

Board-Foot Growth of Loblolly Pine as Related to Age, Site, and Stand Density

Thomas C. Nelson, K. B. Trousdell,
E. V. Brender, and Thomas Lotti

BOARD-FOOT growth of loblolly pine varies widely among forest stands. It has long been recognized that this variation is related to environmental and cultural factors peculiar to each forest stand.

Some of the individual factors affecting board-foot growth are common to all even-aged loblolly pine stands. They can be and are commonly expressed quite simply in numerical terms of stand age, site, and stand density.

Development of the relationships of stand age, site index, and stand density to board-foot growth in loblolly pine is the subject of this paper. It involves remeasurement of permanent plots over a 10-year period in Georgia, Virginia, and South Carolina.

Analyses of earlier remeasurements of this study were reported by Wenger et al. (6), and merchantable cubic-foot volume growth analyses have also been reported (4). But the reasonable degree of fit of board-foot growth in these even-aged, managed stands to the variates of age, site, stand density, and their interactions should further contribute to our knowledge of loblolly pine growth.

Methods

One hundred and three circular 1/4-acre plots with 1/2-chain isolation strips are included in the analyses reported in this paper.¹ These plots, established during 1948-1950, were selected in 20- to 60-year-old stands with a range in site index from less than 60 feet to more than 100 feet and a range in densities from 40 to 130 percent of full stocking (5). Plots were

Abstract. Periodic annual board-foot growth was related to age, site index, total basal area per acre, and some of their interactions in thinned loblolly pine stands in Georgia, Virginia, and South Carolina. Values presented in this paper provide stocking standards

selected so that site index did not vary more than 10 feet within plot boundaries and only essentially pure stands of even-aged, uniformly spaced, and insect- and disease-free loblolly pine were used. The plot distribution in relation to age, site index, and stand density classes was previously reported (4).

Plots were established in Georgia, Virginia, and South Carolina. The plots in Georgia were located on the Hitchiti Experimental Forest; those in Virginia on the Camp Experimental Forest, jointly maintained by the U. S. Forest Service and the Union Bag-Camp Paper Corporation. Part of the plots in South Carolina were located on the Santee Experimental Forest and the other portion on the Westvaco Experimental Forest, the latter maintained by the West Virginia Pulp and Paper Company.

Approximately one-half of the plots were thinned to specified residual densities at the time of plot establishment. These plots were again reduced to the same residual density at the end of five growing seasons, and the other half were thinned for the first time. The thinnings were from below, modified as necessary to give more uniform spacing of the residual stand and allowing the removal of undesirable trees regardless of crown class. Hardwoods 4.6 inches d.b.h. and larger were poisoned.

All pine stems 0.6 inch d.b.h. and larger were tallied by 1-inch diameter classes, and all were included in the density computations; however, only the pine stems 9.6 inches d.b.h. and larger were tallied as sawtimber. Volumes were computed in terms of the International 1/4-inch log rule to a

for loblolly pine grown in uniformly spaced, insect- and disease-free stands. Growth prediction values must be scaled down for extensive holdings because of heterogeneity of stocking, clustering, voids, and nonproducing areas.

7-inch top diameter inside bark from previously computed total height volume tables whose data had been collected on the Hitchiti, Santee, and Camp Experimental Forests. Site index was determined by conventional site index measurements, using Coile's site index curves (2).

All plots were remeasured after 5 and 10 growing seasons. Net growth (including ingrowth) was expressed in terms of periodic (5-year) annual board-foot volume growth. Only the growth from the second remeasurement period, i.e., fifth to tenth growing seasons, is used in this report, the 0 to 5-year growth having been previously reported (6).

Analyses

An all-possible, least-square solution of nine independent variates, singly and in combinations, was used to screen the following form:

$$Y = b_0 + b_1\left(\frac{1}{A}\right) + b_2(S) + b_3(D) + b_4(D^2) + b_5\left(\frac{S}{A}\right) + b_6\left(\frac{D}{A}\right) + b_7\left(\frac{D^2}{A}\right) + b_8(SD) + b_9(SD^2) \quad (1)$$

in which Y = periodic annual board-foot growth (Int. 1/4-inch rule)
 A = total age at the beginning of the 5-year period
 S = site index

D = stand density at the beginning of the 5-year period

b with subscripts = coefficients derived from the data

The best fit from this screening indicated significance of (D) , (SD) , and (SD^2) terms when density was expressed either as Stahelin's percent of full stocking (5) or total basal area per acre. Stahelin's percent of full stocking or density percent expresses the basal area of a stand of given average diameter as a percentage of the

THE AUTHORS are with the Southeastern Forest Expt. Sta., Forest Service, U. S. Dept. Agric., Asheville, N. C.

