GEOGRAPHIC VARIATION OF JACK PINE (PINUS BANKSIANA LAMB.)[1]

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ABSTRACT.--Ten traits were measured on 10-year-old jack pine grown at Cloquet, Minnesota, from seed collected from 90 provenances. The traits were examined by using analysis of variance and computing correlations for all combinations of 9 traits plus latitude, longitude, and elevation of the seed sources and cluster analyses using the D^2 values from the Mahalanobis distance function. Results of the ANOVA showed that seed sources differed greatly for the 10 traits measured and results of the cluster analysis showed that populations can be geographically defined.

Jack pine (*Pinus banksiana* Lamb.) is an important conifer in North America. It is abundant, grows well on drier, sandy soils, has rapid early growth, and is suitable for pulp and solid wood products. Its range extends from northern New England and the Maritime Provinces west to the Lake States, Alberta, and the Mackenzie District of Northwest Territories.

Because of its importance in Minnesota, a provenance study was begun in 1940. Geographic variation among provenances in this test was reported by Schantz-Hansen and Jensen (1952, 1954) and Schoenike *et al*. (1959). An additional test was begun in 1951 by P. O. Rudolf and several reports on this experiment have been published (Stoeckeler and Rudolf 1956, Conover 1957, Arend *et al*. 1961, Batzer 1961, Rudolph 1964, King 1965, King and Nienstaedt 1965, and Alm and Jensen 1969. Schoenike (1962, 1976) did a detailed study of jack pine variation in natural stands and reported large amounts of variation in many traits; some characteristics showed variation patterns related to geographic location. A range-wide provenance study was undertaken by Holst and Yeatman (1961) and Yeatman (1964, 1966). Yeatman (1966) found an overall clinal pattern

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of genetic variation resulting from environmental adaptation. The material from the Holst-Yeatman study was widely distributed within the species range; a test in Minnesota is the basis for this report. It is the most recent and comprehensive jack pine provenance test in Minnesota and was planted in 1966. The objectives of study were to (1) examine the variation among seed sources for a number of morphological traits and (2) examine the pattern of this variation in relation to geographic distribution using cluster analysis.

MATERIALS AND METHODS

In May of 1966, 1-1 stock from 90 seed sources were planted at Cloquet, Minnesota (fig. 1). A randomized complete block planting design was used with 4 tree-row plots and 5 replications.

When the trees were 10 years old from seed, the following measurements were taken: (1) total tree height, (2) tree diameter at 1 foot above the ground, (3) bark thickness at 1 foot above the ground, (4) crown width, (5) average number of live branches per whorl, (6) average branch angle, (7) average cone angle, (8) cone serotiny, (9) cone abundance, and (10) type of cone curvature. Measurements were made on the first two living trees in each plot.[3]

Standard Analysis of Variance was used to evaluate all of the traits measured except type of cone curvature. (The nature of the cone curvature data made it unsuited for analysis of variance.) Missing data were handled using the procedures given by Snedecor and Cochran (1972) because less than 2 percent of observations were missing.

Differences due to geographic variation were estimated for the nine traits from the ANOVA table by:

$$\frac{\sigma_G^2}{\sigma_G^2 + \sigma_E^2}$$

where σ_G^2 = component of geographic variance,

σ_E^2 = component of envi.onmental variance.

Simple correlation coefficients were computed for every possible pair of 12 variables: 9 traits (as previously listed excluding the type

[3]Details on measurement techniques can be found in "Geographic variation of jack pine (Pinus banksiana Lamb.)" by J. O. Hyun (1976) on file at the Library, College of Forestry, University of Minnesota.

