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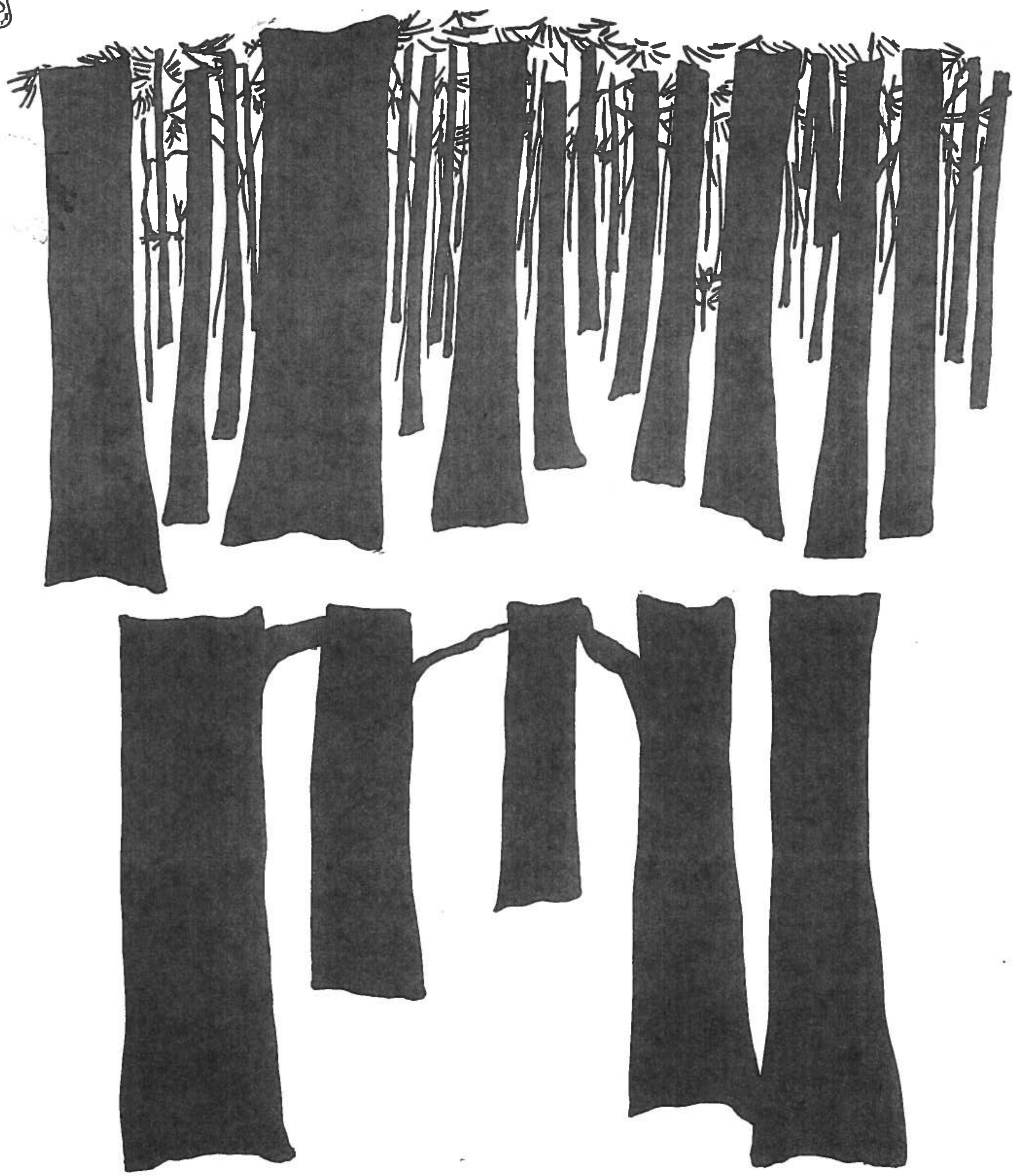
Loblolly Pine Growth and Yield Prediction for Managed West Gulf Plantations

V. C. Baldwin, Jr. and D. P. Feduccia



SUMMARY

A growth and yield prediction system is presented for use in thinned or unthinned loblolly pine plantations in the west gulf region. The equations predict cubic- and board-foot volume, green-weight, and dry-weight yields per unit area of wood only or wood with bark of entire tree boles, boles to any top diameter limit, and branches. Green and dry weight of foliage can also be predicted. Total stand yields for weight or volume are partitioned into 1-inch diameter classes to forecast stand and stock tables for all aboveground tree components for any stage of plantation development from ages 10 through 45. The data for this system of equations came from 859 measurements of thinned and unthinned long-term research study plots on cutover sites located in east Texas, Louisiana, and southern Mississippi. A computer program COMPUTE_P-LOB (Comprehensive Outlook for Managed Pines Using simulated Treatment Experiments—Planted Loblolly Pine) that produces the yield tables can be obtained from the authors.

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INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the most important commercial softwood species in the South and the most widely planted southern pine. Managers of loblolly pine plantations need accurate and complete predictions of tree component growth and yield by weight, as well as volume, to formulate flexible management policies and predict expected monetary returns for numerous product alternatives. There is a critical need for this information on cutover and prepared sites in the west gulf region.

Recently, a yield prediction system for thinned loblolly pine plantations in this region was published by Matney and Sullivan (1982). However, this data base consisted only of old-field plantation study data. Other thinned loblolly pine plantation models (Daniels and Burkhart 1975, Cao and others 1982, Burkhart and Sprinz 1984) utilized either old-field or cutover land data, but those data were from the Southeast region of the United States. Only Coile and Schumacher (1964) used some cutover site data from the west Gulf region in the development of their yield equations.

A growth and yield prediction system is presented that provides both weight and volume yields of aboveground tree components by diameter classes for 10- to 45-year-old thinned or unthinned loblolly pine plantations on cutover sites of the west gulf region. This system expands the earlier work of Feduccia and others (1979) and Strub and others (1981), providing accurate yield forecasts for cutover sites and serving as an interim guide for yields in site prepared plantations.

METHODS

Data

Study plots in unthinned and thinned loblolly pine plantations were established on cutover longleaf pine (*Pinus palustris* Mill.) forest land. In general, frequent wildfires burned the idle lands and prevented natural regeneration and hardwood brush invasion. On some areas, the predominant heavy grass rough was burned before planting; on others, it was not. The established plantations had good initial survival and minimum levels of insect, disease, or other problems.

Data for unthinned stands came from control plots located in thinning studies and from supplementary plots installed to include specific site, age, and initial planting density combinations not well represented in the existing studies. The unthinned plantation data came from 85 unthinned research plots and from 167 before-thinning measurements on thinned plantation research plots.

Thinned stand data came from four long-term studies located in central Louisiana. The thinning interval in all these studies was 5 years unless insufficient growth had occurred during that period. Figure 1 gives the geographic coverage, and tables 1 through 7 provide more detailed background information about the data and summarize the distribution of the observations. Of the 167 thinned stand plots, all were thinned from below except 12 plots that were row thinned.

Diameter growth of the residual trees after row thinning was not significantly different from diameter growth on the residual trees on comparable plots that were thinned from below during the time period covered by these data. Therefore, all the thinned stand data were combined and treated the same in this modeling effort.

The average height of dominant and codominant trees was obtained on each plot at each mesurement to determine site index. Diameter at breast height (d.b.h.) to the nearest 0.1 inch was measured for each tree on the plot. Additionally, individual volume sample trees were measured for total height, height to the base of the full live crown, and upper stem outside bark diameters. Where available, these trees were selected in proportion to the total number within the diameter class.

Trees removed in thinnings were selected and marked by the study leaders. In most cases, felling was done by loggers either employed or contracted by

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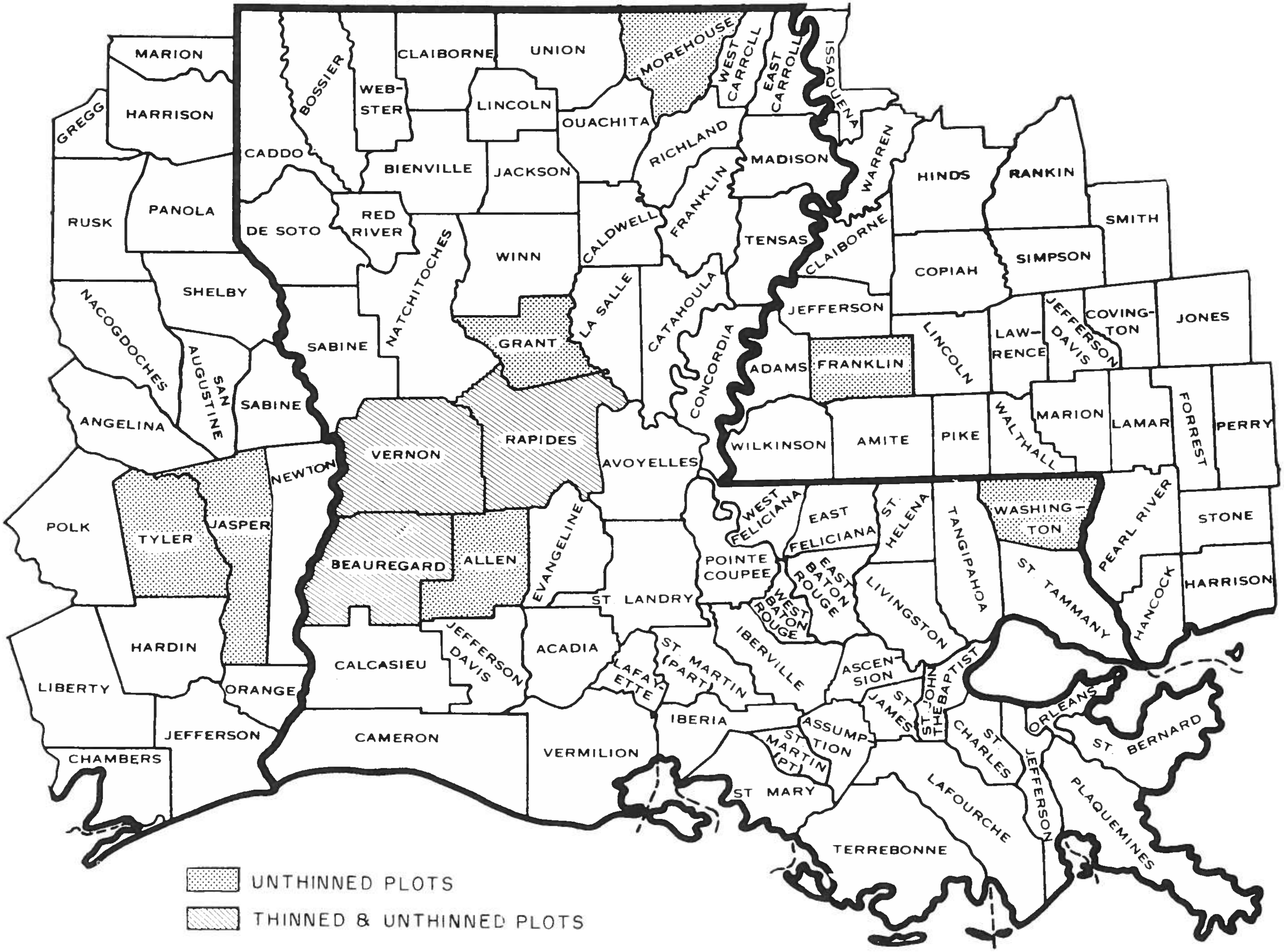

