Yields of EASTERN WHITE PINE in New England Related to Age, Site, and Stocking

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A Cooperative Study

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A STUDY OF THE EFFECTS OF SITE AND STOCKING

EASTERN WHITE PINE (*Pinus strobus* L.) played the leading role in the early lumbering history of New England. This species still is one of the most abundant in the region, accounting for about 20 percent of the board-foot volume in Maine, Massachusetts, and New Hampshire. Although market demands are now moderate, the economic importance of white pine in New England is sure to increase in the future as merchantable timber volumes increase because of better management, including improved insect and disease protection.

Information about growth and yield is basic to the management of any species. Normal yield tables for white pine in New England were developed some time ago *(Frothingham 1914)*, and these tables have proved useful for predicting the yield of unmanaged stands ever since. However, to meet the requirements of more intensive management, we need better methods of predicting growth and yield — methods that reflect site conditions and stocking levels.

To help meet this need, the Universities of Maine, Massachusetts, and New Hampshire, in cooperation with the Northeastern Forest Experiment Station, initiated in 1959-60 a study of the effects of site and stocking on the growth of eastern white pine. The primary purposes of the study were to develop equations for: (1) predicting the volume increment per acre of pure, even-aged, white pine stands from observable characteristics of the stand, soil, and topography; and (2) predicting the increment of individual white pine trees related to characteristics of the tree, stand, and site.

By 1965, measurements of stand growth and development for a 3-year period were available from nearly all field plots. A preliminary analysis revealed that one or more additional remeasurements should be taken before a final summary of the periodic growth of trees and stands is made. Nevertheless, useful and accurate relationships were developed between stand yield, or volumes per acre, and stand age, site, and stocking; and this information is presented in this paper. Yield tables based on the plot data from New Hampshire, using stand height in place of age and site index, have been published by Barrett and Allen *(1966)*.

FIELD METHODS

Field data were obtained from semipermanent field plots. The plots, located in essentially pure white pine stands that generally had at least 80 percent of the overstory basal area in white pine, were 1/20 to 1/5 acre in size. The condition of both the stand and site within and surrounding each plot was judged to be uniform over an area of about 1/2 acre. Within this 1/2-acre area, the stand was even-aged: the range in age of overstory white pine trees was no more than about 10 years. The stands had not been subjected to major disturbance within the past 15 years or light disturbance within the past 6 years.

A total of 218 plots were available for the yield analysis, excluding any plots that had suffered appreciable damage from cutting during the growth period. The distribution of plots by state, breast-height age class, and initial basal area per acre of overstory pine trees (3.0 inches d.b.h. and over) is shown in table 1. Distribution of plots by 10-foot site-index classes is shown in table 2.

Table 1.—*Distribution of field plots in the white pine yield analysis by state, breast-height age class, and initial basal area per acre of overstory pine trees (3.0 inches d.b.h. and over)*

State	Stand age	Basal area per acre, in square feet		
		51-150	151-250	251 +
	Years	*No.*	*No.*	*No.*
Maine	24 — 50	10	16	3
	51 — 75	10	22	3
	76 +	—	1	—
Mass.	26 — 50	8	45	—
	51 — 75	4	15	4
	76 +	2	3	1
N. H.	26 — 50	8	30	—
	51 — 75	4	20	4
	76 +	—	5	—

Table 2.—*Distribution of field plots in the white pine yield analysis by state and 10-foot site-index classes[1] (b.h. age 50)*

State	Site-index class						All
	40	50	60	70	80	90	
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Maine	—	—	13	41	10	1	65
Mass.	1	3	29	36	11	2	82
N. H.	—	—	16	35	18	2	71
All	1	3	58	112	39	5	218

[1] Height attained by free-growing dominant and codominant white pine trees when 50 years of age at breast height.

Plot measurements used in the yield analysis included:

1. An initial tally of all overstory trees 3.0 inches d.b.h. and larger by species, crown class, and diameter breast high (d.b.h.). Trees in the understory that appeared to represent a younger age class than the main stand were excluded from the yield analysis.

2. Breast-height age, crown class, total height, diameter outside bark (d.o.b.) and diameter inside bark (d.i.b.) of the bole

at 17.3 feet above ground, for as many as 20 sample white pine trees per plot.

