Variation in Eastern White Pine Seed Sources Planted in the Lake States

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In 1955 the Northeastern Forest Experiment Station initiated a rangewide seed source study of eastern white pine (*Pinus strobus* L.). Several cooperators have already issued reports on the early results of this study (SANTAMOUR 1960, SLUDER 1963, WRIGHT *et al.* 1963, and FUNK 1965). All of these early reports generally agree that the trees from the southern Appalachian seed sources have made the fastest early growth.

This paper, covering growth of trees in the Lake States from the same seed sources, is the first to show that there is a northern limit beyond which trees from southern Appalachian sources lose their superiority.

Methods of Study

Seed was collected for the white pine study in 1955 and 1956 and sown by most cooperators in other parts of the region in 1957. In the Lake States, however, two seed collections were delayed until 1957, so that seed from the 17 sources in this test (*table* 1) was not sown until spring 1953

TabLe 1. — Location of eastern white pine seed sources.

Source number [1])	Location of origin	Lat.	Long.	Mean Jan. temp. [2])
		°N	°W	F°
1650 (28)	Lake County, Minn.	48.0	91.8	9
1622 (19)	Cass County, Minn.	47.4	94.5	6
1629	Washington County, Minn.	45.2	92.8	11
1623 (18)	Forest County, Wis.	45.9	88.9	11
1651 (31)	Sauk County, Wis.	43.5	90.0	17
1624 (15)	Allamakee County, Iowa	43.3	91.3	16
1656 (29)	Houghton County, Mich.	47.1	88.7	14
1670 (33)	Newaygo County, Mich.	43.5	85.7	22
1636 (25)	Algoma District, Ontario	46.2	82.6	10
1635 (23)	Pontiac, Quebec	47.5	77.0	1
1637 (20)	Luneburg, Nova Scotia	44.4	64.6	26
1638 (14)	Penobscot, Maine	44.9	68.6	20
1639 (12)	Franklin County, N. Y.	44.4	73.4	15
1640 (6)	Monroe County, Penn.	41.1	75.4	25
1632 (16)	Ashland County, Ohio	40.8	82.3	29
1634 (3)	Greene County, Tenn.	36.0	82.8	36
1633 (1)	Union County, Georgia	34.8	84.1	39

[1]) Numbers in parentheses are numbers assigned by the Northeastern Forest Experiment Station.

[2]) U.S. data interpolated from maps in "Climate and Man", US Dep. Agr. 1941 Yearbook. Canadian data from Canadian Meteorological Division Climatic Summaries.

in the Toumey nursery in Watersmeet, Michigan. In spring 1960 the 2–0 stock was transplanted to the Hugo Sauer Nursery near Rhinelander, Wisconsin. The four permanent test plantations discussed in this paper (*table* 2) were established with this 2–2 stock in 1962.

Nursery Measurements

At the end of the first growing season in the nursery the height above the cotyledons was measured in the four-replicate test. While transplanting the seedlings to the Hugo Sauer Nursery after the second growing season, part

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TabLe 2. — Location and climatic data of nurseries and planting sites.[1])

Nursery or plantation	County and State	Location Lat.	Location Long.	Frost-free season	Mean temp. July	Mean temp. Jan.
		°N	°W	Days	°F	°F
Nursery						
Toumey	Gogebic, Michigan	46.2	89.1	90	65	11
Hugo Sauer	Oneida, Wisconsin	45.5	89.5	135	68	14
Plantation						
Pike Bay	Cass, Minnesota	47.4	94.5	105	68	2
Wabeno	Forest, Wisconsin	45.4	88.5	110	68	12
Manistique	Schoolcraft, Michigan	46.0	86.4	108	66	15
Pine River	Wexford, Michigan	44.2	85.8	125	70	20

[1]) Climatic data computed from Weather Bureau Annual Summaries and based only on the data for the years in which the seed sources were growing in the area, i. e., Toumey Nursery data only from 1958 and 1959; Pike Bay data only from 1962—1965, etc.

of the fourth replicate was lost, so all subsequent nursery measurements were made in only three replicates. At the time of transplanting, 20 seedlings of each seed source in each of the first three replicates were picked at random and measured.

Field Plantings

The four test plantings were all of the randomized complete block design with 24 replicates of 1-tree plots. During the first 3 years in the field when there was no fencing, deer browsing introduced some variation into the plantings. All the plantings have since been fenced, and less damage from browsing is expected in the future. In the fall of 1966 after 5 growing seasons in the field, tree heights were measured to the nearest centimeter.