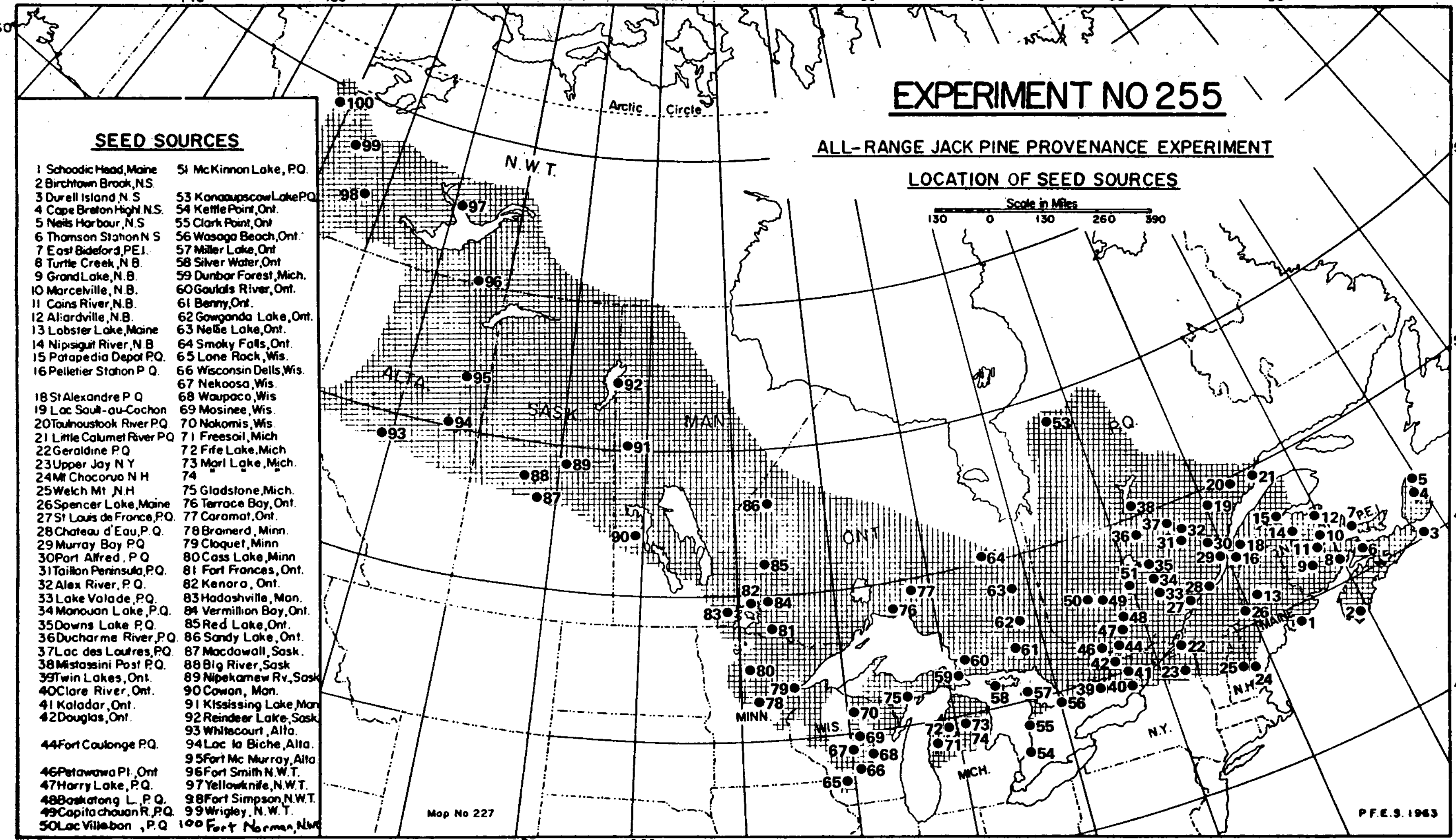

Fig. 1. Natural distribution of jack pine (shaded) and seed sources included in this study (numbered dots). This map was modified from the Map No. 227 for Experiment No. 255 of the Petawawa Forest Experiment Station.

of cone curvature) and 3 geographic gradients (latitude, longitude, and elevation).

The data were fitted to the multivariate analysis using the generalized distance function of Mahalanobis (1936) as treated by Schoenike (1976), Rose (1974), Squillace (1966), Wells (1964), and Wright and Bull (1963). The multivariate analysis made it possible to treat all the traits simultaneously and to compare each seed source with every other one. The formula for generalized distance when more than two traits are compared is:

$$D^2 = \Sigma_i \Sigma_j \; S_{ij}^{\;-1} d_i d_j$$

where

D^2 = generalized distance,

d_i = the mean population distance for the ith variable,

d_j = the mean population distance for the jth variable, and

S_{ij}^{-1} = the element in the inverse of the covariance matrix corresponding to the ith and jth variable.

D^2 values were computed for the 10 traits measured from the trees from the 90 seed sources[3]. The D^2 values were then used in a cluster analysis to develop numerical values expressing the relative similarities among seed sources.

RESULTS AND DISCUSSION

Significant differences (5 percent or 1 percent level) were found among seed sources for all traits except number of live branches per whorl (table 1). The geographic location of the seed source had the most effect on height, diameter, bark thickness, and crown width; had a moderate effect on cone angle, cone abundance, cone serotiny, and branch angle; and had the least effect on number of live branches per whorl.

King (1965) showed that the seed sources best suited for the Lake States are found within the region. However, results from our study show that height growth of three seed sources from Ontario (42, 55, and 60), three seed sources from Quebec (33, 47, and 48), and one from Manitoba (83) exceeded the local source (79). Therefore, in jack pine breeding, seed sources from other regions can be included in addition to local sources.

