	Wis	72	46	88	17

Table 16--Continued.

Ont. number and place of origin		Allegan Height Age 4 1968	Allegan Trees with lammas shoots 1968	Kellogg Height age 4 1968	Kellogg Trees with lammas shoots 1968
3200 +		cm.	percent	cm.	percent
75	Mic	84	53	128	13
74	Mic	80	43	104	13
73	Mic	95	18	93	0
72	Mic	75	52	134	38
56	Ont	74	31	102	63
65	Wis	83	62	97	25
66	Wis	81	68	123	38
67	Wis	91	55	141	71
71	Mic	84	64	94	100
54	Ont	94	74	91	0
Sources east of 80° west longitude.					
53	Que	41	0	47	0
5	NS	37	0	59	0
4	NS	43	3	33	0
38	Que	43	0	67	0
21	Que	46	5	70	0
20	Que	66	10	64	0
19	Que	48	0	40	0
3	NS	-	-	-	-
1	NS	-	-	-	-
15	Que	48	3	70	42
37	Que	59	0	79	25
32	Que	50	6	81	38
13	Mai	56	15	84	38
36	Que	56	0	74	0
35	Que	60	0	73	33
34	Que	57	0	59	0
50	Que	59	0	100	13
29	Que	60	0	71	0
14	NB	61	0	78	25
6	NS	57	31	71	13
2	NS	-	-	-	-
16	Que	66	3	82	13
18	Que	63	3	84	13
30	Que	59	23	90	25
31	Que	61	10	67	25

Table 16--Continued.

Ont. number and place of origin		Allegan Height Age 4 1968	Allegan Trees with lammas shoots 1968	Kellogg Height Age 4 1968	Kellogg Trees with lammas shoots 1968
3200 +		cm.	percent	cm.	percent
51	Que	70	5	82	0
28	Que	66	11	73	17
22	Que	64	24	84	17
24	NH	69	34	96	75
33	Que	53	7	67	25
49	Que	61	3	91	13
48	Que	73	6	104	25
9	NB	64	8	94	0
8	NB	59	34	111	13
7	PEI	65	12	78	17
11	NB	75	15	117	13
10	NB	62	21	112	13
12	NB	67	10	72	17
47	Que	61	13	108	25
25	NH	65	13	67	25
26	Mai	68	5	120	0
23	NY	73	23	114	0
27	Que	80	29	85	25
40	Ont	68	47	102	25
39	Ont	63	48	93	33
41	Ont	73	63	91	58
42	Ont	70	54	105	29
43	Ont	91	32	105	13
44	Ont	70	33	100	0
46	Ont	75	23	75	25
L.S.D.(.05) of a provenance mean		7.4	12.5	24.2	3.2
F value		14.9***	7.5***	3.7***	1.7**
Percent of variance due to source		58	39	58	27

** - significant at 1 percent level.

*** - significant at 0.1 percent level.

Table 17--Flower production at the Nursery, Allegan and Kellogg summarized by source.