Analyses

The mortality data for all four plantations were combined into a single analysis of variance, using seed source totals from each planting. For other characteristics, the analysis of variance was based on plot means. In the nursery data there were no missing plots. However, in the field plantings, where mortality (and hence the number of missing plots) ranged from 11 to 18 percent, no missing plot values were computed. Instead the data were analyzed as a completely random experiment with unequal numbers of replicates. Estimates from each plantation based on complete replicates indicated that the error variance was inflated only by 7 to 14 percent by not partitioning out a replicate sum of squares.

Product moment correlation coefficients were computed between the seedling characteristics using seed source means. In comparing the plantations with each other and with data from other reports, rank correlation coefficients were used.

Nursery Results

At the end of the first growing season in the nursery, there were significant differences in height growth between the seed sources (*table* 3). The five fastest growing sources were from Tennessee, Lower Michigan, southern Wisconsin, Georgia, and Nova Scotia. The slowest growing sources were from Minnesota, Maine, Upper Michigan, and

Table 3. — Summary of data of eastern white pine seedlings in the Toumey Nursery, Watersmeet, Michigan, by seed source.

Number	Location	1958 1-0 stock, height above cotyledons [1]	1959, 2-0 stock: Height above cotyledons [1]	Needle length [2]	Stomatal rows	Serrations
		Mm	*Mm*	*Mm*	*No.*	*No./cm*
1650	Minnesota	7.2	36	42	2.6	6.8
1622	Minnesota	6.2	28	37	2.3	6.4
1629	Minnesota	7.6	31	44	2.5	6.9
1623	Wisconsin	7.5	34	41	2.6	7.0
1651	Wisconsin	8.4	37	42	2.7	6.7
1624	Iowa	7.0	32	42	2.7	7.1
1656	Michigan	6.3	26	39	2.5	6.9
1670	Michigan	8.9	38	49	3.0	7.0
1636	Ontario	7.6	36	41	2.7	6.9
1635	Quebec	8.1	35	40	2.5	7.0
1637	Nova Scotia	8.1	40	45	3.0	7.3
1638	Maine	6.3	25	38	2.3	7.2
1639	New York	7.1	35	43	2.6	7.2
1640	Pennsylvania	6.9	28	41	2.6	7.3
1632	Ohio	7.6	32	38	2.4	6.9
1634	Tennessee	9.1	42	53	2.9	7.5
1633	Georgia	8.3	38	47	2.8	7.8
Mean		7.5	33.7	42.5	2.6	7.1
$s_{\bar{x}}$		0.36	2.62	2.57	.09	0.22
Seed source F-value		6.00*	3.42*	2.52**	5.42*	2.11*

[1]) Measured to the nearest millimeter.
[2]) Needles were randomly picked about 3 centimeters below terminal bud.
* Differences among means significant at .05 level.

Table 4. — Summary of data of eastern white pine transplants in the Hugo Sauer Nursery, Rhinelander, Wisconsin, by seed source.

Source number	Location	1960, 2-1 stock, winter injury [1]	1961, 2-2 stock: Height [2]	Diameter [3]	First-order	Branch Length [2]
		Percent	*Cm*	*Mm*	*No.*	*Cm*
1650	Minnesota	7	13	5.5	2.6	5.1
1622	Minnesota	4	13	5.4	2.4	5.1
1629	Minnesota	6	14	5.3	2.2	5.6
1623	Wisconsin	2	19	6.4	3.0	7.9
1651	Wisconsin	4	17	6.2	2.6	7.1
1624	Iowa	4	15	6.0	2.3	5.6
1656	Michigan	4	13	5.5	2.1	5.1
1670	Michigan	17	19	5.8	2.5	6.9
1636	Ontario	7	17	6.1	2.5	6.4
1635	Quebec	2	12	4.8	2.3	5.1
1637	Nova Scotia	32	15	5.5	2.7	5.6
1638	Maine	17	15	6.0	2.7	5.8
1639	New York	5	16	5.5	2.5	5.8
1640	Pennsylvania	17	15	5.4	2.0	5.8
1632	Ohio	3	15	6.0	2.4	5.8
1634	Tennessee	82	16	5.9	2.3	6.1
1633	Georgia	79	13	4.8	1.9	4.3
Mean		17.1	15.1	5.6	2.4	5.8
$s_{\bar{x}}$		2.74	.79	.21	.17	.32
Seed source F-value		84.46*	5.74*	4.31*	2.54*	6.94*

[1]) Percentage of all trees showing damage symptoms. Damage scored as present or absent for each tree.
[2]) Measured to the nearest 2.5 millimeters.
[3]) Measured to the nearest 0.1 millimeter.
* Differences among means significant at .05 level.

