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Adaptation of Eastern White Pine Provenances to Planting Sites

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Abstract

Eastern white pine provenances from the extreme limits of its natural range are changing from above- and below-average stability to average stability for height growth with increasing age. The regression method is useful for evaluating the stability of provenance to planting sites. The same general conclusions are reached for the performance of provenances at different planting sites from the regression method as from the relative difference method.

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Introduction

Eastern white pine (*Pinus strobus* L.) is one of the most important timber trees in Northeastern United States and Eastern Canada. Provenance and/or genetic variation studies of this species have been underway since 1959 (Garrett et al. 1973; Demeritt and Kettlewood 1976, Funk et al. 1975; Thor 1975; Kriebel et al. 1974).

The ability to identify provenances that are adapted to a wide range of environments would be particularly useful to forest managers. One method of obtaining information on the adaptability of provenances is from the genotype-environment interaction from the analysis of variance of provenances over locations. A second method is a regression technique used by Finlay and Wilkinson (1963) to evaluate the phenotypic stability of 277 barley varieties. The regression technique consists of computing the linear regression of yield on the mean yield of all varieties for each site. The regression coefficient (b) was used as an indicator of stability. Average stability would be: $b = 1.0$, perfect stability $b = 0$ and below average stability $b > 1.0$. Phenotypic stability using the Finlay-Wilkinson technique was reported for jack pine (*Pinus banksiana* Lamb.) by Morgenstern and Teich (1969) and for white spruce (*Picea glauca* [Moench] Voss) by Nienstaedt (1969).

We report on the stability or adaptability of 29 eastern white pine provenances in 12 plantations in the Northeastern United States using 10-year height and 16-year height and diameter with the regression technique. There are no previous reports on the adaptability of eastern white pine provenances to planting sites.

Materials and Methods

In 1955, the USDA Forest Service initiated a rangewide provenance trial of eastern white pine. Cones from 10 trees chosen at random in good stands of natural origin were collected by cooperators. Initially, 32 sources were included in the study, but two provenances (17 and 26) failed to produce seedlings in the nursery, and a third seed source (32) was not included in the northeastern plantings (Fig. 1, Table 1).

Nursery trials of this material were conducted in New York, New Jersey, Maryland, North Carolina, and Wisconsin. Plantations were then established by the USDA Forest Service's Northeastern, Southeastern, Lake States, and Central States Forest Experiment Stations, and by the Southern Research Station of the Ontario Department of Lands and Forests. Seedlings within sources were bulked when lifted from the nursery beds and then selected at random for field trials.The Northeastern Station's plantings in 1959 (plantings 7 to 11) were established with 2-0 stock grown in the Maryland State Forest Nursery. The 1960 plantings (1 to 6) were established with 3-0 stock grown in the New Jersey and New York State Forest Nurseries. Planting locations are shown in Figure 2 and Table 2. Three