Ont. number and place of origin		Nursery: Trees with flowers, male 1967	Nursery: Trees with flowers, fem. 1966	Nursery: Fem. fls. for trees with fls. 1966	Allegan: Trees with female flowers 1968	Allegan: Fem. fls. for trees with fls. 1968	Kellogg: Trees with female flowers 1968	Kellogg: Fem. fls. for trees with fls. 1968
3200 +		percent	percent	number	percent	number	percent	number
Sources west of 80° west longitude.								
99	NWT	0	6	1	0	0	0	0
98	NWT	0	2	1	8	3	0	0
96	NWT	0	4	2	0	0	13	2
92	Sas	0	3	2	0	0	13	1
91	Man	0	9	2	0	0	0	0
89	Sas	13	9	1	3	4	13	4
95	Alb	0	36	2	3	2	37	3
85	Ont	0	9	2	0	0	25	2
94	Alb	0	10	3	0	0	0	0
90	Man	0	31	2	5	3	13	1
87	Sas	6	25	2	0	0	25	2
93	Alb	16	9	2	0	0	37	1
64	Ont	8	9	3	5	4	25	2
76	Ont	18	18	2	0	0	50	3
77	Ont	38	15	2	8	2	13	3
88	Sas	6	20	2	5	3	25	2
86	Ont	27	19	2	3	1	13	1
59	Mic	40	47	3	8	3	0	0
83	Man	16	37	3	10	1	0	0
84	Ont	14	25	3	3	1	37	2
82	Ont	37	43	2	6	1	13	1
81	Ont	37	20	2	5	3	25	2
63	Ont	12	43	3	0	0	0	0
62	Ont	33	46	4	5	5	63	3
61	Ont	36	32	3	13	2	13	1
60	Ont	19	35	2	15	3	25	3
58	Ont	9	36	3	0	0	25	3
57	Ont	33	25	2	19	3	25	2
80	Min	18	46	2	18	3	13	3
79	Min	14	59	4	25	3	37	2
78	Min	13	34	2	3	1	13	8
70	Wis	48	40	5	21	3	37	2
55	Ont	4	58	3	8	4	25	3
69	Wis	31	39	2	23	2	0	0
68	Wis	29	40	3	18	3	50	3

Table 17—Continued.

Ont. number and place of origin	Nursery: Trees with flowers, male 1967	Nursery: Trees with flowers, fem. 1966	Nursery: Fem. fls. for trees with fls. 1966	Allegan: Trees with female flowers 1968	Allegan: Fem. fls. for trees with fls. 1968	Kellogg: Trees with female flowers 1968	Kellogg: Fem. fls. for trees with fls. 1968
3200 +	percent	percent	number	percent	number	percent	number
75 Mic	38	40	3	25	2	88	3
74 Mic	35	20	3	20	3	37	1
73 Mic	60	36	3	32	3	63	2
72 Mic	34	19	3	13	3	37	4
56 Ont	55	36	2	10	2	50	3
65 Wis	25	18	2	0	0	25	2
66 Wis	22	10	2	0	0	0	0
67 Wis	33	25	2	3	3	13	2
71 Mic	22	34	3	8	3	13	1
54 Ont	66	41	3	33	2	13	1
Sources east of 80° west longitude.							
53 Que	0	3	2	3	2	13	1
5 NS	16	24	4	3	2	0	0
4 NS	8	19	2	0	0	13	1
38 Que	38	13	2	6	3	50	3
21 Que	14	17	2	0	0	0	0
20 Que	44	36	3	12	2	50	2
19 Que	9	22	3	0	0	0	0
3 NS	19	30	4	-	-	-	-
1 Mai	42	46	3	-	-	-	-
15 Que	34	31	2	8	2	0	0
37 Que	46	28	2	0	0	13	1
32 Que	67	23	5	5	2	13	3
13 Mai	0	29	2	3	3	37	2
36 Que	46	23	2	6	9	25	2
35 Que	56	26	3	3	4	25	2
34 Que	46	47	4	3	2	37	2
50 Que	39	31	2	23	1	63	2
29 Que	15	21	3	5	2	0	0
14 NB	47	14	2	0	0	13	2
6 NS	39	28	2	3	2	0	0
2 NS	47	43	4	-	-	-	-
16 Que	15	30	3	11	6	13	4
18 Que	39	27	3	3	3	25	3
30 Que	24	42	3	8	2	87	2
31 Que	39	22	2	0	0	13	2

Table 17--Continued.