Figure 1.—*Geographic location by parish or county of the thinned and unthinned plantation study plots.*

Table 1.—*Planted loblolly pine spacing and thinning studies in the west gulf region that provided data for the growth and yield prediction system*

Study	Age first thinned or measured	Age at last measurement	Site index range (base 25)	Planting density	Survival at first measurement	Number of thinnings	Residual densities	No. of plots[1]
	-------- *Years* ---------		*Feet*	*Trees/acre*	*Percent*		*BA*[2]*/acre*	
1	20	45	53–67	400–2700	40–74	6	70–100	65 (4)
2	17	32	56–72+	300–1200	69–85	4	60–120	73 (15)
3	15–22	20–27	56–72+	800–1200	68–78	2	60–130	28 (4)
4	17	17	67–72+	908	48–86	1	50–90	12
5	5–45	15–36	40–72+	100–1400	30–95	0	....	(62)

[1]The number of unthinned plots are in parentheses.
[2]BA: basal area.

Table 2.—*Distribution of unthinned stand observations by plantation age and planting density*

Age class	Planting density class (trees per acre)							
	≤250	251–500	501–750	751–1000	1001–1250	1251–1500	≥1500	Total
Years				*Number*				
3–7	8	4	4					16
8–12	8	7	8	16				39
13–17	8	54	39	26	29			156
18–22		47	21	27	26	18	6	145
23–27		24	13	22	13	5		77
28–32		18	16	9	12	4		59
33–45		19	6	5	5			35
Total	24	173	107	105	85	27	6	527

Table 3.—*Distribution of unthinned stand observations by plantation age and site index*

Age class	Base age 25 site index class (feet)									
	≤42	43–47	48–52	53–57	58–62	63–67	68–72	73–77	≥78	Total
Years					*Number*					
3–7						1	6	8	1	16
8–12						13	8	12	6	39
13–17	4	3	6	18	26	55	30	13	1	156
18–22	4	5	19	50	28	27	8	1	3	145
23–27	5	2	7	19	17	21	5	1		77
28–32	1	1	2	11	13	21	9	1		59
33–45	1	1	2	9	10	7	5			35
Total	15	12	36	107	94	145	71	36	11	527

Table 4.—*Distribution of unthinned stand observations by planting density and site index*

Planting density class	Base age 25 site index class (feet)									
	≤42	43–47	48–52	53–57	58–62	63–67	68–72	73–77	≥78	Total
Trees per acre	Number									
≤250						3	12	9		24
251–500	12	3	5	37	29	41	28	12	6	173
501–750		1	4	19	16	42	12	8	5	107
751–1000	3	2	13	23	15	30	13	6		105
1001–1250		3	2	16	31	26	6	1		85
1251–1500		1	8	12	3	3				27
≥1500		2	4							6
Total	15	12	36	107	94	145	71	36	11	527

Table 5.—*Distribution of thinned stand observations by plantation age and site index*

Age class	Base age 25 site index class (feet)							
	≤47	48-52	53-57	58-62	63-67	68-72	≥73	Total
Years	Number							
13–17			5	15	28	17	5	70
18–22	4	13	37	31	31	20	6	142
23–27	3	9	36	29	29	19	5	130
28–32	3	9	31	15	5			63
33–38	3	9	32	16	4			64
39–45	3	9	32	16	5			65
Total	16	49	173	122	102	56	16	534

Table 6.—*Distribution of thinned stand observations by residual density after thinning and site index*

Residual basal area class	Base age 25 site index class (feet)							
	≤47	48–52	53–57	58–62	63–67	68–72	≥73	Total
Ft.²/acre	Number							
≤55			1	1				2
56–65			5	13	17	21	5	61
66–75	2	13	38	11	12	2		78
76–85	8	6	53	34	19	7	2	129
86–95	5	14	33	30	5		1	88
96–105		14	29	20	28	11	5	107
106–115	1	1	4	4	3	1		14
116–125		1	9	9	15	13	3	50
≥126			1		3	1		5
Total	16	49	173	122	102	56	16	534

Table 7.—*Distribution of thinned stand observations by planting density and residual density after thinning*

Planting density class	Residual basal area class (ft^2 per acre)									
	≤55	56–65	66–75	76–85	86–95	96–105	106–115	116–125	≥126	Total
Trees/acre										
251–500	2	34	24	46	24	33	2	10		175
501–750		16	18	30	16	33	5	20	1	139
751–1000			4	12	17	5	1			39
1001–1250		10	7	15	7	18	4	16	4	81
1251–1500		1	17	18	20	10		4		70
≥1501			8	8	4	8	2			30
Total	2	61	78	129	88	107	14	50	5	534

the cooperating forest industries. The cutting and removal operations were performed with minimal residual tree damage.

Moment-Percentile Estimation Procedure

The three-parameter Weibull function (Bailey and Dell 1973) was selected as a model to describe the distribution of diameters. The probability density function is

$$f(x) = (c/b)[(x-a)/b]^{c-1}\, e^{-[(x-a)/b]^{c}}$$

$$\text{for } a \geq 0, \quad b > 0, \quad c > 0, \quad a \leq x, \tag{1}$$

$$= 0 \text{ elsewhere,}$$

where:
- a = location parameter,
- b = scale parameter,
- c = shape parameter,
- X = random variable representing d.b.h. in inches, and
- e = exponential function.

The cumulative distribution function is

$$F(x) = 1 - e^{-[(x-a)/b]^{c}}. \tag{2}$$

The i^{th} noncentral moment of X is given by

$$E(X^i) = \int_a^{\infty} x^i f(x)dx, \tag{3}$$

and the p^{th} percentile of x is

$$X_p = a + b\left[-\ln\left(\frac{100-p}{100}\right)\right]^{(1/c)} \tag{4}$$

where X_p is that diameter such that p percent of the trees in the stand are smaller, and ln is the natural logarithm.

Rather than predict maximum likelihood or percentile estimates of the Weibull parameters as functions of stand characteristics (age, site index, trees per acre, and so forth) (Smalley and Bailey 1974, Dell and others 1979, Feduccia and others 1979, Baldwin 1982, Little 1983), a parameter recovery technique (Matney and Sullivan 1982, Cao and others 1982, Bailey and others 1981, 1982) was chosen to obtain the scale and shape parameters and to directly estimate the location parameter. This system is based on prediction of two percentiles and the second moment of the distribution.

In selecting moments and/or percentiles to describe the distribution of diameters in a given stand, it is reasonable to choose values that locate the tails of the distribution and to utilize some measure of central tendency. The first percentile (X_1), the ninety-third percentile (X_{93}), and the quadratic mean diameter (X_{qmd}, which is the square root of the second moment of the diameter distribution), or basal area (BA, which is a constant times the second moment of the diameter distribution times the number of trees per unit area in the stand) were chosen to be predicted.

The first percentile was selected because it was an estimate of the "a" Weibull parameter (the minimum diameter of the distribution). Although it is rather poorly predicted in practice, direct prediction of the minimum diameter was necessary in order to insure the natural progression of minimum stand diameter over time. The ninety-third percentile was chosen to tie down the upper tail of the diameter distribution (Zanakis 1979). Finally, the quadratic mean diameter was selected as the measure of central tendency because it is commonly used in forestry, is directly related to BA, and can be accurately predicted.

Estimates of the Weibull parameters are obtained as follows:

1. The "a" parameter is set equal to $k \cdot X_1$. It was found $k = 0.60$ gives the best prediction from these data.
2. Equation (4) is solved for "b", given $p = 93$ and predicted values of X_{93} and a, which yields:

$$b = (X_{93} - a)/[-\ln(.07)]^{(1/c)}, \tag{5}$$

and this expression is substituted into the equation for $E(X^2)$. In its solved form it is (from equation (3) with $i = 2$)

$$E(X^2) = a^2 + 2\, ab\Gamma(1/c + 1) + b^2\Gamma(2/c + 1). \qquad (6)$$

The resulting expression is:

$$X^2_{qmd} = E(X^2) = \frac{2a\,(X_{93} - a)\Gamma(1/c + 1)}{(2.65926)^{1/c}} + \frac{(X_{93} - a)^2\Gamma(2/c + 1)}{(2.65926)^{2/c}} + a^2 \qquad (7)$$

where $\Gamma(x)$ = the gamma function evaluated at the point(x).