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basal area of well-stocked stands of the same average diameter. Total basal area, a term more common to most foresters, was substituted as a measure of stand density and used in subsequent development of a predicting equation.

Although age was not significant in these analyses at the 5-percent level, it did not appear biologically sound to develop a predicting equation without age as a variate. In addition, the residuals from this equation, when plotted in relation to site, showed curvilinearity. Addition of site and site squared terms eliminated the curvilinearity of residuals and produced a final predicting equation which can be expressed as:

$$\begin{aligned} \text{Board-foot growth, periodic annual (Int. } & \\ \frac{1}{4}\text{-inch rule)} = 866.80 + .37917\left(\frac{A}{10,000}\right) & \\ - 23.77740(S) + .14207(S^2) - & \\ 17.08437(D) + .37445(SD) - & \\ .00071(SD^2) & \quad (2) \end{aligned}$$

where A = total age at the beginning of the 5-year growing period
S = site index
D = stand density expressed as total basal area of stems 0.6 inch d.b.h. and larger at the beginning of the growing period.

The coefficient of determination (R^2) for this expression is .794, and the average growth rate was 681 board feet per acre per year with a standard error of estimate of 70 board feet.

Figure 1 shows prediction values at age 50, and illustrates the relations of site and stocking to growth at a fixed age. Insofar as there are no interactions of site or stand density with age in Equation (2), the same shaped family of curves would be evident for other ages but at different levels. Growth rates covering a wide range of age, site, and stand density classes are shown in Table 1, and provide values for prescription and prediction purposes in loblolly pine management.

Discussion

The analytical model derived from these analyses accounted for nearly 80 percent of the variation around the mean value. Clustering, limited mortality, diameter distribution, less than full use of growing space for a short period following heavy thinning, genetic variation, climatic differences, and

measurement error merit consideration as factors that contributed to the unexplained error. These are the same variates that no doubt contributed to the unexplained variation of cubic-foot growth analyses (4), although the relative contributions of each may be quite different in board-foot and cubic-foot growth.

The predicting equation indicates that board-foot growth declines with increasing stand age. The reciprocal term essentially washes out in older stands after ingrowth has become negligible. It is also realized that the form of the age function is not valid for young stands whose stems are just entering sawtimber size classes.

The main effect of stand density in terms of total basal area per acre proved significant, along with interaction terms of stand density and site. The net result of these terms is a series of solutions that show a culmination of growth in relation to stand density. The function of site is to produce greater growth differences between adjacent height classes at high levels than at low levels. In fact, on Site Class 50, and perhaps somewhat higher site classes, the economic advantage could well be with cord-

wood production instead of sawtimber.

As with cubic-foot growth analyses (4), the site-density interaction is exceedingly important statistically.² In the board-foot growth analysis, the interaction occurs as the term itself and with density squared, the two terms accounting for approximately 66 percent of the variation about the mean. Board-foot growth shows a culmination at higher densities on good sites than on poor ones.

Thus, the same terms, i.e., some expression of age, site, stand density, and the site-stand density interaction, were used to characterize both board-foot and cubic-foot growth. The shapes of the curves are similar, although cubic-foot

²The relationship of cubic-foot growth to site index, stand age, and basal area was as follows: Cubic-foot growth = $148.85409 + 0.28630\left(\frac{\text{Age}}{10,000}\right) + 0.0358$

$(\text{Basal Area} \times \text{Site}) - 0.012 (\text{Basal Area})^2 - 6.79599 (\text{Site}) + 0.04451 (\text{Site})^2$ where cubic-foot growth = periodic 5-year net annual merchantable growth in cubic feet per acre of trees 4.6 inches d.b.h. and larger; age = age of stand in years at beginning of the 5-year period; site = site index of stand; and basal area = basal area per acre of all stems 0.6 inch d.b.h. and larger after thinning at the beginning of the 5-year period.