Pennsylvania. The same height growth pattern was noted at the end of the second growing season in the nursery.

By the end of the fourth growing season, the seed source variation pattern of height growth in the 2—2 stock *(table 4)* had shifted to such an extent that there was no significant correlation between 2-year and 4-year height growth (r = .30 with 15 degrees of freedom). The Lower Michigan, southern Wisconsin, and Tennessee sources were still among the fastest growing, but the Nova Scotia and Georgia sources had both dropped to below the all-source average. The local northern Wisconsin source and an Ontario source had moved into the top five.

In the first winter after transplanting, seed sources differed in winter injury, which showed up as needle browning and discolored terminal buds. As might be expected, the trees from the Tennessee and Georgia sources showed the greatest incidence of injury *(table 4)*. The source from Novia Scotia — a maritime climate source — showed less damage than the southern Appalachian sources but distinctly more damage than any of the other sources. The six sources showing the most winter injury were all from areas where the mean January temperature exceeds 20° F. Ten of the remaining eleven sources were from areas where the mean January temperature is less than 18° F.

At the end of the second growing season in the nursery we observed significant seed source differences in needle length, the number of stomatal rows, and the number of serrations per unit of needle length *(table 3)*. There were significant positive correlations between height, needle length, and the number of stomatal rows *(table 5)*. Sources with the longest needles also tended to have a greater number of serrations.

Table 5. — Product-moment correlation coefficients between seedling and transplant characteristics, using seed source means.

Correlation between:	Product-moment[1]) correlation
For 1—0 and 2—0 seedlings	
Height 1—0 and height 2—0	+.88
Height 2—0 and needle length 2—0	+.77
Height 2—0 and stomatal rows 2—0	+.82
Needle length 2—0 and stomatal rows 2—0	+.83
Needle length 2—0 and serration 2—0	+.59
For 2—2 transplants	
Height and diameter	+.76
Height and branch number	+.56
Height and branch length	+.92
Diameter and branch number	+.65
Diameter and branch length	+.81
Branch number and branch length	+.66

[1]) Fifteen degrees of freedom.

Although there were significant negative correlations between latitude and needle length (r = —.62) and between latitude and needle serrations (r = —.76), the geographic pattern of variation in these characters was weak. The two southernmost sources — from Tennessee and Georgia — were among the longest-needled and had the most needle serrations. And the seed source from Cass County, Minnesota, had the shortest needles and the fewest serrations. But beyond that the pattern of geographic variation was essentially random in these characteristics.

At the end of 4 years in the nursery there were significant seed source differences in height, diameter, the number of first-order branches, and branch length *(table 4)*. Significant positive correlations between these same four characteristics were also noted *(table 5)*. There was no correlation between any of these characteristics and the seed source latitude.

Plantation Results

White pine blister rust *(Cronartium ribicola)*, white pine weevil *(Pissodes strobi)*, frost damage, and animal brows-

Table 6. — Mortality in 1966 and total height in the test plantations.

Source number	Location	Percent mortality, all plantings	Height - seed source mean as a percent of plantation mean			
			Pike Bay, Minn.	Wabeno, Wis.	Manistique, Mich.	Pine River, Mich
1650	Minnesota	9	107	103	97	83
1622	Minnesota	10	109	97	97	89
1629	Minnesota	22	110	107	111	111
1623	Wisconsin	13	106	114	97	99
1651	Wisconsin	6	119	124	110	102
1624	Iowa	13	102	112	98	102
1656	Michigan	10	89	93	101	80
1670	Michigan	12	115	108	114	109
1636	Ontario	25	120	103	106	89
1635	Quebec	10	115	98	90	88
1637	Nova Scotia	17	74	77	86	98
1638	Maine	18	89	78	96	90
1639	New York	10	88	113	102	102
1640	Pennsylvania	16	96	94	98	117
1632	Ohio	10	95	119	108	113
1634	Tennessee	19	75	78	88	123
1633	Georgia	33	76	75	99	108
Mortality, percent:						
Mean		15	18	17	13	11
$S_{\bar{x}}$		0.74	—	—	—	—
Height, centimeters:						
Mean			69.6	58.6	86.7	51.3
$S_{\bar{x}}$			5.84	4.66	5.87	3.66
Seed source F-value		4.95*	3.32*	4.48*	1.43*	2.95*

* Differences among means significant at .05 level.

ing were found to some degree in almost every plantation. The incidence of damage from these factors was never high enough to show reliable seed source differences.