Height, diameter, bark thickness, and crown width are highly and positively correlated to each other (table 2). Furthermore, these four traits show moderate negative correlation with latitude. Only diameter and crown width show significant (1 percent level) negative correlation with longitude. No traits have a significant correlation with elevation. The number of live branches per whorl show a small but significant negative correlation with longitude. A significant, negative, correlation was determined between cone serotiny and cone abundance and a significant, positive correlation between serotiny and longitude. Schoenike (1976) found a significant, positive, correlation between serotiny and latitude, but I could not demonstrate this relation.

Table 1.--Summary of field measurements and analysis of variance

Traits	Plantation mean	Standard deviation	Range of seed source means	F ratio seed source/error	Proportion of geographic variation
					percent
Height	12.8 ft.	1.55 (12)[1/]	6.3-16.0	7.05**[2/]	55[3/]
Diameter	3.2 in.	.41 (13)	1.4- 4.2	6.34**	52
Bark thickness	21.5 $\frac{1}{10}$in.	3.12 (15)	8.3-33.5	8.54**	60
Crown width	9.7 ft.	1.27 (13)	3.9-12.2	5.74**	49
Branch angle	61.0°	6.42 (11)	46.1-72.6	2.28**	30
No.of branches	4.4	.57 (13)	3.9- 5.2	1.22	7
Cone angle	32.9°	18.84 (57)	3.1-64.8	2.68**	36
Cone serotiny	0.546	.344(63)	.083-1.00	1.82**	21
Cone abundance	12.58	8.24 (66)	1.3-29.2	2.51**	34

1/ Numbers in parentheses are percent of the plantation mean

2/ ** indicates significant at 1 percent level

3/ Proportion = $\frac{\sigma_G^2}{\sigma_G^2 + \sigma_E^2}$

As latitude increases, tree growth rate decreases. Also, diameter and crown width decrease as both latitude and longitude increase and are smallest in the northwestern part of the species range.

The D^2 values from the Mahalanobis distance function generated by the computer were used to group the 90 seed sources into clusters.

Table 2.--Simple correlation coefficients (r) for 9 traits and 3 geographic gradients

	1 Height	2 Diameter	3 Bark thickness	4 Crown width	5 Branch angle	6 No. of branches	7 Cone angle	8 Cone serotiny	9 Cone abundance	10 Latitude	11 Longitude	12 Elevation
Height	1.0 1/											
Diameter	.887**2/	1.0										
Bark thickness	.703**	.806**	1.0									
Crown width	.783**	.839**	.673**	1.0								
Branch angle	-.038	-.062	-.138	.064	1.0							
No. of branches	.360**	.337**	.146**	.261**	.099*	1.0						
Cone angle	-.091*	-.049	.095*	-.064	-.069	.032	1.0					
Cone serotiny	.025	-.010	-.030	.002	-.053	.009	-.028	1.0				
Cone abundance	.297**	.305**	.090*	.353**	.091*	.198**	-.253**	-.101*	1.0			
Latitude	-.393**	-.409**	-.453**	-.453**	.065	-.063	-.147**	.076	-.096*	1.0		
Longitude	-.073	-.151**	-.037	-.220**	-.125**	-.090*	-.138**	.124**	-.134**	--	1.0	
Elevation	.013	-.025	.009	-.067	.009	-.051	-.077	.042	-.021	--	--	1.0

1/ Coefficients in the block are based on data of 5 replications and others are based on 3 replications.

2/ Significant at 1 percent level (**) or 5 percent level (*).

Then, I plotted a dendrograph on the computed within- and between-cluster distances. On the dendrograph, degree of similarity was expressed by the distance between clusters--the shorter the distance between clusters, the more similar they were to each other.

Examination of distances between seed sources and distances within prospective clusters led to the decision to divide seed sources into five final clusters. Cluster A contains 30 seed sources mostly from Ontario, southern Quebec, and eastern Manitoba (table 3 and fig. 2). In cluster B there are 17 seed sources mostly from eastern Quebec, southern Ontario, and along the St. Lawrence River plus several from Alberta, Manitoba, and western Ontario. Three seed sources from the Northwest Territories and Alberta in the western portion of the natural distribution of jack pine plus one source from northwestern Quebec make up cluster C. Cluster D contains 25 seed sources mainly from the eastern portion of the species range (southern Ontario, southeastern Quebec, northern New York, New Hampshire, Maine and Nova Scotia. The last and most distinct cluster, E, is made up of sources primarily from the Lake States. They are taller, have broader crowns, more accute branch angles, larger cone angles, higher serotiny frequency, and fewer cones compared to plantation averages.