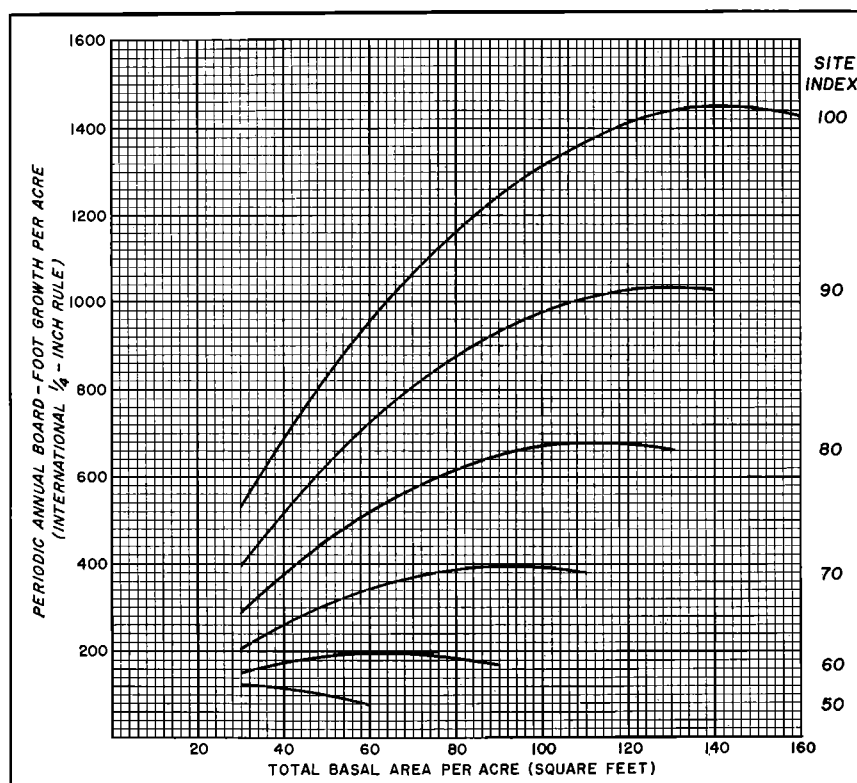


Fig. 1.—Board-foot growth expressed as a function of site index and total basal area per acre at age 50.

TABLE 1.—PERIODIC ANNUAL BOARD-FOOT GROWTH (INT. ¼-INCH RULE) PER ACRE OF TREES 9.6 INCHES D.B.H. AND LARGER TO A 7-INCH TOP DIAMETER INSIDE BARK AS RELATED TO AGE, TOTAL BASAL AREA PER ACRE, AND SITE INDEX

Age (years)	30	40	50	60	70	Total basal area per acre		110	120	130	140	150	160
						80	90	100					
Board feet													
Site 50													
30	177	168	153	130	100	63	19						
40	145	137	121	98	69	32							
50	126	118	102	79	50	13							
60	114	105	89	67	37	0							
70	104	96	80	58	28								
Site 60													
30	201	225	241	248	246	236	217						
40	170	194	209	216	214	204	186						
50	151	175	190	197	195	185	167						
60	138	162	177	184	183	173	154						
70	129	153	168	175	174	164	145						
Site 70													
30	254	310	357	394	420	437	444	441	427				
40	222	279	325	362	389	405	412	409	396				
50	203	260	306	343	370	386	393	390	377				
60	191	247	294	330	357	374	381	377	364				
70	182	238	285	321	348	365	372	368	355				
Site 80													
30	335	424	502	568	623	666	699	719	729	727	714		
40	304	393	470	536	591	635	667	688	697	695	682		
50	285	374	451	518	572	616	648	669	678	676	663		
60	272	361	439	505	560	603	635	656	666	664	650		
70	263	352	430	496	551	594	626	647	657	655	641		
Site 90													
30	445	566	675	771	854	924	982	1027	1059	1078	1084	1078	
40	413	535	643	739	822	893	950	995	1027	1046	1053	1046	
50	394	516	624	720	803	874	931	976	1008	1027	1034	1027	
60	382	503	612	708	791	861	919	963	995	1016	1021	1015	
70	373	494	603	699	782	852	910	954	986	1006	1012	1006	
Site 100													
30	579	737	877	1002	1113	1211	1293	1362	1417	1457	1492	1493	1476
40	547	705	845	971	1082	1179	1262	1331	1385	1425	1461	1461	1445
50	528	686	826	952	1063	1160	1243	1312	1366	1406	1442	1442	1426
60	516	674	813	939	1050	1147	1230	1299	1354	1394	1429	1430	1413
70	507	665	804	930	1041	1138	1221	1290	1344	1385	1420	1421	1404

growth tended to maximize at a higher stand density than board-foot growth, the difference being more pronounced on poor sites (Table 2).