3. Equation (7) is set equal to zero and is solved by numerical techniques to obtain an estimate, c, of the shape parameter.
4. Finally, c is substituted back into equation (5) to obtain an estimate of the scale parameter b. Thus with estimates of a, b, and c, the Weibull distribution of diameters in that stand can be completely described. This fundamental procedure is repeatedly utilized to describe diameter distributions in unthinned stands, residual stands after thinning, and thinned stands at any particular age desired by the user.

Growth and Yield Prediction System Options

This prediction system allows a user to begin the process by: starting and ending with an unthinned stand, starting with an unthinned stand and ending with a stand thinned one or more times, or starting with a previously thinned stand and ending with a stand thinned one or more times.

Required input information when starting with an initially unthinned stand includes stand age from planting (A), average height of the dominant and codominant trees (HD), and surviving trees per acre (TS). If HD or TS is unknown, then site index (SI), basal area per acre (BA), or trees planted per acre (TP) are input variables that can be substituted for the required site and density measures.

When starting with a previously thinned stand, the system requires A, HD, and TS. As in the unthinned case, an estimate of SI can be substituted for HD. Furthermore, if an estimate of TS is not known, it can be predicted by providing the stand age and the residual trees surviving (TS_r) at the time of the last thinning. Figure 2 summarizes the prediction system process.

PROCEDURES AND EQUATIONS

Yield Prediction in Unthinned Stands

If height of the dominant and codominant trees is not available as an input, it is predicted using a given site index function. The following site index equation is solved for dominant height:

$$HD = SI\,[2.14915\,(1 - e^{-0.025042\,A})]^{0.755862} \qquad (8)$$

$$n = 1061 \qquad FI^1 = 0.78 \qquad S_E{}^2 = 6.23 \text{ ft}$$

where:
SI = site index (feet) at base age 25,
HD = average height (feet) of dominants and codominants,
A = plantation age (years),
e = exponential function.

Figure 3 illustrates the characteristics of site index function for various index values for base age 25.

If initial survival (TS) in terms of trees per acre is not known, the variable can be predicted using the following equation derived from Feduccia and others (1979):

$$TS = TP/\{EXP\,[A_1\,(0.013480 \ln (TP) + 0.00139956\,(HD) - 0.01937002\,(HD)^{.5})]\} \qquad (9)$$

if only TP is known, or by

$$TS = [0.02509\,(HD)^{1.40533}\, e^{0.91934\,A}\, BA^{-1}]^{-2.08056} \qquad (10)$$

if only BA is known, where A, HD, and BA are initial age, initial average height of the dominants and codominants, and initial basal area per acre, respectively.

Given this initial information, the current stand can be described as mentioned before. The stand diameter attributes X_1, X_{qmd}, and X_{93} are predicted as follows:

$$X_1 = 2.14462\,(HD)^{0.70266}\,(TS)^{-0.36282}\, e^{-1.96895\,A} \qquad (11)$$

$$n = 527 \qquad FI = 0.63 \qquad S_E = 1.04 \text{ in},$$

$$X_{qmd} = 2.14462\,(HD)^{0.70266}\,(TS)^{-0.25968}\, e^{-0.45967\,A} \qquad (12)$$

$$n = 527 \qquad FI = 0.91 \qquad S_E = 0.60 \text{ in},$$

[1] FI = Fit Index = $\{1-[\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$
[2] S_E = Standard error of the estimate

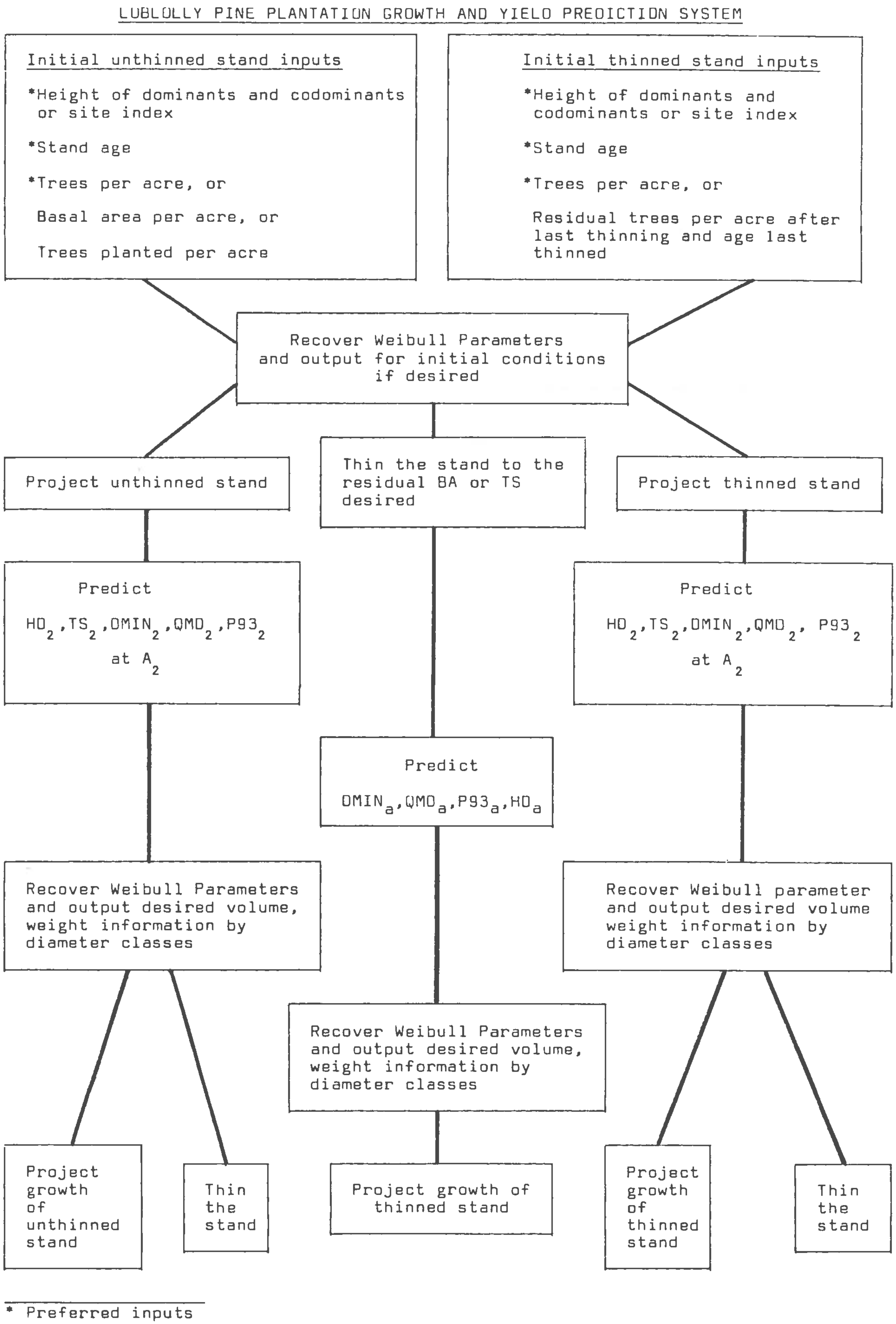

Figure 2.—*Schematic diagram summarizing the operation of the yield prediction system.*

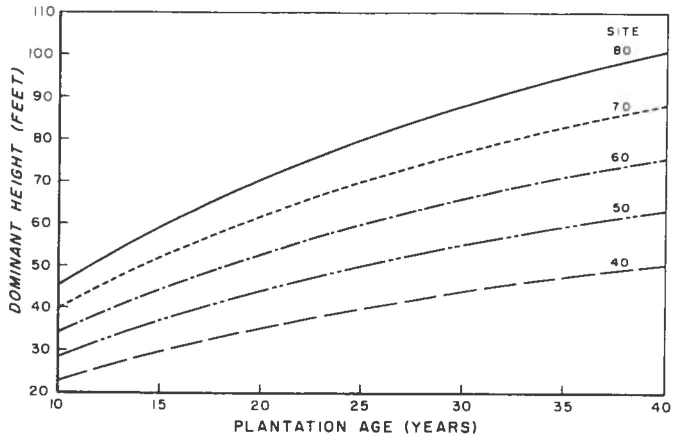

Figure 3.—*Height of dominants and codominants by planation age for site indices 40–80.*

$$X_{93} = 2.24213\,(HD)^{0.71401}\,(TS)^{-0.22932}\,e^{-0.45967/A} \quad (13)$$

$n = 527 \qquad FI = 0.91 \qquad S_E = 0.74$ in

This system of equations was constrained to insure that $X_1 \leq X_{qmd} \leq X_{93}$. The constraining was accomplished in this case by using the same model form and predictor variables for each equation. It was insisted that during the fitting process comparable coefficients in equation (11) were always ≤ the comparable coefficients in equation (12) and that comparable coefficients in equation (13) were always ≥ the comparable coefficients in equation (12). With estimates of X_1, X_{qmd}, and X_{93}, the Weibull parameters can then be estimated.