Ont. number and place of origin		Nursery: Trees with flowers male 1967	Nursery: Trees with flowers fem. 1968	Nursery: Fem. fls. for trees with fls. 1966	Allegan: Trees with female flowers 1968	Allegan: Fem. fls. for trees with fls. 1968	Kellogg: Trees with female flowers 1968	Kellogg: Fem. fls. for trees with fls. 1968
3200 +		percent	percent	number	percent	number	percent	number
51	Que	21	24	2	12	2	13	1
28	Que	33	40	4	0	0	25	2
22	Que	14	10	2	8	2	13	1
24	NH	46	28	2	5	3	25	3
33	Que	27	26	3	0	0	25	2
49	Que	35	31	2	3	3	37	2
48	Que	38	27	2	10	4	37	1
9	NB	27	37	1	18	1	25	2
8	NB	48	28	3	3	2	13	1
7	PEI	39	22	2	15	2	25	2
11	NB	67	32	2	15	3	37	2
10	NB	52	29	2	3	3	50	4
12	NB	53	40	3	3	1	0	0
47	Que	64	31	3	6	2	37	1
25	NH	68	49	2	8	6	13	2
26	Mai	46	43	3	34	2	37	2
23	NY	37	29	4	13	3	37	2
27	Que	70	57	4	18	3	37	2
40	Ont	63	51	2	7	1	13	1
39	Ont	13	29	3	3	8	25	1
41	Ont	52	22	3	12	4	25	1
42	Ont	68	37	2	10	3	37	1
43	Ont	45	30	3	22	3	25	2
44	Que	34	73	3	3	2	13	1
46	Ont	68	52	4	9	5	37	2
Percent of sources with flowers		89	100		77		83	
L.S.D.(.05) of a source mean		6.1	17.65	5.02	0.39	1.63	3.69	3.14
F value		3.9***	3.2***	3.1***	2.14***	2.09***	1.54*	1.44*
Percent of variance source explains		43	35	34	11	10	21	18

* - significant at 5 percent level.
*** - significant at 0.1 percent level.

Table 18--Analyses of variance for provenance test at the Tree Research Center, includes seedlot 97 which was later discarded.

Degrees of freedom for source 95, replicate 3, error 285 - total 383.

Character	Date measured	Unit of measurement	Mean Square: Seedlot	Mean Square: Replicate	Mean Square: Rep. x Seed.	$\sigma = \sqrt{\frac{\text{Rep. x Seed. M.S.}}{4}}$	F value	Percent variance explained by source
(5) Height	9/65	1/8 in.	495.09298	295.79861	37.04072	3.04	7.987***	63
(6)	12/65	cm.	686.58421	1014.54861	72.32756	4.25	9.493***	68
(7)	6/66	inches	273.27103	282.98872	15.58521	1.99	17.534***	81
(8) Color	10/64	Grade	16.62456	4.077778	2.569883	0.80	6.469***	58
(9)	10/65	Grade	3.379578	1.523438	0.353262	0.29	9.567***	68
(10) Buds	9/64	No. per 16 trees	11.287911	105.79427	6.017078	1.23	1.877***	18
(11) Crooks	10/65	No. per tallest tree in row	1.710088	3.631944	0.560015	0.37	3.054***	34
(12) Deviation	10/65	inches	1.742078	2.155382	0.739592	0.43	2.355***	25
(13) Female fls.	6/66	No. per source	109.86042	67.517361	34.40508	2.92	3.193***	35
(14)	6/66	No. trees with	8.464474	27.125000	2.765351	0.83	3.061***	34
(15) Male fls.	6/67	No. trees with	16.297780	48.176215	4.123584	1.01	3.952***	43

*** = significant at 0.1 percent level.

Table 19 --Analyses of variance for provenance test planted at Kellogg, includes seedlot 97 which was later discarded.

Degrees of freedom for source 92, replicate 1, error 92 - total 185.

Character	Unit of measurement	Mean Square			σ = Rep. x Seed. M.S. / 2	F value	Percent variance explained by source
		Seedlot	Replicate	Rep. x Seed.			
Height	1/10 feet	118.8504	114.60215	32.05867	4.001	3.707***	58
Two-year cones	No. trees with	0.29604	0.08602	0.11863	0.244	2.496***	43
	No. per source	0.48492	0.13441	0.21049	0.324	2.304***	39
One-year cones	No. trees with	1.15054	1.55376	0.74942	0.612	1.535*	21
	No. per source	7.26367	3.63441	5.04745	1.590	1.439*	18
Secondary-growth	No. trees with	0.94460	0.00538	0.54885	0.524	1.721**	27

* = significant at 5 percent level.
** = significant at 1 percent level.
*** = significant at 0.1 percent level.