Table 3.--Seed sources after grouped into clusters

Clusters	No. of seed sources	Seed sources
A	30	51, 63, 48, 33, 83, 47, 49, 60, 26, 76, 89, 64, 50, 57, 44, 82, 86, 58, 46, 40, 8, 42, 84, 10, 87, 55, 90, 91, 85, 81
B	17	31, 41, 16, 39, 88, 30, 32, 62, 15, 18, 4, 13, 95, 77, 92, 94, 20
C	4	53, 97, 93, 99
D	25	27, 35, 98, 12, 38, 19, 25, 36, 5, 28, 34, 29, 11, 70, 6, 9, 56, 7, 23, 21, 61, 22, 24, 37, 14
E	14	68, 72, 69, 66, 65, 78, 67, 80, 73, 79, 71, 74, 75, 54

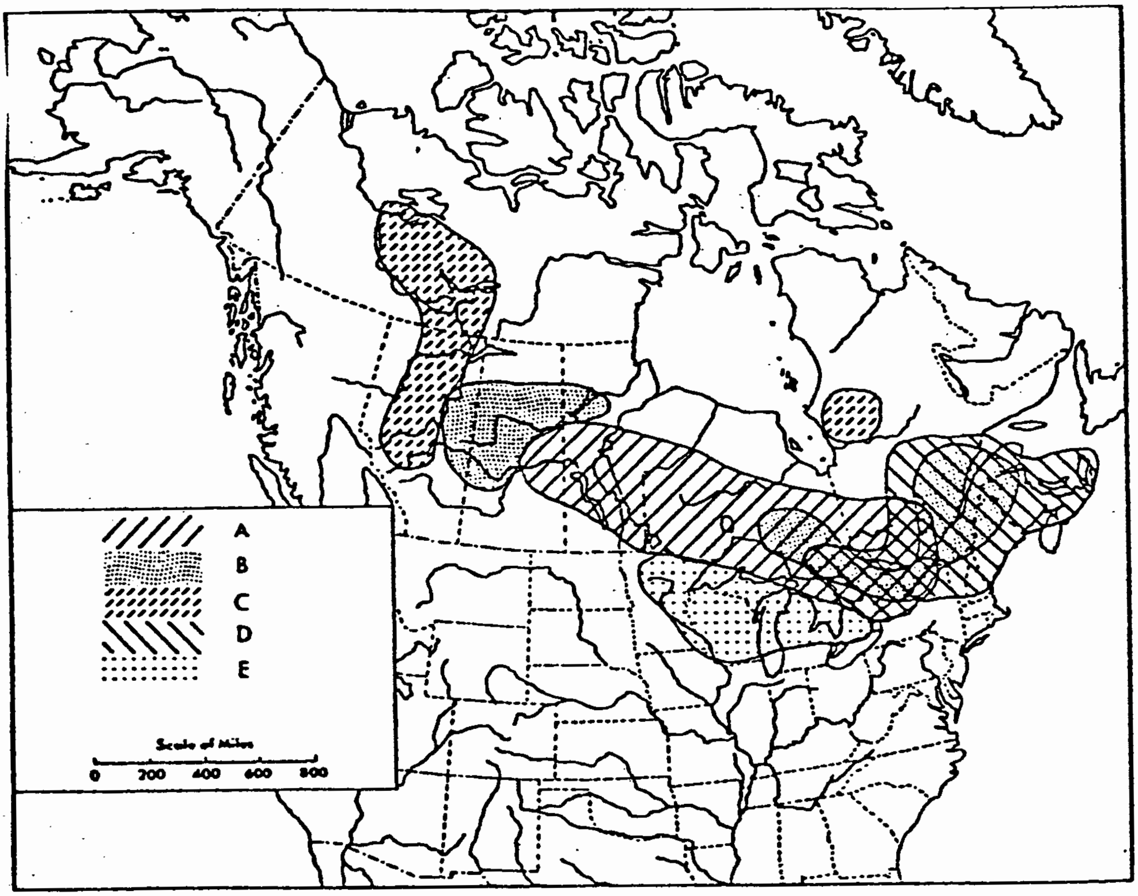

Fig. 2. Proposed subpopulations derived from the dendrograph of the cluster analysis.

Clusters C and E are geographically the most distinct but cluster A is also fairly clear (fig. 2). Clusters B and D do not occupy clearly separated geographic regions.

These results were compared with the results of the study of geographic variation in jack pine done in natural stands by Schoenike (1976). Cluster E, the Lake States group, covers an area similar to that occupied by two of his groups. However, clusters A, B, C, and D are different from any of Schoenike's groups. This is not unexpected because different materials were used for the two studies, the data were collected in different ways, and different traits were evaluated. However, both studies suggest somewhat similar geographic grouping that can be used in working with the species.

CONCLUSIONS

1. There are large variations among seed sources in the 10 traits measured.

2. Most traits that are related to tree growth show large differences in seed source location.

3. Latitude of seed source affected height, diameter, bark thickness, and crown width.

4. Cluster analysis provided a strong indication of geographically defined populations that can be used for tree and seed source improvement.

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