Predictions of future stand attributes and, hence future stand table information in unthinned stands, are accomplished first by projecting TS from A_1 to A_2 using the following equation:

$$TS_2 = 100\,\{(TS_1/100)^{-0.87372} + (0.01859 - 0.39120/SI)\,[(A_2/10)^{2.11947} - (A_1/10)^{2.11947}]\}^{-1.14454} \quad (14)$$

$n = 224 \qquad FI = 0.95 \qquad S_E = 37$ trees/acre

where: TS_1, TS_2 = number of trees surviving per acre at times A_1 and A_2, respectively.

Equation (8) is then employed to obtain an estimate HD_2 at A_2, and then these predictions of HD_2, TS_2, and A_2 are substituted for HD, TS, and A in equations (11) – (13) to obtain the new predictions of X_1, X_{qmd}, and X_{93} at A_2.

Figures 4 through 7 give examples of the behavior of these functions over time for selected site index and initial density values.

Predicting Stand Attributes After Thinning

The residual stand after thinning is determined by prediction of "thinned" values of X_1, X_{qmd}, X_{93}, TS, and BA, followed by recovery of the new Weibull parameters, as already explained.

Many types of thinning could easily have been modeled and built into the prediction system. However, since these data represent stands essentially thinned from below, only that thinning option was included in this yield prediction system.

The low thinning in the study plots was not strictly a process of removing only the suppressed and intermediate trees until the desired leave-tree basal area per acre was obtained. Spacing, stand uniformity, and stand vigor were also factors of equal weight. In some cases, especially during the first thinning, codominants or even dominants were removed if they were deformed or diseased, or if large "holes" would have otherwise been left in the stand.

Graphical examination of the diameter distributions before and after thinning showed the most change occurred in both shape and location after the first thinning, the next greatest after the second thinning, and so forth. It was determined that the data, at least for thinnings beyond the second, should be combined. In some cases, the data beyond the first thinning should be combined. The attribute (X_1, X_{qmd}, X_{93}) equations for these groups were tested using an analysis of covariance procedure (Freese 1964, Milliken 1982) to see if there was some statistical, as well as visual, justification for combining or separating some or all of the equations. The tests[3] indicated X_1, and X_{qmd} predictions would be much less variable if there was one set of equations to accomplish this for the first thinning and another set for all subsequent thinnings. The tests also showed that X_1 prediction would be less variable and X_{qmd} predictions slightly less variable if there was also a separate set of equations for the second thinning, as well as a set for the first thinning and a set for all subsequent thinnings. In all cases there were no significant differences for X_{93} predictions. For the sake of simplicity, only two sets of equations were chosen: one to predict the residual stand after the first thinning and another set to predict the residual stand after all subsequent thinnings.

[3]The test of the hypothesis that the regressions (to predict X_1, X_{qmd}, X_{93} after a thinning) for the first thinning should be kept separate from the others rather than one overall regression be used, yielded calculated $F_{4,666}$ values of 16.11, 14.94, 2.21 for X_1, X_{qmd}, and X_{93}, respectively. The test of the hypothesis that the regressions for the second thinning should be kept separate from the 2nd through last thinnings rather than the 2nd through last thinning regressions be combined into one overall regression, yielded calculated $F_{4,493}$ values of 7.67, 3.30, 0.86 for X_1, X_{qmd}, and X_{93} respectively.

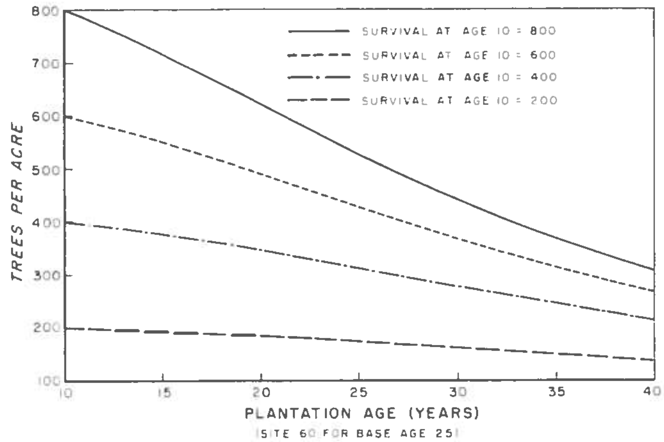

Figure 4.—*Surviving trees per acre by plantation age for unthinned loblolly pine planted at four initial densities.*

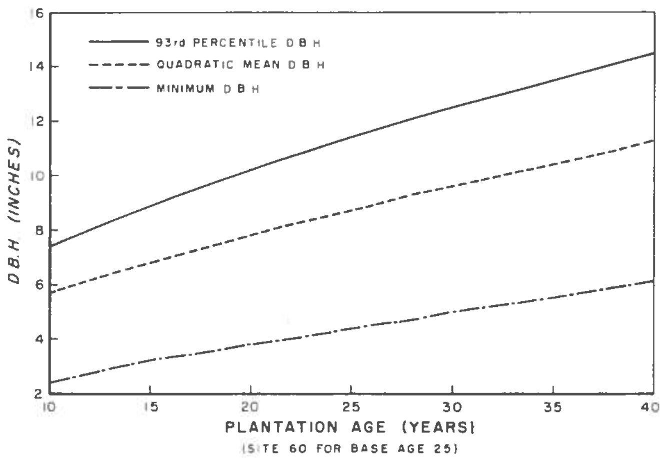

Figure 5.—*Predicted diameter growth relationships over time for unthinned loblolly pine stand (site index 60) with survival at age 10 of 400 trees per acre.*

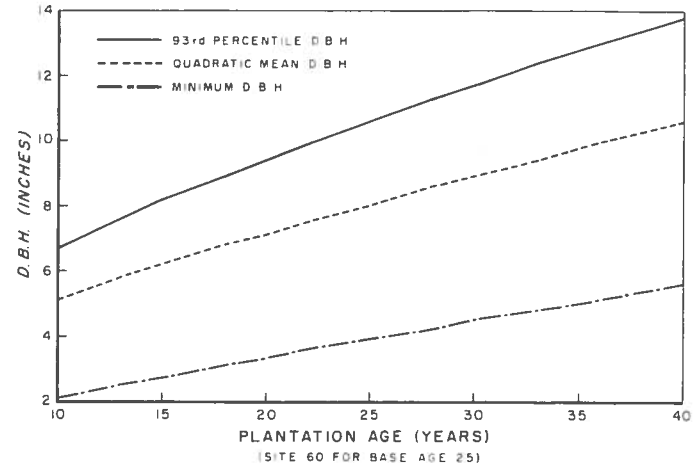

Figure 6.—*Predicted diameter growth relationships over time for unthinned loblolly pine stand (site index 60) with survival at age 10 of 600 trees per acre.*

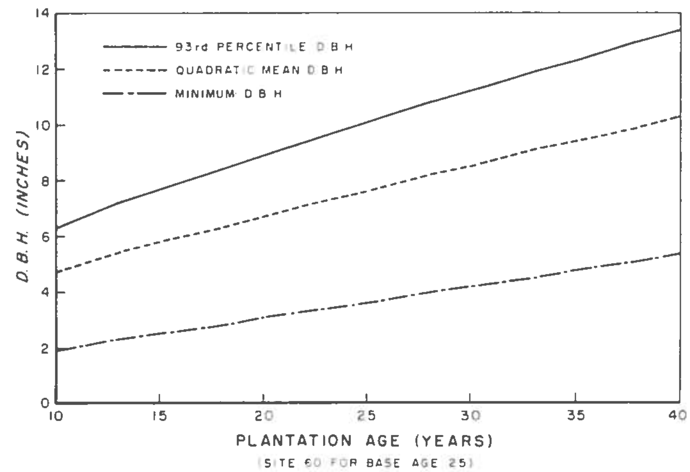

Figure 7.—*Predicted diameter growth relationships over time for unthinned loblolly pine stand (site index 60) with survival at age 10 of 800 trees per acre.*

Input information is typically based on unthinned stand attributes that have been provided by the user or predicted from appropriate equations given in the previous section. The target density for each thinning may be in terms of residual stand basal area per acre or residual trees per acre. Equations 15 through 17 and 19 through 21, which follow, are based on an assumed residual BA target. If a residual TS target is chosen, either equation 18 or 22 is utilized to predict BA following the thinning. This value is then used in the previously mentioned equations as if it were the target BA. The b and a subscripts in the following equations reference before and after thinning conditions; otherwise the definitions for the variables are as before:

I. *First Thinning*

$$X_{1,a} = 1.28767\ X_{1,b} - 0.410403(BA)_a/(BA)_b \qquad (15)$$

$n = 173 \qquad R^2 = (0.94)$[4] $\qquad S_E = 0.96$ in,

$$X_{qmd,a} = 1.069587\ X_{qmd,b} - 0.350918(BA)_a/(BA)_b \qquad (16)$$

$n = 173 \qquad R^2 = (0.99) \qquad S_E = 0.36$ in,

$$X_{93,a} = 0.95074\ X_{93,b} + 0.017485(HD)_b - 0.298543(BA)_a/(BA)_b \qquad (17)$$

$n = 173 \qquad R^2 = (0.99) \qquad S_E = 0.45$ in,

[4]Coefficient of Determination (R^2) values enclosed in parentheses were calculated using an uncorrected sum of squares value since there was no constant term in those equations.

$$BA_a = BA_b[1 - (1 - TS_a/TS_b)0.83888]0.71395 \quad (18)$$

$n = 173 \quad FI = 0.85 \quad S_E = 7.9\ ft^2$

II. *Subsequent thinnings*

$$X_{1.a} = 2.63243 + 0.766348X_{1.b} - 5.144246(BA)_a/(BA)_b \quad (19)$$

$n = 501 \quad R^2 = 0.82 \quad S_E = 1.17$ in,

$$X_{qmd.a} = 1.278159 + 0.953873X_{qmd.b} + 0.008981(HD)_b - 1.265008(BA)_a/(BA)_b \quad (20)$$

$n = 501 \quad R^2 = 0.98 \quad S_E = 0.29$ in.

$$X_{93.a} = 1.084635 + 0.972118X_{93.b} - 0.67333(BA)_a/(BA)_b \quad (21)$$

$n = 501 \quad R^2 = 0.96 \quad S_E = 0.48$ in,

$$BA_a = BA_b[1 - (1 - TS_a/TS_b)0.85566]0.56963 \quad (22)$$

$n = 501 \quad FI = 0.95 \quad S_E = 3.5\ ft^2$

In those cases where the residual density is specified as basal area per acre, the number of residual trees after thinning is obtained directly from the relationship

$$(TS)_a = (BA)_a/0.005454(X_{qmd.a})^2 \quad (23)$$

where $X_{qmd.a}$ is predicted using equation (16) or (20), as appropriate.