Table 20—Analyses of variance for provenance test planted at Allegan, includes seedlot 97 which was later discarded.

Degrees of freedom for source 92, replicate 9, error 828 - total 929.

Character	Unit of measurement	Mean Square			$\sigma = \sqrt{\frac{\text{Rep. x Seed. M.S.}}{10}}$	F value	Percent variance explained by source
		Seedlot	Replicate	Rep. x Seed.			
Height	1/10 feet	223.4044	33.26834	14.93405	1.225	14.934***	58
Two-year cones	Number per source	1.52840	1.30227	0.73101	0.271	2.091***	10
	Percent of trees with	3.80920	0.58695	20.86583	1.443	1.643***	6
One-year cones	Percent of trees with	0.06723	0.10843	0.03138	0.056	2.142***	11
Secondary-growth	Percent of trees with	35.29207	0.56419	42.41776	2.060	7.488***	39

*** = significant at 0.1 percent level.

Table 21—Analyses of variance for provenance test arranged by regions. All measurements were made at the Tree Research Center except for the percent of trees with lammas growth, which was measured at Allegan.

At the Tree Research Center - degrees of freedom between stands 8, within stands 86, error 282.
At Allegan - degrees of freedom between stands 8, within stands 86, error 828.

Character	Date measured	Unit of measurement	Mean Square			Percent of Total Variance		
			Between regions	Within regions	Error	Between regions	Within regions	Error
Height	6/66	Inches	8269	428	63	55	26	19
Color	10/64	Grade	500	27	10	44	16	40
Male fls.	6/67	Percent of trees with	256	48	17	17	27	56
Female fls.	6/66	Percent of trees with	101	28	11	10	24	66
Female fls.	6/66	No. per source	1304	364	137	11	26	63
Crooks	10/65	No. per tallest tree in row	43.5	3.5	2.3	28	9	63
Crook size	10/65	Inches	44.1	3.6	3.0	24	4	72
Lammas shoots	8/68	Percent of trees with	25.2	1.8	0.5	24	16	60

Table 22.— Correlations between characters in provenance study.

Key to characters:

1 thru 3 were measured at place of seed collection

1. latitude
2. length of growing season
3. number of growing degree-days

4 thru 12 were measured at the Tree Research Center

4. height at age 1.
5. height at age 2.
6. height at age 3.
7. autumn color at age 1.
8. number of male flowers for trees with flowers.
9. number of female flowers for trees with flowers.
10. percent of trees with female flowers.
11. percent of trees with buds set by September 22, 1966.
12. number of crooks for the tallest tree in each plot.

13 thru 16 were measured at Kellogg

13. height ate age 4.
14. number of female flowers for trees with flowers.
15. percent of trees with female flowers.
16. percent of trees with lammas growth.

17 thru 20 were measured at Allegan

17. height at age 4.
18. number of female flowers for trees with flowers.
19. percent of trees with female flowers.
20. percent of trees with lammas growth.

Table 22.--Correlations between characters in provenance test.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
6	-.77	.73	.80	.93	.97	1.0														
7	-.85	.71	.72	-	-	.78	1.0													
8	-.56	.36	.35	-	-	.55	-	1.0												
9	-.43	.39	.40	-	-	-	-	-	1.0											
10	-.55	.46	.45	-	-	-	-	.44	-	1.0										
11	-.22	.19	.22	-	-	-	-	-	-	-	1.0									
12	-	-	-	-	-	.72	-	-	-	-	-	1.0								
13	-.63	.63	.65	.71	.77	.77	-	-	-	-	-	-	1.0							
14	-.33	.29	.39	-	-	.61	-	-	-	-	-	-	-	1.0						
15	-.22	.12	.11	-	-	-	-	-	-	.26	-	-	.39	-	1.0					
16	-.33	.36	.38	-	-	-	-	-	-	-	-	-	.39	-	-	1.0				
17	-.75	.74	.77	.79	.82	.83	-	-	-	-	-	-	.74	-	-	-	1.0			
18	-.41	.34	.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0		
19	-.40	.41	.42	-	-	-	-	-	-	.40	-	-	-	-	.37	-	.62	-	1.0	
20	-.57	.24	.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Table 23--Tests of interaction for height between Allegan, Kellogg and the Tree Research Center in the provenance study.