3. A stem-analysis of about five dominant or codominant standing pine trees, consisting of paired ring counts and measurements of height-above-ground at a series of points along the bole.

COMPUTATIONS

Equations for individual tree volumes were developed from a series of about 400 white pine stem-analysis diagrams available in the Northeastern Station. Measurements of inside-bark diameter were taken at 4-foot intervals along the bole from these diagrams. Then cubic-foot volume to a 3.0-inch inside-bark top (Smalian's rule) and board-foot volume to a 6.0-inch top (International 1/4-inch rule) were computed. Regression was used to develop the following equations:

Volume in board feet $= -34.57 + 0.0001915\ (\text{D.b.h.})^2\ (\text{HT})\ (\text{GFC})$
$R = 0.993$
SE (of the mean value) = 1.62 board feet.

Volume in cubic feet $= 1.837 + 0.00002636\ (\text{D.b.h.})^2\ (\text{HT})\ (\text{GFC})$
$R = 0.994$
SE (of the mean value) = 0.206 cubic feet.

Where D.b.h. = diameter in inches at breast height.
HT = total height in feet.
GFC = Girard form class in percent (75%, 80%, etc.).

Plot volumes were computed as follows: A separate linear regression of HT x GFC over d.b.h. was computed for each plot, using data from the sample trees on the plot. Then the volume of each overstory tree was computed by using measured d.b.h. to predict HT x GFC, and inserting measured d.b.h. and predicted HT x GFC into the appropriate volume equation. Cubic-foot volumes were determined for trees 3.0 inches d.b.h. and larger; board-foot volumes were determined for trees 9.0 inches d.b.h. and larger.

Yields, or volumes per acre, were predicted, using three independent variables: mean breast-height stand age, site index, and percent stocking.

Mean breast-height stand age was determined by averaging the ages of the dominant and codominant sample trees on each plot.

Records on the stem-analyzed trees from each state were examined to determine whether available site-index curves could be used. It was found that Frothingham's site-index curves fit the data reasonably well, although some discrepancies were noted at the lower and upper extremes. Thus, the average site index for each plot was estimated from four to five free-growing trees per plot, using Frothingham's site-index curves corrected to breast-height age 50 (fig. 1).

Stocking percent was calculated by dividing basal area per acre in overstory pines (trees 3.0 inches d.b.h. and over) by predicted basal area for a fully stocked stand of the same mean diameter (arithmetic mean). Predicted fully stocked basal area

Figure 1.—Site-index curves for eastern white pine in New England (b.h. age 50) based on Frothingham's site-index curves corrected to a breast height age of 50.