Thinned Stand Predictions

Equations in the thinned stand section of the yield system take either predicted or user supplied after-thinning stand information at age A_1 and project these values into the future to time A_2 to provide stand table predictions at the new age. The same stand diameter and height attributes as used elsewhere are also predicted here, and these values are used to obtain Weibull parameters for description of the new stand.

The equations for prediction of diameters at a second age in thinned stands are

$$X_{1.2} = [-529.8956 + 0.59995(TS_1) + 529.8956(A_2/A_1) - 0.59995(TS)_1(A_2/A_1) + (A_2/A_1)(X_{1.1})^{3.39763}]^{1/3.39763} \quad (24)$$

$n = 534, \quad FI = 0.88, \quad S_E = 0.97$ in,

$$X_{qmd.2} = [-109.9872 + 0.12169(TS_1) + 109.9872(A_2/A_1) - 0.12169(TS_1)(A_2/A_1) + (A_2/A_1)(X_{qmd.1})^{2.39998}]^{1/2.39998} \quad (25)$$

$n = 534, \quad FI = 0.98, \quad S_E = 0.33$ in,

$$X_{93.2} = [-146.8410 + 0.15597(TS_1) + 146.8410(A_2/A_1) - 0.15597(TS_1)(A_2/A_1) + (A_2/A_1)(X_{93.1})^{2.33778}]^{1/2.33778} \quad (26)$$

$n = 534, \quad FI = 0.97, \quad S_E = 0.48$ in.

where

$X_{1.1}, X_{1.2}$ = smallest diameter tree at time A_1, and at time A_2, respectively,

$X_{qmd.1}, X_{qmd.2}$ = quadratic mean diameter at time A_1, and at time A_2, respectively,

$X_{93.1}, X_{93.2}$ = 93rd percentile diameter at time A_1, and at time A_2, respectively.

The equation for prediction of survival in thinned stands is

$$TS_2 = 100\{(TS_1/100)^{-1.06699} + (0.00941 + 15.43171/SI)[A_2/10)^{0.29683} - (A_1/10)^{0.29683}]\}^{-0.93722} \quad (27)$$

$n = 534 \quad FI = 0.98 \quad S_E = 15.6$ trees/acre

TS_1 = initial trees surviving per acre.

In figures 8 through 10, the behavior of these functions is illustrated for one site index value assuming some common post-first thinning densities and no further thinning.

It must be noted here that equations 24, 25, and 26 are not time invariant. In other words, given an ordered time sequence t_1, t_2, t_3, predictions for values of the variables at time t_3 based on initial values at time t_1 ($t_1 \rightarrow t_3$) will not be exactly the same as those at time t_3 that were projected from those at time t_2, which were based on those at time t_1 ($t_1 \rightarrow t_2 \rightarrow t_3$). Time invariant equations, which are desirable, were developed and tried, but the precision of predictions from the equations presently given, when used in conjunction with equation 27, was much better than the precision of the predictions from the time invariant set of equations.

Nevertheless, this improved precision can be lost if the projection interval length differs much from 5 years, the data measurement interval length. Therefore, to achieve the most reliable and consistent pre-

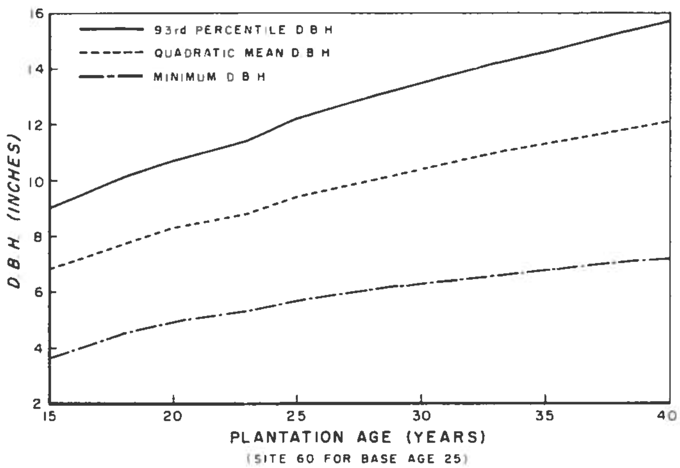

Figure 8.—*Predicted diameter growth relationships over time for loblolly pine stand (site index 60) thinned once at age 15 to 300 trees per acre.*

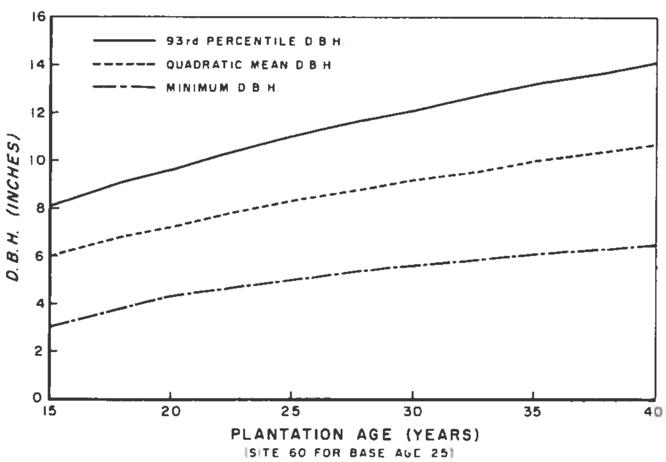

Figure 9.—*Predicted diameter growth relationships over time for loblolly pine stand (site index 60) thinned once at age 15 to 500 trees per acre.*

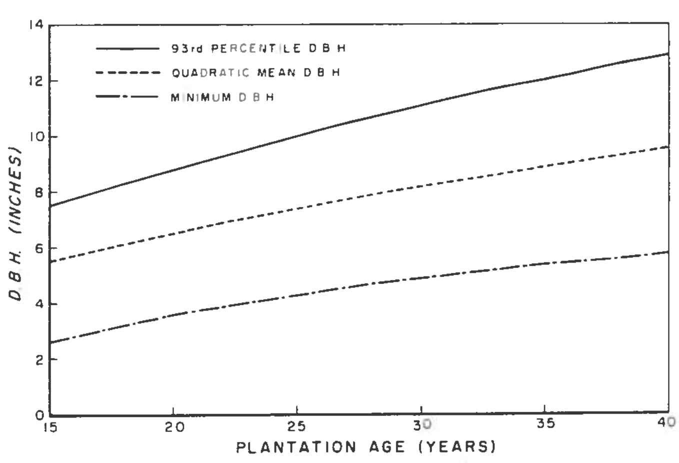

Figure 10.—*Predicted diameter growth relationships over time for loblolly pine (site index 60) thinned once at age 15 to 700 trees per acre.*

dictions with this system of equations, after-thinning growth projection intervals should be in multiples of 5 years with the final projection, if required, done over the remaining years.

Volume and Weight Prediction

Stand tables are generated at any age by apportioning the total number of trees surviving into 1-inch diameter classes according to the predicted Weibull distribution for that age. The average total height of all trees within a diameter class is predicted with the following equations:[5]

$$H = \exp[1.203241 + 0.751234 \ln(HD) - 1.767749/A + 0.048913 \ln(TS/D) + 9.057581/(A)(D) - 3.113997/D] \quad (28)$$

$n = 7872 \qquad FI = 0.94, \qquad S_E = 3.45$ ft,

for trees in unthinned stands, and

$$H = \exp[1.124364 + 0.80562 \ln(HD) - 3.880531/A + 0.049332 \ln(TS/D) + 42.279443/(A)(D) - 4.816993/D] \quad (29)$$

$n = 6007 \qquad FI = 0.90 \qquad S_E = 3.34$ ft,

for trees in thinned stands, where:

H = mean predicted height of a tree, in feet,

D = d.b.h., in inches, represented by the midpoint of a diameter class.

Given the mean height and midpoint of the diameter class for all the predicted numbers of trees, the following measurements are calculated for each average tree: cubic foot volume, green weight, or oven-dry weight of the total stem or stem to a merchantable top diameter limit, either inside or outside bark. This quantity is then multiplied by the predicted number of trees per acre in that diameter class to obtain the volume or weight per acre for each diameter class. Finally, the stand averages are obtained by summation over all diameter classes.

Board-foot volume for trees with d.b.h(o.b.) $\geq$ 10 inches to an o.b. top diameter of 8 inches is also predicted. The user may elect to use either the Doyle, Scribner, or International 1/4-inch log rules.

[5]Equations 28 and 29 are presented in arithmetic form with FI and S_E in arithmetic units although the equations were fitted in logarithmic form.