Stahelin's percent of full stocking (5) was also used in lieu of total basal area as a measure of stand density. It showed the same expressions of variates to be important as in Equation (2) and provided essentially the same curve forms and goodness of fit ($R^2=.796$) as compared with .794 using total basal area.

In the analysis of the first 5-year growth period of this same study, Wenger et al. (6) also utilized expressions of age, site, and a site-stand density interaction. They did not find a significant main effect of stand density, but did show a stand density-age interaction. In the present analyses, the individual contribution of the

stand density-age interaction was very small and nonsignificant ($r^2=.100$). Although the main effect of age, (—), only showed sig-

nificance at approximately the 10-percent level, the decision was made to include this variate because it is biologically sound to retain an expression of age. Also, all

our past work has indicated that loblolly pine growth declines with age but at a diminishing rate. At our present state of knowledge, the main effect was considered the most important expression.

The results of the study are similar in many respects with those obtained by Brender (1) from compartment studies on the Hitchiti Experimental Forest in the lower

TABLE 2.—STAND DENSITIES AT WHICH MERCHANTABLE CUBIC-FOOT AND BOARD-FOOT GROWTH MAXIMIZED BY SITE CLASS AND LOWER THRESHOLD OF STOCKING FOR 90 PERCENT OF MAXIMUM GROWTH RATE

Site index class	Stand density at maximum growth rate for ...		Stand density at lower threshold of stocking for 90 percent of maximum growth rate for ...	
	Merchantable cubic-foot growth ¹	Board-foot growth	Merchantable cubic-foot growth ¹	Board-foot growth
Total basal area in square feet per acre—				
60	90	63	66	41
70	104	92	76	63
80	119	113	86	78
90	134	130	95	89
100	149	143	103	96

¹Merchantable cubic-foot growth values obtained from solutions in Southeastern Forest Expt. Sta. Paper 127 (4)

Piedmont of Georgia. He also showed significant contributions to board-foot growth from age, site, and stand density. The analysis of the Hitchiti compartment data, however, does not show culmination within the upper limits of the data, which were below those in this study, nor do they show a site-stand density interaction. In the study reported here, the site-stand density interaction terms accounted for 66 percent of the variation out of a total of R^2 of 79.4 percent.

The relatively flat growth curves between moderate to heavy stocking when growth is plotted in relation to stand density (Fig. 1 and Table 2) are in agreement with other growth work (3). They indicate that a rather broad range of stocking can be maintained while still producing near-maximum growth. This concept is of considerable importance to the forest manager because it allows the establishment of stocking standards using conventional methods of site measurement. It further means that if he pursues a conservative approach to thinning, he will have ample opportunity to correct stocking at successive cutting cycles.

The values presented in this paper should need no correction factors if used for prescription purposes, i.e., for setting stocking standards and rotation ages. It should be borne in mind, however, that for growth prediction purposes, the

values expressed in this paper represent $\frac{1}{4}$ -acre plots of uniformly spaced, insect- and disease-free stands. Extensive holdings, because of heterogeneity of stocking, clustering, voids, and nonproducing areas will have lower growth rates. Scale-down factors for extrapolating to total forest acreages will vary with each individual holding and no attempt has been made to arrive at such factors in this paper. The growth values for a given age, site index, and stand density as shown in Table 1 should approach the maximum growth rate that can be expected on a plot without cultural measures that will increase site index per se.

Summary

This progress report summarizes board-foot analyses for the 5- to 10-year measurement period of thinned stands in a loblolly pine stand density study under way at the Southeastern Forest Experiment Station. Periodic annual board-foot growth was related to age, site index, and total basal area per acre:

$$\begin{aligned} \text{Board-foot growth} &= 866.80 + .37917 \left(\frac{10,000}{\text{Age}} \right) - 23.77740 \\ &\quad (\text{Site}) \\ &\quad + 14207 (\text{Site})^2 - 17.08437 (\text{Basal Area}) \\ &\quad + .37445 (\text{Site} \times \text{Basal Area}) \\ &\quad - .00071 [\text{Site} \times (\text{Basal Area})^2] \\ R^2 &= .794 \end{aligned}$$

It is concluded that the relations between board-foot growth and the independent variates confirm the

adequacy of the study design and analysis model synthesized for this study. Comparisons of this study with other studies point out that these analyses provide the first clear indication of the importance of the site-stand density interaction in loblolly pine board-foot growth.

Values presented in this paper provide stocking standards for loblolly pine grown in uniformly spaced, insect- and disease-free stands. Growth prediction values must be scaled down for extensive holdings because of heterogeneity of stocking, clustering, voids, and nonproducing areas.

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