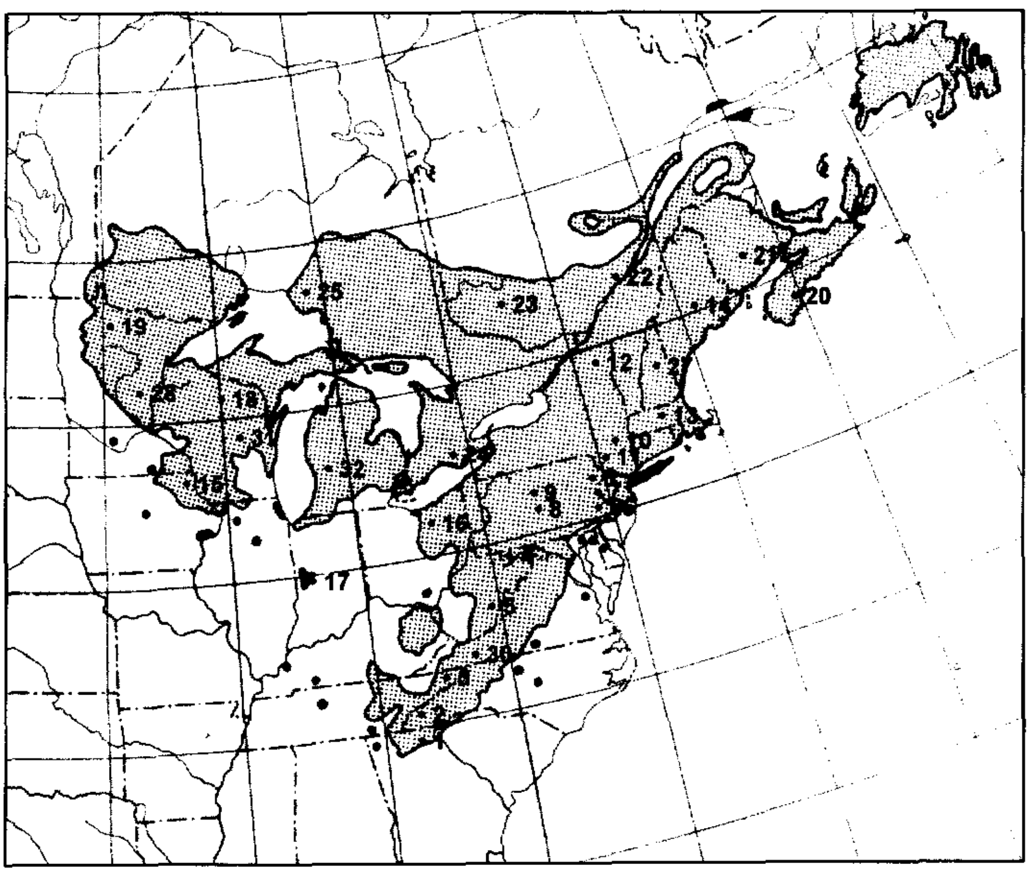

Figure 1.—Seed sources used in the provenance tests (shaded areas indicate the natural range of eastern white pine; numbers indicate seed collection points, Table 1).

Table 1.—Seed sources for eastern white pine provenance study

Source	Location	Latitude	Longitude	Elevation
				Feet
1	Union County,GA	34°46'N	84°03'W	2,450
2	Transylvania County, NC	35°14'N	82°38'W	2,120
3	Greene County, TN	36°00'N	82°48'W	2,250
4	Garrett County, MD	39°39'N	78°45'W	2,460
5	Greenbrier County, WV	38°00'N	80°30'W	2,600
6	Monroe County, PA	41°05'N	75°25'W	1,800
7	Monroe County, PA	41°05'N	75°25'W	740
8	Clearfield County, PA	41°00'N	78°30'W	
9	Clearfield County, PA	41°00'N	78°30'W	
10	Ulster County, NY	41°45'N	74°15'W	
11	Ulster County, NY	41°45'N	74°15'W	
12	Franklin County, MA	44°25'N	74°15'W	1,600
13	Worcester County, MA	42°30'N	72°15'W	1,275
14	Penobscot County, ME	44°51'N	68°38'W	150
15	Allamakee County, IA	43°15'N	91°30'W	1,000
16	Ashland County, OH	40°45'N	82°15'W	1,000
18	Forest County, WI	45°30'N	88°30'W	1,500
19	Cass County, MN	47°30'N	94°30'W	1,300
20	Lunenburg County, NS	44°25'N	64°35'W	150
21	Sunbury County, NB	46°00'N	66°15'W	200
22	Quebec County, PQ	47°30'N	72°00'W	550
23	Pontiac County, PQ	47°30'N	77°00'W	1,000
24	Norfolk County, ON	42°40'N	80°27'W	750
25	Algoma District, ON	46°10'N	82°37'W	650
27	Carroll County, NH	43°45'N	71°25'W	610
28	Lake County, MN	48°00'N	91°45'W	1,300
29	Houghton County, MI	47°00'N	88°30'W	625
30	Palaski County, VA	37°00'N	80°50'W	2,400
31	Sauk County, WI	43°30'N	89°30'W	1,000