This procedure requires predictions of i.b. diameters at various log heights and also the prediction of height to the 8-inch (o.b.) top diameter, of each average tree in each diameter class $\geq$ 10 inches. Our stem taper data were fitted to the Max and Burkhart (1976) model in order to provide equations for these predictions. The model is presented below and the parameter coefficients and supporting statistics (Baldwin and Feduccia 1987) are given in table 8:

$$\frac{d^2}{D^2} = b_1(X - 1) + b_2(X^2 - 1) + b_3(a_1 - X)^2 I_1 + b_4(a_2 - X)^2 I_2 \tag{30}$$

where:

$$I_i = \begin{cases} 1, \text{ if } X \leq a_i \\ 0, \text{ if } X > a_i \end{cases} \quad i = 1,2$$

d = stem diameter i.b. or o.b. (inches) at any given height, h,

D = d.b.h. (inches) o.b.,

X = h/H,

h = height (feet) at which diameter is to be determined ($\leq$H),

H = tree total height (feet),

a_i = join points estimated from the data and

b_i = coefficients estimated from the data.

There are separate equations for height or diameter prediction of trees from unthinned stands (or trees from stands thinned less than 5 years previously) and for trees from stands thinned 5 or more years earlier.

The volume and weight model selected was that of Schumacher and Hall (1933). It is

$$\ln(Y) = b_1 + b_2 \ln(D) + b_3 \ln(H) \tag{31}$$

where b_1, b_2, b_3 are coefficients to be estimated from the data, and Y represents either cubic-foot volume, green weight, or dry weight of appropriately defined tree components.

Table 8.—*Regression coefficients for a stem-taper model useful in predicting upper stem diameters at a specified height given breast-height diameter and total tree height.*[1]

Dependent ratio[2]	Parameter estimates						Statistics[3]	
	b_1	b_2	b_3	b_4	a_1	a_2	FI	S_E
Unthinned stands								
dob^2/D^2	−8.07778	4.02542	−3.65499	229.739	0.89406	0.05703	0.95	0.11
dib^2/D^2	−4.58266	2.24195	−2.34978	138.546	0.80645	0.05980	0.97	0.07
Thinned stands								
dob^2/D^2	−13.31391	6.73098	−6.65501	203.959	0.91195	0.06035	0.96	0.08
dib^2/D^2	−7.43322	3.74079	−4.03111	191.149	0.85190	0.04833	0.95	0.07

[1]The model is:

$$\frac{d^2}{D^2} = b_1(X - 1) + b_2(X^2 - 1) + b_3(a_1 - X)^2 I_1 + b_4(a_2 - X)^2 I_2$$

$$\text{where: } I_i = \begin{cases} 1, \text{ if } X \leq a_i \\ 0, \text{ if } X > a_i \end{cases} \quad i = 1,2$$

d = stem diameter i.b. or o.b.

D = d.b.h. (inches) o.b.,

X = h/H

h = height (feet) at which diameter is to be determined ($\leq$H),

H = tree total height (feet),

a_i = join points estimated from the data, and

b_i = coefficients estimated from the data.

[2]dob = diameter o.b. at any given height, h.

dib = diameter i.b. at any given height, h.

D = d.b.h. (inches) o.b.

[3]$FI = \{1 - [\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$

$$\text{where: } \hat{Y}_i = \sqrt{D^2\left(\frac{d^2}{D^2}\right)} \text{ and } Y_i = d_i.$$

S_E = Standard error of the estimate in original units.

As explained in Baldwin (1987) and Baldwin and Feduccia (1987), this model was best when fitted separately to cubic-foot volume stem data from thinned stands and from unthinned stands. It also worked well when utilized to develop equations to fit both weight and volume of various crown components with unthinned and thinned stand tree data combined. However, an age variable, A^2, was added to provide more precise predictions of total stem green and dry weight from combined thinned and unthinned stand data.

Therefore, combined data from both thinned and unthinned plantations were fitted to Schumacher and Hall's model to predict the following yield components:

(1) cubic-foot volume, green weight, and oven-dry weight of branch wood and branch bark, and

(2) green and dry weight of the foliage.

Combined data were also fitted to this model, with the age variable added, to predict green-weight and oven-dry weight of the main stem. To precisely predict cubic-foot volume (o.b. and i.b.) of the main stem, separate equations using the Schumacher and Hall model were developed from the thinned stand data and from the unthinned stand data. Coefficients for all of these equations and accompanying fit statistics are found in tables 9 through 11.

Merchantable cubic-foot volume and green and dry weight of the main stem (i.b.or o.b.) to any top diameter limit (i.b. or o.b.) are obtained from equations developed from the following ratio model (Van Deusen and others 1981, Parresol 1983):

$$R = \exp[b_1(d^{b_2}/D^{b_3})] \qquad (32)$$

where:

R = predicted ratio of merchantable to total volume (cubic feet) or weight (green or dry weight in pounds),

b_1, b_2, b_3 = coefficients estimated from the data.

The coefficients, from Baldwin (1987) and Baldwin and Feduccia (1987), are given in table 12.

Testing

To avoid unneccessarily weakening the development data set, a subset of the development data was not withheld for testing purposes; instead it was decided to later validate against truly independent data sets. However, to make sure the combined system of equations behaved well as a unit, the completed growth and yield predictions system was tested against the data used to develop it. The tests verified that predicted values were close to those observed.

The prediction phases tested were: initial prediction in an unthinned stand, growth prediction in an unthinned stand, residual stand after thinning, and growth prediction in a thinned stand. In each case

Table 9.—*Regression coefficients for total stem volume*[1]

Dependent variable[2]	Parameter estimates			Statistics[3]		
	b_1	b_2	b_3	FI	S_E	CV
Unthinned stands						
TVob	−5.731735	1.896449	1.010252	0.99	1.93	11.2
TVib	−6.897192	1.886827	1.245844	0.98	1.96	13.6
Thinned stands						
TVob	−5.816087	2.036340	0.953537	0.99	2.93	10.8
TVib	−6.885331	2.040995	1.150022	0.98	3.50	15.6

[1]The model is:

$$\ln(Y) = b_1 + b_2\ln(D) + b_3\ln(H)$$

where:

Y = predicted stem volume (cubic feet) from a 6-in stump to the stem tip,

D = diameter outside bark (inches) at 4.5 feet,

H = total tree height (feet), and

b_1, b_2, b_3 = coefficients estimated from the data.

[2]TVob = total stem volume outside bark.
TVib = total stem volume inside bark.

[3]Fit Index (FI) = $\{1 - [\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$

S_E = Standard error of the estimate in original units.
CV = Coefficient of variation in percent.

Table 10.—*Regression coefficients for total stem weight equations*[1]

Dependent variable[2]	Parameter estimates				Statistics[3]		
	b_1	b_2	b_3	b_4	FI	S_E	CV
TGWob	−2.06033	1.93926	1.05077	.000061	0.99	153.4	11.4
TGWib	−2.53232	1.96524	1.12691	.000060	0.99	152.9	12.4
TGWob	−3.31353	1.91029	1.19118	.000076	0.99	70.1	10.5
TGWib	−4.20913	1.87667	1.38064	.000088	0.99	69.0	11.8

[1]The model is:

$$\ln(W) = b_1' + b_2\ln(D) + b_3\ln(H) + b_4A^2$$

where:

W = predicted stem volume (pounds) from a 6-in stump to the stem tip,
D = diameter outside bark (inches) at 4.5 feet,
H = total tree height (feet),
A = age from planting, and
b_1', b_2, b_3, b_4 = coefficients estimated from the data.

[2]TGWob = total stem green weight outside bark.
TGWib = total stem green weight inside bark.
TDWob = total stem dry weight outside bark.
TDWib = total stem dry weight inside bark.

[3]Fit Index (FI) = $\{1 - [\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \overline{Y})^2]\}$

S_E = Standard error of the estimate in original units.
CV = Coefficient of variation in percent.

Table 11.—*Regression coefficients for crown green and dry weight equations*[1]

Dependent variable[2]	Parameter estimates			Statistics[3]		
	b_0	b_1	b_2	FI	S_E	CV
CGWW	1.735217	3.492293	−1.243386	0.90	61.5	41.2
CDWW	0.379049	3.454388	−1.088445	0.90	28.5	41.3
CGWB	1.203148	3.023912	−1.136030	0.85	14.6	36.9
CDWB	0.264828	3.033934	−1.109824	0.86	6.9	38.2
CGWF	3.652443	2.864732	−1.454774	0.86	25.1	32.4
CDWF	2.796233	2.912819	−1.474651	0.85	11.4	33.5

[1]The model is:

$$\ln(W) = b_0 + b_1\ln(D) + b_2\ln(H)$$

where:

W = predicted weight (pounds) of crown component,
D = diameter outside bark (inches) at 4.5 feet,
H = total tree height (feet), and
b_0, b_1, b_2 = coefficients estimated from the data.

[2]CGWW = crown green weight of wood.
CDWW = crown dry weight of wood.
CGWB = crown green weight of bark.
CDWB = crown dry weight of bark.
CGWF = crown green weight of foliage.
CDWF = crown dry weight of foliage.

[3]Fit Index (FI) = $\{1 - [\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \overline{Y})^2]\}$

S_E = Standard error of the estimate in original units.
CV = Coefficient of variation in percent.