There are differences between plantations and between seed sources in mortality 5 years after planting *(table 6)*. Plantation mortality ranged from 11 to 18 percent, with the highest mortality occurring in the plantations with the lowest mean January temperature. Mortality by seed source over all plantings ranged from 6 to 33 percent. There tended to be a relationship between seed source mortality and seed source winter injury as measured in the nursery. The five sources showing the highest winter injury *(table 4)* were all included in the seven highest mortality sources. There is no obvious reason why the other two high-mortality sources (from Ontario and Minnesota) survived so poorly.

The mean height of the plantations 5 years after field planting ranged from 51 centimeters at Pine River, Michigan, to 86 centimeters at Manistique, Michigan *(table 6)*. Only in the tallest planting, Manistique, were no significant differences found between seed sources. Possibly the seed source variation in the Manistique planting was reduced by seed source × plantation interaction.

Because of the large seed source × plantation interaction no source or group of sources was consistently best in all four Lake States plantings. Source 1634 from Tennessee was the tallest in Lower Michigan, but was never better than the fourteenth tallest in the other three plantings. Source 1636 from Ontario was tallest in Minnesota but was only thirteenth tallest in Lower Michigan. The best overall sources (both of which were from only slightly south of the plantations) were from Sauk County, Wis. (1651), and Newaygo County, Mich. (1670). The poorest source was from Nova Scotia.

The three southern Appalachian sources (1633, 1634, and 1640) include the two tallest at Pine River, Mich., the three tallest in southern Lower Michigan (Wright *et al.* 1963), the three tallest in the Central States (Iowa, Illinois, Indiana, Ohio, and Kentucky) (Funk 1965), and the three tallest in North Carolina (Sluder 1963). But none of these three sources is in the tallest five in the Wisconsin and Minnesota plantings.

Table 7. — Rank correlation coefficients for the height of trees of various seed sources between several geographic locations.

Correlation between:	Rank correlation coefficient
For the 17 seed sources in this study	
Pine River, Mich., and Manistique, Mich.	+.44
Pine River, Mich., and Wabeno, Wis.	+.33
Pine River, Mich., and Pike Bay, Minn.	—.23
Manistique, Mich., and Wabeno, Wis.	+.54
Manistique, Mich., and Pike Bay, Minn.	+.16
Wabeno, Wis. and Pike Bay, Minn.	+.52
For the 12 seed sources common to three studies[1]	
Pine River, Mich., and Central States	+.78
Pine River, Mich., and North Carolina	+.71
Pine River, Mich., and Wabeno, Wis.	—.01
Pine River, Mich., and Pike Bay, Minn.	—.59
Pike Bay, Minn., and Wabeno, Wis.	+.50
Pike Bay, Minn., and Central States	—.45
Pike Bay, Minn., and North Carolina	—.32
Central States and North Carolina	+.84
Central States and Wabeno, Wis.	—.15
North Carolina and Wabeno, Wis.	—.16

[1]) A Central States study, a North Carolina study, and the one reported here.

If the seed source ranking at Pine River, Mich., is compared with the ranking in the other three Lake States plantings, one finds that as the distance from the Pine River planting increases, the similarity decreases *(table 7)*. That is, the Pine River planting is different from Manistique, more different from Wabeno, and most different from Pike Bay.

Moreover, comparing the ranking of the 12 sources common to this study, the Central States study (Funk 1965), and the North Carolina study (3-year results), one finds that the ranking at Pine River, Mich., more closely resembles the Central States and North Carolina plantings than do either the Wisconsin or Minnesota plantings *(table 7)*.

It seems especially noteworthy that the seed source × plantation interaction is not directly proportional to either geographic or climatic change. The data show effectively no seed source × plantation interaction northward from North Carolina until one passes north and west of Lower Michigan. Then in a relatively short distance (Wabeno, Wis., to Pine River, Mich.) a strong interaction is encountered. This emphasizes that generalizations regarding interactions based on plantations located within a limited area should not be extended beyond that area.

Only one significant correlation was found between nursery heights and plantation heights; the 1—0 growth was correlated with the 1966 heights in the Pine River, Mich. planting (r = .55 with 15 degrees of freedom). Thus, the sources from milder climates show the fastest growth rate in protected nursery beds but then lose their superiority when exposed to severe winters. These faster growing sources then regain their superiority only when moved back into milder climatic regions.