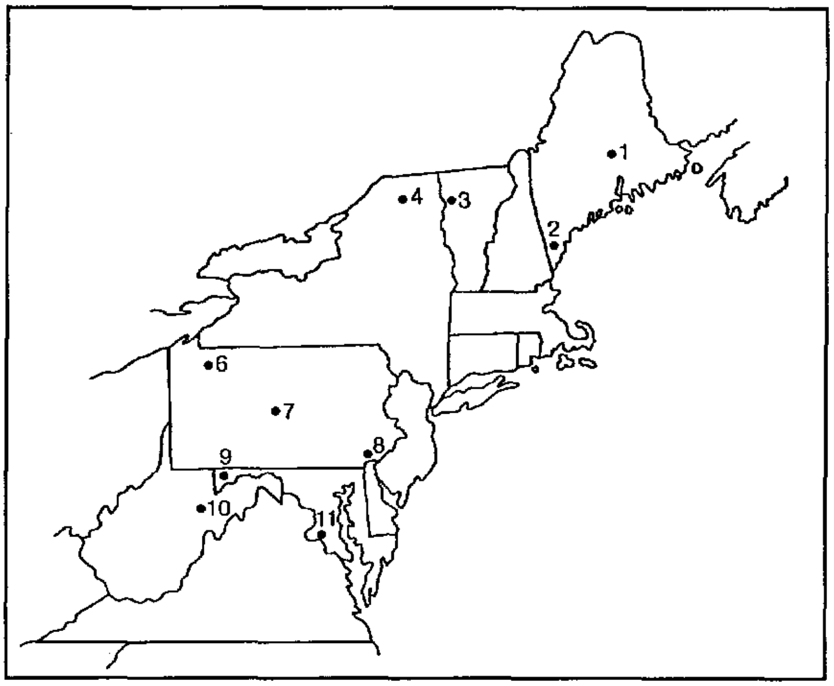

Figure 2.—White pine provenance planting sites (Table 2).

Table 2.—Location and design of plantings with mean plantation 10- and 16-year height and 16 year diameter

Plantation no.	Location	Design	Latitude	Longitude	Elevation	Mean 10-year height	Mean 16-year height	Mean 16-year diameter
					Feet	*Feet*	*Feet*	*Inches*
1	Orono, ME	III	44°53'N	68°39'W	100	4.1	15.7	2.70
2	Alfred, ME	I	43°32'N	70°40'W	300	6.8	16.8	4.21
2	Alfred, ME	II	43°32'N	70°40'W	300	6.8	18.7	4.32
2	Alfred, ME	III	43°32'N	70°40'W	300	7.4	19.5	4.54
3	Essex Junction, VT	III	44°28'N	73°09'W	327	6.5	17.3	3.67
4	Paul Smiths, NY	I	44°26'N	74°13'W	1,815	5.3	14.3	3.04
6	Warren, PA	I	41°50'N	79°15'W	1,180	8.4	22.2	4.64
7	Standing Stone, PA	III	40°37'N	78°55'W	960	5.8	17.3	3.25
8	Kennett Square, PA	I	39°52'N	75°41'W	400	7.1	20.5	4.53
9	Savage River State Forest, MD	III	39°40'N	79°15'W	2,740	9.0	16.1	2.98
10	Horseshoe Run, WV	I	39°11'N	79°35'W	1,720	13.1	29.1	5.89
11	Rison, MD	II	38°30'N	77°20'W	100	4.8	26.7	4.14

planting designs, each a randomized complete-block, are included in this report (Table 2):

Design I: A single tree from each provenance located randomly in each of 24 blocks. Spacing was 10 feet within rows and 10 feet between rows.

Design II: Two-tree row plots of each provenance located randomly in each of 24 blocks. Provenance trees were planted at a spacing of 7 feet in rows and 14 feet between provenance rows. Additional seedlings were planted between provenance rows to achieve a final spacing of 7 x 7 feet.

Design III: Four-tree row plots of each provenance located randomly in each of 12 blocks. Provenance trees were planted at the same spacing as those in Design II with additional seedlings between rows to again achieve a final spacing of 7 x 7 feet.