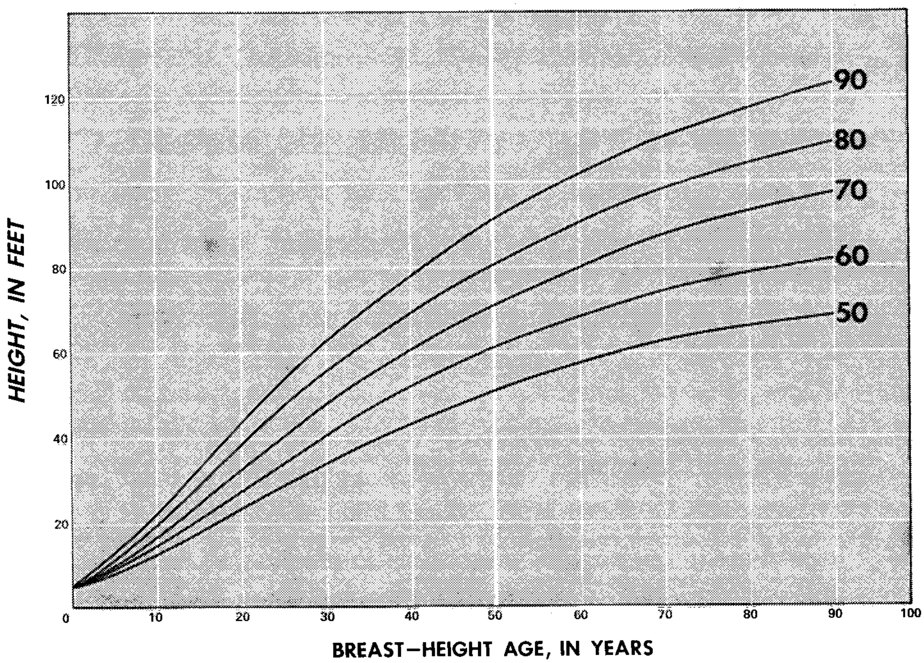
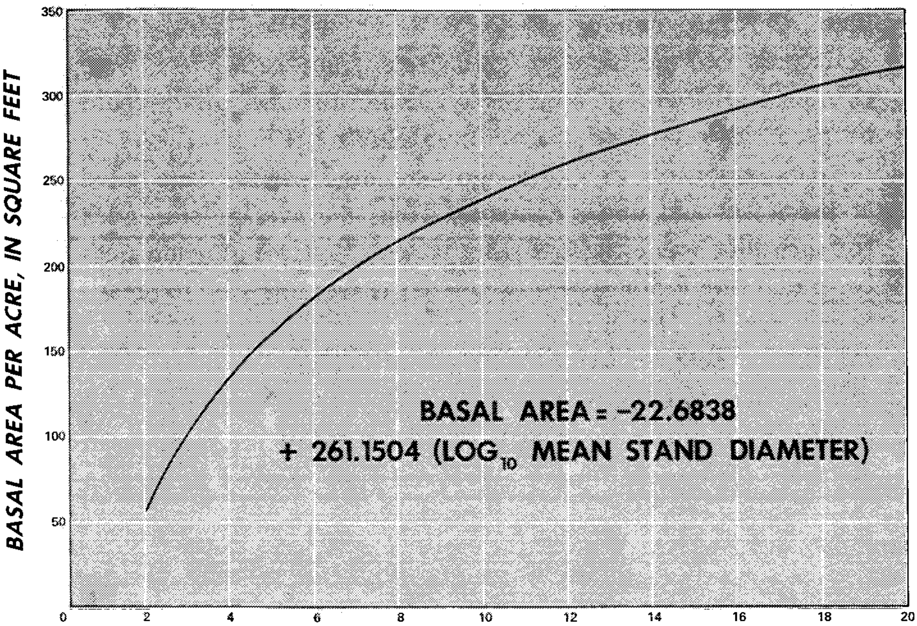


Figure 2.—Fully stocked basal area per acre over mean stand diameter, based on Frothingham's yield data.



was developed from data (all sites combined) presented by Frothingham and expressed as a regression equation (fig. 2):

$$\text{Basal area} = -22.6838 + 261.1504\ (\log_{10} \text{mean stand diameter})$$

Yields were related to age, site, and stocking by regression analysis. We used a slight adaptation of the yield model derived by Clutter *(1963)* for loblolly pine:

$$\text{Log}_{10}\ \text{Yield} = a + b_1(S) + b_2(\log_{10} P) + b_3\ (1/A)$$

Where S = site index.
P = percent stocking.
A = stand age.

In Clutter's model, logarithms were taken to the base *e*, whereas logarithms in our analysis were taken to the base 10 to facilitate practical use. More important, instead of using basal area in square feet as Clutter did, we used percent stocking, which is equivalent to relative basal area per acre. This yield model was used to predict both cubic-foot and board-foot yields.

RESULTS

Cubic Feet

The regression equations for cubic-foot volume per acre developed for each state and for all states combined are listed below with corresponding values of R, the multiple correlation coefficient, and SE, the standard error of estimate (the standard deviation of the residuals about the regression surface).[1]

All States: $\text{Log}_{10}\ CV = 1.88039 + 0.00686\ (S) + 0.90268\ (\log_{10}P) - 15.76028\ (1/A)$

Maine: $\text{Log}_{10}\ CV = 1.80868 + 0.00663\ (S) + 0.93192\ (\log_{10}P) - 14.34643\ (1/A)$

Mass.: $\text{Log}_{10}\ CV = 1.92384 + 0.00703\ (S) + 0.88790\ (\log_{10}P) - 16.75412\ (1/A)$

N.H.: $\text{Log}_{10}\ CV = 1.95626 + 0.00677\ (S) + 0.86691\ (\log_{10}P) - 15.88561\ (1/A)$

The correlation is 0.98 and the standard error is 0.8 to 0.9 percent of the mean for each of the four equations.