Table 12.—*Regression coefficients for volume and weight ratio equations*[1]

Dependent variable[2]	Parameter estimates			Statistics[3]	
	b_0	b_1	b_2	FI	S_E
Unthinned stands					
MVob/TVob	−0.799015	4.975752	4.686168	0.98	0.048
MVib/TVib	−0.938014	4.950338	4.706034	0.98	0.049
MGWob/TGWob	−1.153726	4.911545	4.723876	0.97	0.050
MGWib/TGWib	−1.171351	4.957184	4.772917	0.97	0.055
MDWob/TDWob	−0.842507	5.128205	4.854891	0.97	0.060
MDWib/TDWib	−0.932732	5.101845	4.857412	0.96	0.059
Thinned stands					
MVob/TVob	−1.718906	5.261784	5.262902	0.97	0.053
MVib/TVib	−2.177444	5.239462	5.314077	0.97	0.057
MGWob/TGWob	−2.058914	5.124867	5.170415	0.97	0.050
MGWib/TGWib	−2.075039	5.171997	5.218171	0.97	0.056
MDWob/TDWob	−1.875204	5.346034	5.397755	0.96	0.060
MDWib/TDWib	−2.020278	5.367307	5.436636	0.97	0.057

[1]The ratio model is:

$$R = \exp[b_0(d^{b_1}/D^{b_2})],$$

where:

R = predicted ratio of merchantable to total volume (ft^3) or weight (pounds),
d = upper stem diameter limit (inches, o.b.)
D = diameter o.b. (inches) at 4.5 feet, and
b_0, b_1, b_2 = coefficients estimated from the data.

[2] MVob = Merchantable volume outside bark.
TVob = Total volume outside bark.
MVib = Merchantable volume inside bark.
TVib = Total volume inside bark.
MGWob = Merchantable green weight outside bark.
TGWob = Total green weight outside bark.
MGWib = Merchantable green weight inside bark.
TGWib = Total green weight inside bark.
MDWob = Merchantable dry weight outside bark.
TDWob = Total dry weight outside bark.
MDWib = Merchantable dry weight inside bark.
TDWib = Total dry weight inside bark.

[3]Fit Index (FI) = $\{1 - [\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$

S_E = Standard error of the estimate in original units.

predicted values of stand and yield table variables were compared with their respective observed values. Mean predicted, mean observed, correlation coefficient, mean difference, and mean percent difference statistics were calculated. Results of these tests are found in tables 13 through 17. Note that with the general exception of the two lowest percentiles (X_1 and X_{10}), which are highly variable, nearly all the other stand and yield table variables were predicted within ±5 percent of the observed values.

These statistics, along with the Fit Index and Standard Error of the estimate statistics presented for each separate prediction equation within the system, indicate that the entire system accurately predicts growth and yield within the stands from which it was developed. This system should provide good results when used to make predictions in similar loblolly pine plantations.

Validation of the unthinned stand prediction system is in process, and a later publication will report these results and any necessary system updates if required. Validation of the thinned stand system will be accomplished as soon as an independent data set is available.

DISCUSSION AND RESULTS

Trends

Prediction trends for unthinned plantations and thinned plantations and some comparisons of results between those two management alternatives are noted. In most cases, 700 trees per acre planted (about

Table 13.—*Comparison of some observed versus predicted stand and yield table variables for initial values in an unthinned stand*

Parameter	Mean predicted[1]	Mean observed[2]	Correlation coefficient[3]	Mean difference[4]	Mean percent difference[5]
X_1[6]	3.48	3.34	0.80	0.14	19.84
X_{10}	4.97	4.79	0.84	0.18	6.82
X_{17}	5.51	5.47	0.90	0.03	2.47
X_{24}	5.92	5.96	0.92	−0.04	0.81
X_{50}	7.13	7.25	0.95	−0.12	−0.69
X_{63}	7.70	7.82	0.95	−0.11	−0.63
X_{82}	8.69	8.75	0.96	−0.06	0.05
X_{93}	9.61	9.66	0.96	−0.05	0.08
X_{97}	10.26	10.45	0.93	−0.20	−1.22
X_{qmd}	7.33	7.37	0.96	−0.04	0.17
BA	127.92	130.26	0.92	−2.33	1.11
VOL	3298.0	3317.0	0.97	−9.04	−1.38

[1]Mean predicted value = $\overline{P} = \Sigma P_i/n$

[2]Mean observed value = $\overline{O} = \Sigma O_i/n$

[3]Correlation coefficient = $r = \dfrac{\Sigma[(P_i - \overline{P})(O_i - \overline{O})]}{\sqrt{\Sigma(P_i - \overline{P})^2\Sigma(O_i - \overline{O})^2}}$

[4]Mean difference = $\overline{d} = \Sigma(P_i - O_i)/n$

[5]Mean percent difference = $\overline{\%d} = 100/n\Sigma(P_i - O_i)/O_i$

[6]X_i, i = 1-97, are the ith percentile values of the variable X.
X_{qmd} = Quadratic mean diameter (in).
BA = Basal area per acre (ft^2).
VOL = Total ft^3 volume.

Table 14.—*Comparison of some observed versus predicted stand and yield table variables for unthinned plantations after growth over 4–6 year time periods.*

Parameter	Mean predicted[1]	Mean observed[2]	Correlation coefficient[3]	Mean difference[4]	Mean percent difference[5]
X_1[6]	4.07	4.33	0.69	−0.26	−1.94
X_{10}	5.62	5.67	0.74	−0.05	−1.32
X_{17}	6.21	6.39	0.84	−0.18	−1.54
X_{24}	6.66	6.91	0.86	−0.25	−2.40
X_{50}	7.99	8.33	0.90	−0.34	−3.43
X_{63}	8.61	8.96	0.91	−0.35	−3.34
X_{82}	9.69	10.03	0.92	−0.34	−2.86
X_{93}	10.70	11.11	0.92	−0.41	−3.33
X_{97}	11.40	11.96	0.89	−0.56	−4.46
X_{qmd}	8.20	8.48	0.92	−0.29	−2.95
BA	130.6	136.7	0.83	−6.18	−3.46
TS	396.3	394.3	0.98	2.00	1.32
HD	56.7	59.3	0.83	−2.5	−3.00
VOL	3616.3	3913.3	0.90	−297.0	−5.20

[1]Mean predicted value = $\overline{P} = \Sigma P_i/n$

[2]Mean observed value = $\overline{O} = \Sigma O_i/n$

[3]Correlation coefficient = $r = \dfrac{\Sigma[(P_i - \overline{P})(O_i - \overline{O})]}{\sqrt{\Sigma(P_i - \overline{P})^2\Sigma(O_i - \overline{O})^2}}$

[4]Mean difference = $\overline{d} = \Sigma(P_i - O_i)/n$

[5]Mean percent difference = $\overline{\%d} = 100/n\Sigma(P_i - O_i)/O_i$

[6]X_i, i = 1-97, are the ith percentile values of the variable X.
X_{qmd} = Quadratic mean diameter (in).
BA = Basal area per acre (ft^2).
VOL = Total ft^3 volume.
TS = Trees surviving per acre.
HD = Mean height (ft) of dominant and codominant trees.

Table 15.—*Comparison of some observed versus predicted stand and yield table variables immediately following the first thinning*

Parameter	Mean predicted[1]	Mean observed[2]	Correlation coefficient[3]	Mean difference[4]	Mean percent difference[5]
X_1[6]	3.99	3.45	0.74	−0.21	24.99
X_{10}	5.25	4.71	0.80	−0.36	13.70
X_{17}	5.72	5.50	0.86	−0.08	4.62
X_{24}	6.10	6.02	0.90	−0.03	1.41
X_{50}	7.24	7.26	0.95	−0.10	−0.81
X_{63}	7.80	7.79	0.96	−0.01	−0.34
X_{82}	8.78	8.68	0.97	−0.11	−1.4
X_{93}	9.73	9.56	0.96	−0.17	2.08
X_{97}	10.41	10.21	0.91	−0.19	2.36
X_{qmd}	7.48	7.34	0.96	−0.14	2.33
TS	332.2	351.2	0.97	−18.98	−3.68
HD	50.7	50.8	0.99	−0.11	−0.30
VOL	2279.4	2356.1	0.96	−76.6	−2.94

[1]Mean predicted value $= \overline{P} = \Sigma P_i/n$

[2]Mean observed value $= \overline{O} = \Sigma O_i/n$

[3]Correlation coefficient $= r = \dfrac{\Sigma[(P_i - \overline{P})(O_i - \overline{O})]}{\sqrt{\Sigma(P_i - \overline{P})^2 \Sigma(O_i - \overline{O})^2}}$

[4]Mean difference $= \overline{d} = \Sigma (P_i - O_i)/n$

[5]Mean percent difference $= \overline{\%d} = 100/n\Sigma(P_i - O_i)/O_i$

[6]X_i, i = 1-97, are the ith percentile values of the variable X.
X_{qmd} = Quadratic mean diameter (in).
BA = Basal area per acre (ft^2).
VOL = Total ft^3 volume.
TS = Trees surviving per acre.
HD = Mean height (ft) of dominant and codominant trees.

Table 16.—*Comparison of some observed versus predicted stand and yield table variables immediately following all thinnings after the first thinning*

Parameter	Mean predicted[1]	Mean observed[2]	Correlation coefficient[3]	Mean difference[4]	Mean percent difference[5]
X_1[6]	6.97	7.82	0.87	−0.85	−6.33
X_{10}	8.60	8.53	0.93	0.06	2.8
X_{17}	9.17	9.12	0.95	0.05	1.17
X_{24}	9.61	9.56	0.96	0.05	0.50
X_{50}	10.89	10.76	0.98	0.13	0.73
X_{63}	11.49	11.32	0.98	0.17	1.23
X_{82}	12.52	12.34	0.99	0.18	1.36
X_{93}	13.48	13.48	0.99	0.00	0.09
X_{97}	14.15	14.20	0.95	−0.05	0.07
X_{qmd}	11.04	10.93	0.99	0.11	0.91
TS	151.0	152.3	0.99	−1.32	−1.56
HD	68.1	68.3	0.99	−0.21	−0.29
VOL	2926.4	2978.4	0.96	−52.0	−1.77

[1]Mean predicted value $= \overline{P} = \Sigma P_i/n$

[2]Mean observed value $= \overline{O} = \Sigma O_i/n$

[3]Correlation coefficient $= r = \dfrac{\Sigma[(P_i - \overline{P})(O_i - \overline{O})]}{\sqrt{\Sigma(P_i - \overline{P})^2 \Sigma(O_i - \overline{O})^2}}$

[4]Mean difference $= \overline{d} = \Sigma (P_i - O_i)/n$

[5]Mean percent difference $= \overline{\%d} = 100/n\Sigma(P_i - O_i)/O_i$

[6]X_i, i = 1-97, are the ith percentile values of the variable X.
X_{qmd} = Quadratic mean diameter (in).
BA = Basal area per acre (ft^2).
VOL = Total ft^3 volume.
TS = Trees surviving per acre.
HD = Mean height (ft) of dominant and codominant trees.