The added (nonstudy) trees were removed from all Design II and III plantings 1 to 3 years before the 16-year measurements were taken. Total height was measured on each provenance tree after the 1966 growing season (10 years from seed), and total height and diameter were recorded for each tree after the 1972 growing season (16 years from seed), except for three plantings in Alfred, Maine. Those plantings were remeasured after the 1973 growing season (17 years from seed) and the data were corrected for the extra year's growth. Not all provenances were represented in every planting; this accounts for the different number of plantings in the test for each provenance (Tables 3 -4).

Simple linear regression and correlation coefficients for 10- and 16-year height and 16-year diameter were computed for each provenance across all plantings. Provenance means were the dependent variables (y) and planting means for all provenances at the planting were the independent variables (x).

Simple linear correlation coefficients of provenances over planting locations were positive and high for 10- and 16-year diameters (Table 3). High correlation coefficients indicate that regression coefficients (b) for provenances over plantings are good measures of provenance stability with respect to the environments tested. The planting mean of the trait measured was used as an indication of the productivity of that environment. A relatively low planting mean would indicate a poor environment and a relatively high mean would indicate a good environment (Table 2).

The average relative difference for each provenance was determined by the following formula:

$$\text{Average Relative Difference (\%)} = \text{(for each provenance)} \quad \frac{\text{sum provenance means at each plantation}}{\text{Sum plantation means.}} \times 100$$

This statistic was used to compare the performance of a provenance to all provenances across all planting sites (Table 4). No confidence intervals were constructed for average relative differences in height and diameter measurements. Confidence intervals (95%) were constructed around each provenance's regression coefficients (Steel and Torrie 1960) to assign provenances to stability classes.

Provenances were assigned to one of three stability classes for 10- and 16-year height and 16-year diameter based on their respective regression coefficients (Table 5). The three stability classes are:

Above Average = b significantly less than 1.
Average = b not significantly different from 1.
Below Average = b significantly greater than 1.

Stability classes were divided into two performance classes: provenances with above- and below-average relative differences when evaluated across all plantations (Table 5).

Table 3.—Linear regression, standard error, and correlation coefficients of seed-source mean height at 10 and 16 years, and mean diameter at 16 years at each of the plantations on their respective mean heights or diameters of all seed sources at the plantations