Test between Allegan and Kellogg.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	8586.8	8586.8		
Rep(plantations)	10	414.0	41.4		
Source	92	31136.3	338.4		
Plantation x Source	92	351.1	3.8	0.229	Not significant.
Error	920	15335.8	16.7		
TOTAL	1115	55824.0			

Test between Allegan and Tree Research Center.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	97881.6	97881.6		
Rep(plantations)	12	1148.4	95.7		
Source	92	38981.4	423.7		
Plantation x Source	92	6981.8	75.9	5.0**	Significant at 1 percent level.
Error	1104	16828.2	15.2		
TOTAL	1301	161821.4			

Test between Kellogg and Nursery.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	17119.8	17119.8		
Rep(plantations)	4	990.4	247.6		
Source	92	32962.4	358.3		
Plantation x Source	92	3381.8	36.8	1.80**	Significant at 1 percent level.
Error	368	7552.6	20.5		
TOTAL	557	62007.0			

Table 24--Test of interaction for percent of trees with female flowers between Allegan, Kellogg and the Tree Research Center in the provenance test.

Test between Allegan and Kellogg.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	1.2702	1.2702		
Rep(plantations)	10	1.0002	.10002		
Source	92	6.2745	.06820		
Plantation x Source	92	0.4757	.00517	1.759**	Significant at 1 percent level.
Error	920	27.0618	.00294		
TOTAL	1115	36.0824			

Test between Allegan and Tree Research Center.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	11.4620	11.462		
Rep(plantations)	12	1.3045	.10870		
Source	92	9.7140	.10559		
Plantation x Source	92	3.7613	.04088	1.337*	Significant at 5 percent level.
Error	1104	33.7513	.03057		
TOTAL	1301	59.9931			

Test between Kellogg and Nursery.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	3.4968	3.4968		
Rep(plantations)	4	0.3529	.08823		
Source	92	3.1545	.03429		
Plantation x Source	92	5.8011	.06306	2.624**	Significant at 1 percent level.
Error	368	8.8441	.02403		
TOTAL	557	21.6494			

Table 25 --Test of interaction for percent of trees with lammas growth between Allegan and Kellogg in the provenance test.

Source of variance	Degrees of freedom	Sum of squares	Mean square	F value	
Plantations	1	0.0014	.0014		
Rep(plantations)	10	0.5645	.0565		
Source	91	35.2077	.3869		
Plantation x Source	91	6.4256	.0706	1.404**	Significant at 1 percent level.
Error	910	45.8168	.0503		
TOTAL	1103	88.0160			

Table 26—Origin and growth data for 1966 sown Michigan 1/2-sib progeny test, summarized by stand of origin.

Stand	No. of trees in stand	County of origin(a)	North Lat.	West Long.	Frost free days	Height Sept. 1968	Trees with lammas shoots Oct. 1967	Trees with female flowers June 1968	Female flowers June 1968
			degrees	degrees	no.	percent of overall mean	percent	percent	per 40 trees
1	14	Osc	44.70	84.20	90	102	13	11	7
2	4	Osc	44.80	84.32	90	96	17	25	13
3	6	Osc	44.83	84.20	90	106	14	17	11
4	5	Osc	44.83	84.13	90	93	29	12	7
5	4	Ios	44.47	83.45	129	105	13	23	10
6	4	Ios	44.48	83.37	129	106	11	16	9
7	6	Cra	44.58	84.62	85	102	20	17	9
8	8	Cra	44.58	84.82	85	95	13	10	4
9	6	Cra	44.70	84.37	90	97	18	7	4
10	4	Cra	44.53	84.84	85	103	17	22	13
11	4	Kal	44.72	85.22	120	104	10	12	5
12	10	Ots	45.15	84.45	96	101	20	13	8
13	6	Ots	45.33	84.40	96	96	20	13	8
14	4	Ots	44.90	84.48	90	99	5	23	11
15	5	Oge	44.32	84.28	100	101	17	16	9
16	5	Oge	44.43	84.25	96	95	16	12	9
17	5	Oge	44.47	84.35	98	104	15	9	6
18	5	Oge	44.43	84.30	97	104	11	14	11
19	5	Oge	44.40	84.33	99	102	14	18	11
20	4	Ros	44.47	84.37	92	99	16	13	7

Table 26--Continued.