Examination of the above equations shows that all depict logical relationships; all are highly accurate; and all of them have similar regression coefficients. The pooled variance from the separate equations for each state was less than that for all states combined by an amount that was just significant at the 5-percent level. But practically speaking, the equation for all states combined provides accurate estimates of cubic-foot yield for any state. This combined equation is tabulated in table 3.

Board Feet

The first set of regressions developed for board-foot volumes was based on all 218 plots. However, because of low accuracy and inconsistencies among states, we decided to rerun the re-

[1] Standard errors are expressed as a percentage of the mean, since errors expressed as logarithms or antilogs are not readily interpreted.

Table 3.—*Cubic-foot yields per acre to a 3.0-inch i.b. top in Maine, Massachusetts, and New Hampshire, by age, site index (b.h. age 50), and stocking percent*

[Applies to overstory pine trees 3.0 inches d.b.h. and over]

Age (years)	Site Index	Stocking percent									
		40	50	60	70	80	90	100	110	120	130
20	50	761	931	1,098	1,262	1,423	1,583	1,741	1,897	2,052	2,206
	60	892	1,090	1,286	1,477	1,667	1,854	2,039	2,222	2,403	2,583
	70	1,044	1,277	1,506	1,730	1,952	2,171	2,387	2,602	2,814	3,025
	80	1,223	1,496	1,763	2,026	2,286	2,542	2,796	3,047	3,296	3,543
	90	1,432	1,752	2,065	2,373	2,677	2,977	3,274	3,569	3,860	4,149
40	50	1,886	2,307	2,719	3,125	3,526	3,921	4,313	4,700	5,084	5,465
	60	2,209	2,702	3,185	3,660	4,129	4,592	5,051	5,504	5,954	6,400
	70	2,587	3,164	3,730	4,287	4,836	5,378	5,915	6,446	6,973	7,495
	80	3,029	3,075	4,368	5,020	5,663	6,298	6,927	7,549	8,166	8,778
	90	3,548	4,339	5,115	5,879	6,632	7,376	8,112	8,841	9,563	10,280
60	50	2,552	3,121	3,680	4,229	4,771	5,306	5,836	6,360	6,879	7,395
	60	2,989	3,656	4,309	4,953	5,587	6,214	6,834	7,448	8,057	8,660
	70	3,500	4,281	5,047	5,800	6,543	7,277	8,003	8,722	9,435	10,142
	80	4,099	5,014	5,910	6,793	7,663	8,523	9,373	10,215	11,050	11,878
	90	4,800	5,871	6,922	7,955	8,974	9,981	10,977	11,963	12,940	—
80	50	2,968	3,631	4,280	4,919	5,550	6,172	6,788	7,398	8,002	8,602
	60	3,476	4,252	5,013	5,761	6,499	7,228	7,950	8,664	9,372	10,074
	70	4,071	4,980	5,871	6,747	7,611	8,465	9,310	10,146	10,975	11,798
	80	4,768	5,832	6,875	7,902	8,914	9,914	10,903	11,882	12,853	—
	90	5,584	6,830	8,052	9,254	10,439	11,610	12,769	—	—	—
100	50	3,250	3,976	4,687	5,387	6,077	6,758	7,433	8,100	8,762	9,419
	60	3,806	4,656	5,489	6,308	7,116	7,915	8,704	9,486	10,262	11,031
	70	4,458	5,453	6,428	7,388	8,334	9,269	10,194	11,110	12,018	12,918
	80	5,221	6,386	7,528	8,652	9,760	10,855	11,938	—	—	—
	90	6,114	7,478	8,816	10,133	11,431	12,713	—	—	—	—

Table 4.—*Board-foot yields per acre (International ¼-inch rule) to a 6.0-inch i.b. top for eastern white pine in Maine by age, site index (b.h. age 50) and stocking percent.*
[For stands 40 years old or more. Applies to overstory pine trees 9.0 inches d.b.h. and over]