Seed source	Location	N	10-year height			16-year height			16-year diameter		
			b	SE of reg. coef.	r	b	SE of reg. coef.	r	b	SE of reg. coef.	r
1	Georgia	12	1.386	0.129	0.959	1.305	0.127	0.956	1.514	0.258	0.881
2	North Carolina	12	1.237	0.090	0.975	1.179	0.088	0.973	1.422	0.190	0.923
3	Tennessee	12	1.310	0.115	0.964	1.285	0.133	0.951	1.460	0.224	0.900
4	Maryland	12	1.063	0.082	0.972	0.983	0.092	0.958	1.024	0.126	0.932
5	West Virginia	12	1.138	0.037	0.995	1.106	0.047	0.991	1.152	0.068	0.983
6	Pennsylvania	12	1.121	0.050	0.990	1.049	0.069	0.979	1.193	0.097	0.968
7	Pennsylvania	5	0.922	0.105	0.981	1.132	0.113	0.985	0.902	0.183	0.944
8	Pennsylvania	11	1.083	0.063	0.985	1.013	0.067	0.981	1.130	0.088	0.974
9	Pennsylvania	12	1.268	0.040	0.995	1.162	0.062	0.986	1.325	0.109	0.968
10	New York	12	1.021	0.041	0.992	0.930	0.037	0.992	0.947	0.082	0.965
11	New York	12	1.100	0.070	0.980	0.932	0.054	0.983	0.971	0.076	0.971
12	New York	12	0.970	0.029	0.996	0.986	0.038	0.993	1.006	0.075	0.974
13	Massachusetts	12	1.164	0.067	0.984	1.071	0.041	0.993	1.381	0.072	0.987
14	Maine	12	0.827	0.064	0.972	0.795	0.062	0.971	0.704	0.098	0.915
15	Iowa	11	0.909	0.039	0.992	0.983	0.035	0.994	0.935	0.081	0.968
16	Ohio	12	0.990	0.063	0.980	0.859	0.040	0.989	0.927	0.093	0.953
18	Wisconsin	10	0.778	0.144	0.886	0.919	0.120	0.939	0.810	0.183	0.842
19	Minnesota	12	0.882	0.059	0.978	1.016	0.049	0.989	0.982	0.082	0.967
20	Nova Scotia	12	0.864	0.068	0.970	0.966	0.068	0.976	0.768	0.136	0.873
21	New Brunswick	12	0.782	0.062	0.970	0.900	0.092	0.951	0.647	0.111	0.879
22	Quebec	12	0.666	0.067	0.953	0.775	0.113	0.908	0.532	0.137	0.775
23	Quebec	9	0.729	0.055	0.981	0.867	0.073	0.976	0.809	0.095	0.955
23	Quebec	9	0.729	0.055	0.981	0.867	0.073	0.976	0.809	0.095	0.955
25	Ontario	10	0.912	0.043	0.991	1.018	0.100	0.963	0.791	0.103	0.939
27	New Hampshire	7	1.155	0.206	0.929	1.229	0.135	0.971	1.083	0.103	0.978
28	Minnesota	8	0.820	0.041	0.993	0.919	0.061	0.987	0.769	0.129	0.925
29	Michigan	9	0.856	0.054	0.986	0.924	0.073	0.979	0.859	0.137	0.921
30	Virginia	7	0.923	0.120	0.960	0.882	0.175	0.914	0.724	0.312	0.720
31	Wisconsin	5	1.024	0.058	0.995	1.165	0.087	0.992	1.165	0.100	0.989

Table 4.—Average 10- and 16-year height and 16-year diameter of each seed source as a percentage of all plantations

Seed source	Location	N	10-year height	16-year height	16-year diameter
1	Georgia	12	110	105	115
2	North Carolina	12	100	99	102
3	Tennessee	12	111	109	114
4	Maryland	12	100	100	98
5	West Virginia	12	96	101	99
6	Pennsylvania	12	110	106	111
7	Pennsylvania	5	106	101	101
8	Pennsylvania	11	99	101	102
9	Pennsylvania	12	114	110	114
10	New York	12	109	104	108
11	New York	12	114	109	111
12	New York	12	106	103	105
13	Massachusetts	12	108	106	112
14	Maine	12	99	98	96
15	Iowa	11	97	94	94
16	Ohio	12	103	101	100
18	Wisconsin	10	95	96	94
19	Minnesota	12	96	98	95
20	Nova Scotia	12	95	100	96
21	New Brunswick	12	90	93	89
22	Quebec	12	80	81	76
23	Quebec	9	76	87	77
24	Ontario	12	107	107	108
25	Ontario	10	95	96	94
27	New Hampshire	7	103	105	110
28	Minnesota	8	96	92	84
29	Michigan	9	89	90	86
30	Virginia	7	88	87	85
31	Wisconsin	5	100	102	103

Table 5.—Assignment of seed sources by source number (Table 1) to stability and performance classes for 10- and 16-year height and 16-year diameter

Stability Class	Performance Class	10-year height	16-year height	16-year diameter
Below average	Specifically adapted to favorable environments (source above average)	1, 2, 3, 6, 9, 13, 24	1, 5, 9	2, 9, 13
Below average	Specifically adapted to favorable environments (source below average)	5	none	5
Average	Well adapted to all environments in the tests	4, 7, 10, 11, 12, 16, 27, 31	3, 4, 6, 7, 8, 10, 11, 12, 13, 20, 24, 27, 31	1, 3, 6, 7, 8, 10, 11, 12, 16, 24, 27, 31
Average	Poorly adapted to all environments in the tests	8, 18, 19, 20, 25, 30	2, 15, 18, 19, 21, 22, 23, 25, 28, 29, 30	4, 15, 18, 19, 20, 23, 25, 28, 29, 30
Above average	Specifically adapted to poor environments (source above average)	none	16	none
Above average	Specifically adapted to poor environments (source below average)	14, 15, 21, 22, 23, 28, 29	14	14, 21, 22