Stand	No. of trees in stand	County of origin(a)	North Lat.	West Long.	Frost free days	Height Sept. 1968	Trees with lammas shoots Oct. 1967	Trees with female flowers June 1968	Female flowers June 1968
			degrees	degrees	no.	percent of overall mean	percent	percent	per 40 trees
21	5	Ros	44.27	84.48	98	99	20	11	5
22	4	Ros	44.47	84.65	80	99	14	12	7
23	5	Ros	44.18	84.64	100	106	17	21	13
24	2	Ros	44.33	84.80	81	106	11	9	8
25	3	Ros	44.45	84.46	100	96	15	16	9
26	5	Mis	44.37	85.15	107	106	21	14	8
27	3	Ros	44.32	84.80	100	104	22	22	13
28	3	GT	44.72	85.38	130	103	9	2	2
29	3	GT	44.71	85.38	100	106	28	16	9
30	4	Ben	44.45	85.58	118	100	14	10	6
31	5	Ros	44.53	85.89	130	100	11	10	5
32	2	Che	44.35	84.55	125	95	17	8	6
33	7	Emm	44.68	84.93	130	97	27	16	9
34	5	Che	44.38	84.45	126	101	14	13	9
35	6	Che	44.47	84.32	125	95	13	10	5
36	4	PI	44.28	84.03	130	98	16	13	11
37	6	PI	45.70	83.98	129	96	14	13	9
38	5	PI	45.25	84.09	128	98	30	14	10
39	5	PI	45.32	84.22	129	99	16	16	8
40	3	PI	45.29	83.95	130	86	17	8	3

Table 26—Continued.

	Height Sept. 1968	Trees with lammas shoots Oct. 1967	Trees with female flowers June 1968	Female flowers June 1968
	percent of overall mean	percent	percent	per 40 trees
F value	0.990	2.061**	0.839	0.928

** - significant at 1 percent level.

(a) County names are as follows: Osc = Oscoda, Ios = Iosco, Cra = Crawford, Kal = Kalkaska, Ots = Otsego, Oge = Ogemaw, Ros = Roscommon, Mis = Missaukee, GT = Grand Traverse, Ben = Benzie, Che = Cheboygan, Emm = Emmet, PI = Presque Isle.

Table 27—Origin and growth data for 1967 sown Michigan 1/2-sib progeny test, summarized by stand of origin.

Stand	Number of trees in stand	County of origin(a)	North Lat.	West Long.	Frost free days	Height Oct. 1968	Color Oct. 1968	Trees with lammas shoots Oct. 1968
			degrees	degrees	no.	percent of overall mean	grade	percent
1	4	Alp	45.12	83.63	125	128	4	4
2	15	Mon	45.08	84.23	95	92	8	7
3	7	Mon	45.13	84.32	95	84	6	14
4	7	Mon	45.08	84.03	95	92	7	9
5	10	Mon	44.93	84.11	93	96	8	11
6	9	Lak	44.03	85.78	100	106	9	15
7	1	Lak	43.95	85.78	100	114	9	18
8	3	Lak	43.98	85.80	100	121	7	14
9	9	GT	44.63	85.47	125	107	8	13
10	11	GT	44.63	85.45	125	99	8	10
11	8	GT	44.62	85.40	130	106	6	16
12	16	Oge	44.48	84.35	98	94	8	12
13	7	Oge	44.42	84.22	97	89	8	12
14	11	Osc	44.87	84.22	90	107	8	10
15	2	Osc	44.80	84.27	90	87	6	7

Table 27—Continued.