Age (years)	Site index	Stocking percent							
		50	60	70	80	90	100	110	120
40	60	5,742	6,248	6,709	7,136	7,536	7,912	8,269	8,608
	70	8,776	9,548	10,253	10,906	11,517	12,092	12,636	13,155
	80	13,411	14,590	15,669	16,667	17,600	18,478	19,311	20,104
60	60	15,110	16,439	17,654	18,779	19,830	20,820	21,758	22,652
	70	23,091	25,123	26,979	28,697	30,304	31,817	33,251	34,616
	80	35,288	38,392	41,229	43,855	46,310	48,623	50,814	52,900
80	60	24,511	26,667	28,637	30,461	32,167	33,773	35,294	36,744
	70	37,457	40,752	43,763	46,551	49,157	51,612	53,937	56,152
	80	57,242	62,277	66,879	71,139	75,122	78,872	82,426	85,811
100	60	32,765	35,647	38,281	40,720	42,999	45,146	47,180	49,118
	70	50,071	54,476	58,501	62,228	65,711	68,992	72,101	75,061
	80	76,518	83,250	89,401	95,096	100,419	105,434	110,184	114,709

Table 5.—*Board-foot yields per acre (International ¼-inch) to a 6.0-inch i.b. top for eastern white pine in Massachusetts by age, site index (b.h. age 50) and stocking percent*

[For stands 40 years old or more. Applies to overstory pine trees 9.0 inches d.b.h. and over]

Age (years)	Site index	Stocking percent							
		50	60	70	80	90	100	110	120
40	50	5,953	6,587	7,176	7,729	8,251	8,749	9,224	9,681
	60	8,279	9,161	9,980	10,748	11,475	12,167	12,828	13,464
	70	11,513	12,740	13,879	14,948	15,958	16,920	17,840	18,724
	80	16,011	17,718	19,302	20,788	22,193	23,531	24,810	26,039
	90	22,266	24,640	26,842	28,909	30,864	32,724	34,503	36,212
60	50	12,985	14,368	15,653	16,858	17,998	19,083	20,120	21,116
	60	18,058	19,982	21,768	23,444	25,030	26,538	27,981	29,366
	70	25,112	27,789	30,273	32,604	34,808	36,906	38,913	40,840
	80	34,924	38,646	42,100	45,342	48,408	51,325	54,116	56,795
80	50	19,177	21,221	23,118	24,898	26,581	28,183	29,715	31,187
	60	26,669	29,511	32,150	34,625	36,966	39,194	41,325	43,371
	70	37,088	41,041	44,710	48,152	51,408	54,506	57,470	60,316
	80	51,578	57,075	62,178	66,965	71,492	75,802	79,923	83,880
100	50	24,232	26,814	29,211	31,460	33,588	35,612	37,548	39,407
	60	33,699	37,290	40,624	43,752	46,710	49,525	52,218	54,804
	70	46,864	51,859	56,495	60,845	64,959	68,874	72,619	76,215
	80	65,174	72,120	78,567	84,617	90,338	95,782	100,990	105,991

Table 6.—*Board-foot yields per acre (International ¼-inch) to a 6.0-inch i.b. top for eastern white pine in New Hampshire by age, site index (b.h. age 50) and stocking percent*

[For stands 40 years old or more. Applies to overstory pine trees 9.0 inches d.b.h. and over]

Age (years)	Site index	Stocking percent							
		50	60	70	80	90	100	110	120
40	60	7,660	7,876	8,064	8,230	8,379	8,514	8,639	8,755
	70	10,405	10,699	10,953	11,179	11,381	11,566	11,735	11,892
	80	14,134	14,533	14,878	15,184	15,460	15,710	15,940	16,153
60	60	19,864	20,425	20,911	21,341	21,728	22,080	22,403	22,702
	70	26,983	27,744	28,404	28,988	29,514	29,992	30,431	30,838
	80	36,652	37,686	38,582	39,376	40,090	40,739	41,336	41,888
80	60	31,988	32,891	33,673	34,366	34,989	35,556	36,076	36,558
	70	43,451	44,677	45,740	46,681	47,527	48,297	49,004	49,659
100	60	42,574	43,774	44,816	45,738	46,567	47,322	48,014	48,656
	70	57,830	59,461	60,875	62,128	63,254	64,279	65,220	66,092

gressions, excluding all plots in stands less than 40 years old — stands with only a small amount of sawtimber. The resulting regressions were considerably better in both consistency and accuracy. However, because of certain differences among states in predicted values, standard errors, and ranges in the basic data, separate regressions are presented for each state:

Maine: $\log_{10} BV = 3.12884 + 0.01842\ (S) + 0.46245\ (\log_{10} P) - 50.42094\ (1/A)$
$R = 0.79$
$SE = 3.4$ percent of the mean
$N = 48$ plots

Mass.: $\log_{10} BV = 3.13095 + 0.01432\ (S) + 0.55547\ (\log_{10} P) - 40.64337\ (1/A)$
$R = 0.88$
$SE = 2.8$ percent of the mean
$N = 47$ plots

N.H.: $\log_{10} BV = 4.06855 + 0.01330\ (S) + 0.15253\ (\log_{10} P) - 49.65985\ (1/A)$
$R = 0.78$
$SE = 3.9$ percent of the mean
$N = 45$ plots

As might be expected, the equations for board-foot yield were less accurate than those for cubic-foot yield. However, the correlation coefficients and standard errors indicate that this degree of accuracy is useful for practical application.

The three equations are tabulated over the approximate applicable range of data in tables 4, 5, and 6.

APPLICATIONS

The application of yield tables covering a range of stocking percents is complicated by the fact that the stocking percent may change over time.

Where the stocking percent of a stand is near 100 percent — between 90 and 110, for example—changes in stocking percent over time probably can be ignored. For example, beginning with a 40-year-old-stand, on site index 70, and at 100 percent stocking, we would predict 9,310 cubic feet per acre at age 80 (table 3).

Where the initial stocking percent is well above 100 percent, we would assume that the stocking percent would decrease with time. If changes in stocking percent were ignored, estimates of future yield would be overestimated in both cubic feet and board feet. Changes in stocking percent of eastern white pine have not been studied, to our knowledge.[2] However, intensive investigations in western white pine *(Watt 1960)* have shown that changes in stocking percent, or normality percent, are related to initial stocking, age, and composition index:

$$Y = 16.51873 - 0.16165\ X_1 - 0.07555\ X_2 + 0.04267\ X_3$$

Where:

Y = 5-year change in stocking percent.
X_1 = initial stocking percent.
X_2 = stand age in years.
X_3 = composition index (= 100 for a pure pine stand).

Using this equation, we find that percent stocking of a 40-year-old stand, at 120 percent stocking, decreases by not quite 1 percent in 5 years. Thus we might expect such a stand to decrease to about 116 percent stocking by age 60.

Conversely, where initial stocking is below 100 percent, we would expect the stocking percent to increase with time. The main exception would be where hardwoods make up the difference between current pine stocking and full stocking; under such conditions, pine stocking probably would not change greatly with time.

For a 40-year-old stand, the estimated increase in stocking percentage (using Watt's equation) is about 2 percent a year for an initial stocking of 50 percent and about 1 percent a year for an initial stocking of 80 percent. Thus we might expect a 40-year-old stand to increase from 50 percent to 70 percent stocking in roughly 10 years, or from 80 percent to 100 percent in about a 20-year period. We would expect these rates to vary directly with site quality.

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[2] Projected hypothetical changes in stocking percent have been applied by Barrett and Allen *(1966)* in their yield analysis of white pine in New Hampshire. However, their correction equation applies to yield tables based on stand height rather than the variables of age and site index used in this paper.

Where the stocking has been reduced by silvicultural treatment, we would expect that stocking percent would increase with time. However, because of improved spacing and vigor as a result of treatment, changes in both stocking percent and volume production would no doubt take place more rapidly than in the unmanaged stands covered by this study.

■

LITERATURE CITED

Barrett, James P., and Peter H. Allen. 1966. PREDICTING YIELD OF EXTENSIVELY MANAGED WHITE PINE STANDS. Univ. N. H. Agr. Exp. Sta. Tech. Bull. 108, 15 pp., illus.

Clutter, Jerome L. 1963. COMPATIBLE GROWTH AND YIELD MODELS FOR LOBLOLLY PINE. Forest Sci. 9:354-371.

Frothingham, E. H. 1914. WHITE PINE UNDER FOREST MANAGEMENT. U. S. Dep. Agr. Bull. 13, 70 pp.

Watt, Richard F. 1960. SECOND-GROWTH WESTERN WHITE PINE STANDS. U. S. Dep. Agr. Tech. Bull. 1226, 60 pp.

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