Although the trees in this study are still too young to furnish a basis for any specific seed procurement recommendations, they do suggest certain guides that might be followed in planning future tests. Funk's (1965) conclusion that the southern Appalachian seed sources should receive more intensive investigation in the Central States is probably valid for Lower Michigan as well. But in the more severe climate of Upper Michigan, northern Wisconsin, and Minnesota one should confine the search for superior seed sources to areas where the mean January temperature is less than 20 degrees F. This would reduce the chance of testing sources that are ill-adapted to the colder winters without reducing the amount of potential improvement.

Abstract

Seventeen seed sources of eastern white pine from throughout the species' natural range were studied in nurseries in Upper Michigan and Wisconsin and at 5 years of age in field plantings in Minnesota, northern Wisconsin, and Upper and Lower Michigan. No seed source or group of sources was consistently best either in the nursery or in all field plantings. The ranking (by height) of the seed sources growing in Lower Michigan very strongly resembled the ranking of the same sources growing in southern Illinois, Indiana, Ohio, and North Carolina. There is little resemblance to the ranking of the same sources being grown in Wisconsin and Minnesota. The data suggest that the mean January temperature of the seed source will be a very useful guide in selecting sources for further testing in Minnesota and Wisconsin.

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Cone Distribution in Crowns of Slash Pine (Pinus elliottii Engelm.) in Relation to Stem, Crown and Wood Increment[1])

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Nitrogen fertilizers applied to slash pine *Pinus elliottii* Engelm.) seed orchards in North Florida, increased the production of female cones (Goddard and Strickland, 1965). Similar observations have been reported in other pines and plant species. In pine, total cone counts are made to determine fertilizer effects. Pine buds and tissues are often removed for chemical analysis in physiological studies of cone induction or in studies of fertilizer effects on nutrient deficiencies. They are generally selected at random from the top or lower parts of the tree. Chemical assay of microscopically determined anatomical components of these samples (Kupila-Ahvenniemi *et al.*, 1966) probably reflect microsite environmental differences.

The present study tested the hypothesis that female strobili are randomly distributed in *Pinus elliottii.* Such an assumption is generally made in recording reproductive responses and in removing tissues for chemical assay. Our results show that a non-random cone distribution often occurs in pine. Branch, crown, and wood growth patterns were measured as potential indicators of differential cone production. Possible reasons for a skewed pattern of female strobili formation, and implications for selecting tissue for physiological studies are discussed.

Related Literature

Sources of stimulation and environmentally induced differences in cone formation in pine have been reported. Flowering generally occurs in forest trees after a certain size or number of annual growth cycles (Wareing, 1959). This averages four to five years for pine (Righter, 1939) but exceptions occur. *P. mugo* may produce staminate cones its first year (Mergen and Cutter, 1957); *P. densiflora* and *P. sinensis* produce ovulate cones at two years (Righter, 1939). *P. nigra* and *P. sylvestris* produce staminate cones earlier than ovulate cones. Absolute size has been proposed to control male flowering while some other factor induces female flowering (Matthews, 1963). Slash pine usually produces cones of both sexes at about five years, and nitrogen fertilizer treatment appears to hasten the onset of larger crops.

Early flowering has been induced with gibberellic acid in *Cryptomeria* (Shidei *et al.*, 1960) and with NAA and 2,4-D in horticultural crops (Priol, 1962). In general, growth substances have been unsuccessful in hastening flowering in pine (Mirov and Stanley, 1959) and have been most useful in horticultural crops through their effect on abscission.

Hormones and nutritional levels appear to be involved in pine sporangia induction. Treatments which probably alter the inherent levels of growth substances and nutrients usually stimulate formation. Some of these treatments are: (a) orientation of branches (Longman and Wareing, 1959), (b) meristem removal by branch-pruning (Melchior and Heitmüller, 1961) or root pruning (Hoekstra and Mergen, 1957), and (c) girdling or strangulation (Matthews, 1963).

Another indication that a bud-derived substance is active in formation of female strobili is that ovulate cones occur in the middle or upper crown on low-order branches where growth is most rapid and growth substances presumably highest (Anikeyeva and Minina, 1959; Hard, 1964; Winjun and Johnson, 1964). The effect of bud removal on female flowering decreased from top to bottom leaders, and from branch tip to the insertion point of the branch on the stem (Melchior and Heitmüller, 1961). This effect is reversed for male flowers and conforms to the general observation that male flowers occur in the lower crown on higher-order branches (Anikeyeva and Minina, 1959).

Increasing flower numbers and seed production after the tree attains the physiological age or condition to flower

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