Stand	Number of trees in stand	County of origin(a)	North Lat.	West Long.	Frost free days	Height Oct. 1968	Color Oct. 1968	Trees with lammas shoots Oct. 1968
			degrees	degrees	no.	percent of overall mean	grade	percent
16	16	Ots	45.13	84.48	96	99	7	8
17	5	Ots	44.87	84.87	90	94	8	6
18	8	Cra	44.58	84.93	85	94	7	17
19	11	Cra	44.57	84.52	85	98	7	9
20	12	Ros	44.36	84.40	99	92	9	10
21	11	Ros	44.22	84.78	100	98	8	12
				F value		1.638	1.077	2.739**

** - significant at 1 percent level.

(a) County names are as follows: Alp = Alpena, Mon = Montmorency, Lak = Lake, Oge = Ogemaw, GT = Grand Traverse, Ots = Otsego, Cra = Crawford, Ros = Roscommon, Osc = Oscoda.

Color grades: 0-3 purple, 4-6 intermediate, 7-10 green.

Table 28.—Analyses of variance for 1967 sown Michigan 1/2-sib progeny test.

Degrees of freedom for source 182, replicate 3, error 546 - total 731.

Character	Date measured	Unit of measurement	Mean Square			σ = Rep x Seed MS / 4	F value	Percent variance explained by source
			Seedlot	Replicate	Rep x Seed			
Height	10/68	Inches	110.07477	29.029144	33.312111	2.386	3.304***	37
Color	10/68	Grade	11.668994	181.61521	6.2928652	1.254	1.854***	18
Lammas shoots	10/68	Percent of trees with	0.0321509	0.0831988	0.0274161	0.083	1.173*	4

* = significant at 10 percent level.
*** = significant at 0.1 percent level.

Table 29.—Analyses of variance for 1966 sown Michigan 1/2-sib progeny test.

Degrees of freedom for source 198, replicate 3, error 594 - total 795.

Character	Date measured	Unit of measurement	Mean Square: Seedlot	Mean Square: Replicate	Mean Square: Rep x Seed	$\sigma = \sqrt{\frac{\text{Rep x Seed MS}}{4}}$	F value	Percent variance explained by source
Height	6/67	Inches	70.529669	11.672948	32.835406	2.865	2.148***	22
Height	9/68	Inches	276.08156	166.74874	151.30682	6.150	1.825***	17
Lammas shoots	6/67	Percent of trees with	0.0395963	0.9092662	0.0300156	0.087	1.319**	7
One-year cones	6/68	Percent of trees with	0.0436065	0.1075361	0.0349072	0.093	1.249*	6
One-year cones	6/68	Number per tree	0.1125774	0.3041909	0.0878631	0.148	1.281*	7

* = significant at 5 percent level.
** = significant at 1 percent level.
*** = significant at 0.1 percent level.

Table 30.--Analyses of variance for between- and within-stand variances for Michigan 1/2-sib progeny tests.

Test sown in 1966.

Height age 3.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	39	10,683.55	273.94	0.990
Within stands	159	43,980.60	276.61	
Between progenies	198	54,664.15		

Trees with lammas growth age 3.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	39	2.63	0.270	2.061**
Within stands	159	5.21	0.131	Significant at
Between progenies	198	7.84		1 percent level.

Trees with female flowers age 3.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	39	1.468	0.0377	0.835
Within stands	159	7.166	0.0451	
Between progenies	198	8.634		

Number of female flowers per source age 3.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	39	4.1331	0.1060	0.928
Within stands	159	18.1572	0.1142	
Between progenies	198	22.2903		

Table 30.—Continued.

Test sown in 1967.

Height age 2.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	20	3,369.1	168.46	1.638
Within stands	162	16,664.5	102.87	
Between progenies	182	20,033.6		

Trees with lammas growth age 2.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	20	0.6864	0.0343	1.076
Within stands	162	5.1651	0.0319	
Between progenies	182	5.8515		

Autumn color age 2.