Results and Discussion

In the Northeastern United States, eastern white pine provenances are becoming more stable for height growth with increasing age. At 10 years of age, of the 29 provenances tested, 8 had below-average stability and 7 had above-average stability. At 16 years, only three of the initial eight provenances with below-average stability at 10 years were still below average, and only one of the seven with above-average stability still was above average. One provenance (Ohio 16) was stable at 10 years and above average stability at 16 years. The assignment of provenances 7 and 31 to the average-stability class should be interpreted with caution. Provenance 7 was planted only in northern plantings (less favorable environment) and provenance 31 only in southern plantings (more favorable environment).

The values for provenance stability may have been influenced by how far from their origin the provenance was planted. Central provenances were moved only a maximum of 4° latitude north or south, while southern provenances were moved a maximum of 9° latitude north and northern provenances a maximum of 10° latitude south.

When 10-year height measurements are used, there is a tendency for southern Appalachian provenances to have below-average stability. This also is true for some provenances from the central part of the eastern white pine range. Below-average stability implies that the provenance will grow well in good environments. Garrett et al. (1973) found that 10-year-old trees from southern Appalachia, and some sources from as far north as central Pennsylvania, were preferred for southern plantings. Funk (1971) reported that 10-year-old trees from the southern Appalachian sources were superior in height growth in midwestern plantings. Provenance 24, a source from southern Ontario, has below-average stability and thus might grow well in good environments. This may be the result of modifying effects of Lake Erie on its evolution.

There is a tendency for northern provenances to have above-average stability for 10-year height growth. This implies that these provenances will be specifically adapted (grow best) in less favorable environments (northern locations). Some provenances from the central portion of the species natural range also fall into this category. On the basis of 10-year height growth, Garrett et al. (1973) found that these sources were preferred for northern plantings.

About half of the provenances were assigned to the average-stability class and thus were adapted (well or poorly) to all environments based on 10-year data. Because most of these were from the central portion of the natural range of eastern white pine, they were moved a relatively short distance to any planting site in this test.

Using height data at 16 years, no provenance could be associated with stability class with any degree of reliability. Provenance 16 (Ohio) was the only source that changed from average stability at 10 years to above-average stability at 16 years. Using the same data and the relative difference method, Demeritt and Kettlewood (1976) found that provenances were becoming more similar in growth from age 10 to age 16. Also, Funk et al. (1975) found that in the Central United States, southern Appalachian sources were losing their superiority by age 15.

When diameter is used as the measurement, provenance stability at age 16 is nearly identical to that using 16-year height growth. The lone difference with the 16-year height data is that Provenance 13 (Massachusetts) has below-average rather than average stability, and Provenances 21 (New Brunswick) and 22 (Quebec) have above-average rather than average stability. Demeritt and Kettlewood (1976) generally found the same good correlation between 16-year height and diameter data for eastern white pine provenances.

The use of performance classes within stability classes only serve as indicators of the performance of provenances in their stability class. However, only three provenances (5, West Virginia), (8, Pennsylvania), (20, Nova Scotia) changed from below- to above-average performance between age 10 and 16 for height growth. Only provenance 2 (North Carolina) changed from above- to below-average for height growth during the same period. In no case did any change in average relative difference in height growth exceed 5 percent (Table 4). Overall, there is good agreement for assigning provenances to stability-adaptation classes for 10- and 16-year height and 16-year diameter. Three were some provenance shifts when stability and performance classes were evaluated simultaneously.

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Keywords: Pinus strobus, provenances, adaptation

Headquarters of the *Northeastern Forest Experiment* Station is in Radnor, Pennsylvania. Field laboratories are maintained at:

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Burlington, Vermont, in cooperation with the University of Vermont

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