Source of variance	Degrees freedom	Sum of squares	Mean square	F value
Between stands	20	536.69	26.835	2.739**
Within stands	162	1587.07	9.799	Significant at
Between progenies	182	2123.76		1 percent level.

Table 31 —Correlations for Michigan 1/2-sib progeny collections.

Key to characters:

1966 sown collections.

1 and 2 were measured at the place of seed collection.
1. latitude.
2. length of growing season.

3 thru 6 were measured at the Tree Research Center.
3. height at age 3.
4. percent of trees with lammas growth.
5. percent of trees with female flowers.
6. number of female flowers for trees with flowers.

1967 sown collections.

1 and 2 were measured at the place of seed collection.
1. latitude.
2. length of growing season.

3 thru 5 were measured at the Tree Research Center.
3. height at age 2.
4. percent of trees with lammas growth.
5. autumn color at age 2.

Table 31.--Correlations for Michigan 1/2-sib progeny collections.

1966 sown collections.

	1	2	3	4	5	6
1	1.00					
2	----	1.00				
3	-.45	-.15	1.00			
4	.36	.28	-.08	1.00		
5	-.11	-.17	.21	----	1.00	
6	-.09	-.23	.23	----	----	1.00

1967 sown collection.

	1	2	3	4	5
1	1.00				
2	----	1.00			
3	-.30	.50	1.00		
4	-.64	-.06	----	1.00	
5	-.51	-.33	----	----	1.00

Table 32.--Data on budworm resistance study, summarized by source.

MSFG	County of origin(a)	Egg masses	Height	Needle Weight	Needle Width
		(1)	(2)	(3)	(4)
4000 +		number	inches	mg.	mm.
206	Osc	3.9	17.1	4.7	11.67
221	Osc	4.7	17.1	3.3	11.68
238	Ios	4.0	15.9	3.0	11.69
240	Cra	3.8	14.7	4.0	11.69
251	Cra	2.6	14.6	3.2	11.52
257	Cra	3.0	16.6	3.2	11.58
274	Ots	2.6	16.1	3.3	11.68
280	Ots	4.4	17.5	4.4	11.61
288	Ots	3.6	16.4	3.9	11.57
299	Oge	2.6	15.4	3.4	11.49
302	Oge	3.4	17.1	4.0	11.76
310	Oge	4.8	17.7	4.0	11.38
327	Ros	2.9	16.8	3.9	11.66
338	Ros	4.4	16.7	3.4	11.57
357	Ros	4.6	16.6	4.0	11.59
364	Ros	3.0	17.9	3.9	11.64
376	GT	1.7	16.2	2.9	11.60
379	Wex	3.5	16.5	3.6	11.68
380	Ben	3.0	17.3	3.0	11.67
384	Che	2.4	13.4	2.4	11.42
388	Emm	3.3	16.5	3.4	11.63
391	Emm	2.7	15.5	3.1	11.66
405	Che	3.3	15.6	2.9	11.67
407	PI	3.7	16.6	3.0	11.68
427	PI	3.7	15.0	3.2	11.63

(a) County names are as follows: Osc = Oscoda, Ios = Iosco, Cra = Crawford, Ots = Otsego, Oge = Ogemaw, Ros = Roscommon, GT = Grand Traverse, Wex = Wexford, Ben = Benzie, Che = Cheboygan, Emm = Emmet, PI = Presque Isle.

Table 33.--Analysis of variance for number of egg masses per source in budworm resistance study.

Source of variation	Degrees freedom	Sum of squares	Mean square	F value
Between sources	24	166.5000	6.938	1.007[NS]
Replication	11	391.8267	35.621	
Reps x Seedlot	264	1819.3400	6.891	
Total	299	2377.6667		

Table 34.--Correlations in budworm resistance study.

Key to characters:

1. Height.
2. Volume of needles on tree.
3. Number of egg masses.
4. Needle width.

	1	2	3	4
1	1.00			
2	----	1.00		
3	.23	.18	1.00	
4	----	----	.08	1.00