Table 17.—*Comparison of some observed versus predicted stand and yield table variables for plantations after a 5-year growth period following thinning*

Parameter	Mean predicted[1]	Mean observed[2]	Correlation coefficient[3]	Mean difference[4]	Mean percent difference[5]
X_1[6]	6.10	6.92	0.91	−0.81	−5.96
X_{10}	7.78	7.81	0.94	−0.03	2.03
X_{17}	8.39	8.49	0.96	−0.10	−0.02
X_{24}	8.88	9.01	0.97	−0.13	−0.79
X_{50}	10.28	10.38	0.98	−0.09	−0.88
X_{63}	10.95	11.00	0.98	−0.05	−0.45
X_{82}	12.12	12.08	0.98	−0.04	−0.40
X_{93}	13.22	13.24	0.98	−0.02	−0.03
X_{97}	14.00	13.97	0.96	−0.02	0.37
X_{qmd}	10.51	10.53	0.99	−0.01	−0.03
BA	102.5	102.5	0.93	−0.88	−0.82
TS	204.1	204.1	0.99	−1.87	−0.75
HD	67.3	68.0	0.96	−0.67	−0.94
VOL	3421.9	3493.9	0.90	−72.0	−2.1

[1]Mean predicted value $= \overline{P} = \Sigma P_i/n$

[2]Mean observed value $= \overline{O} = \Sigma O_i/n$

[3]Correlation coefficient $= r = \dfrac{\Sigma[(P_i - \overline{P})(O_i - \overline{O})]}{\sqrt{\Sigma(P_i - \overline{P})^2 \Sigma(O_i - \overline{O})^2}}$

[4]Mean difference $= \overline{d} = \Sigma (P_i - O_i)/n$

[5]Mean percent difference $= \overline{\%d} = 100/n\Sigma(P_i - O_i)/O_i$

[6]X_i, i = 1-97, are the ith percentile values of the variable X.
X_{qmd} = Quadratic mean diameter (in).
BA = Basal area per acre (ft^2).
VOL = Total ft^3 volume.
TS = Trees surviving per acre.
HD = Mean height (ft) of dominant and codominant trees.

8- by 8-ft spacing) was assumed on lands of site index (base age 25) of 50 and 70 feet. After prediction of initial stand conditions at age 10, projections were made over 2 or 3 year intervals to age 40 for unthinned stand examples or to age 50 for thinned stand examples. In the thinned stand examples, the site 70 plantation was thinned back to 80 square feet of basal area at ages 15, 22, 30, and 40 years. Thinning of the site 50 plantation was delayed until age 22, when it was thinned the same as the higher site plantation.

Unthinned Plantation

Survival.—On both sites the survival decreased less with increasing age (fig. 11). In the early years, survival was highest on the higher site. However, because of intensified competition on the better site, at about age 17 survival became better on the poorer site. The latter relationship remained for the growth period.

Mean Diameter.—The average gain in mean diameter for the site index 70 plantation over the site index 50 plantation was 2.04 inches by age 40 (fig. 12).

Basal Area.—Basal area of all trees increased with increasing site index (fig. 13) but increased more rapidly on the high site. Basal area culminated by age 40 in the site index 70 plantation but had not culminated in the site index 50 planations.

Total Stem Volume Yield.—Total stem cubic-foot (o.b.) yields did not culminate before age 40 on either site, but the high-site volume was on average 2,855 cubic feet per acre more than on the low site (fig. 14).

Mean and Periodic Annual Increment.—Total stem cubic-foot (o.b.) volume mean annual increment (MAI) culminated at about age 24 in the site index 70 plantation and at about age 27 in the site index 50 plantation. The higher site stand's peak MAI was about 125 cubic feet per acre per year greater than the peak MAI in the lower site stand (fig. 15).

Thinned Plantation

Survival.—In this example, the stand was thinned before the survival crossover occurred, as mentioned in the previous section. After both stands were thinned at least once, there were about 155 fewer trees per acre in the higher site stand than in the lower site stand. This relationship persisted through age 50, but the magnitude of the difference decreased over time because the rate of survival was better on

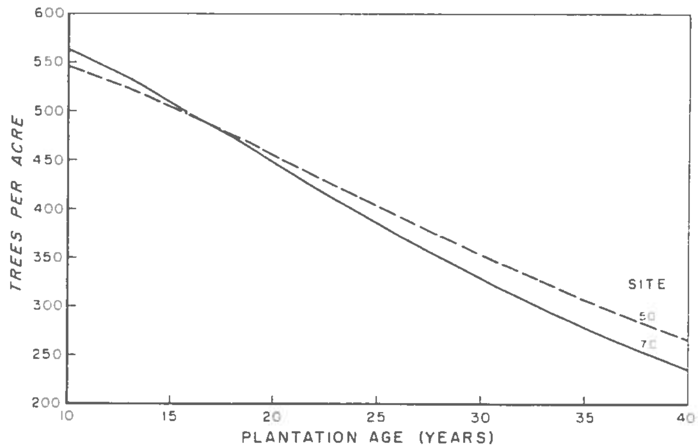

Figure 11.—*Predicted survival trends within an unthinned loblolly pine stand (site index 50) and an unthinned loblolly pine stand (site index 70) both planted with 700 trees per acre.*

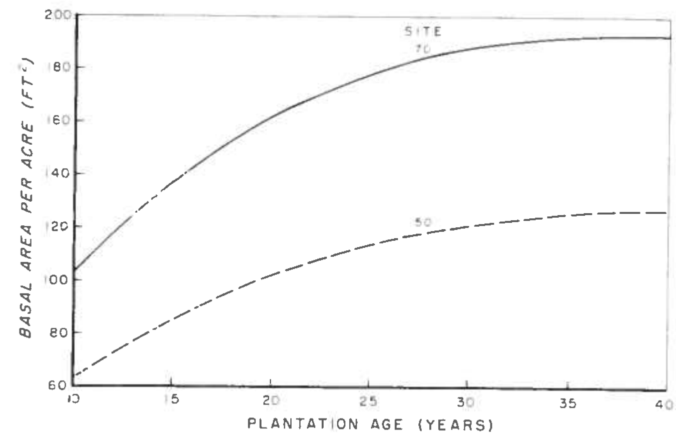

Figure 13.—*Predicted basal area per acre trends within an unthinned loblolly pine stand (site index 50) and an unthinned loblolly pine stand (site index 70) both planted with 700 trees per acre.*

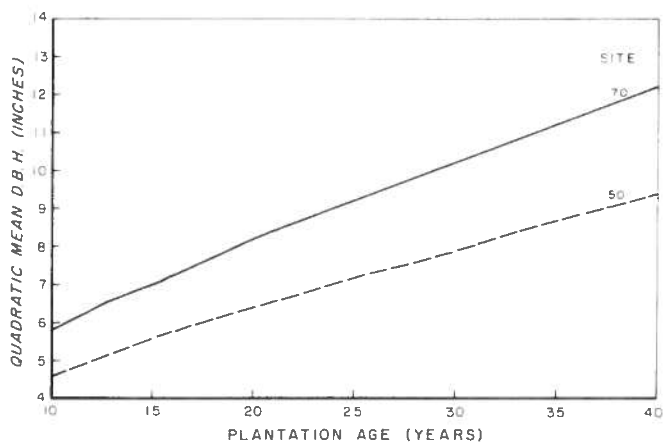

Figure 12.—*Predicted quadratic mean diameter trends within an unthinned loblolly pine stand (site index 50) and an unthinned loblolly pine stand (site index 70) both planted with 700 trees per acre.*

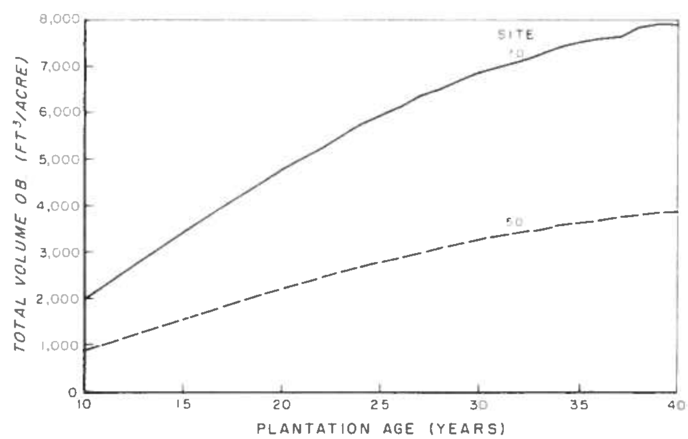

Figure 14.—*Predicted total cubic foot volume per acre trends within an unthinned loblolly pine stand (site index 50) and an unthinned loblolly pine stand (site index 70) both planted with 700 trees per acre.*

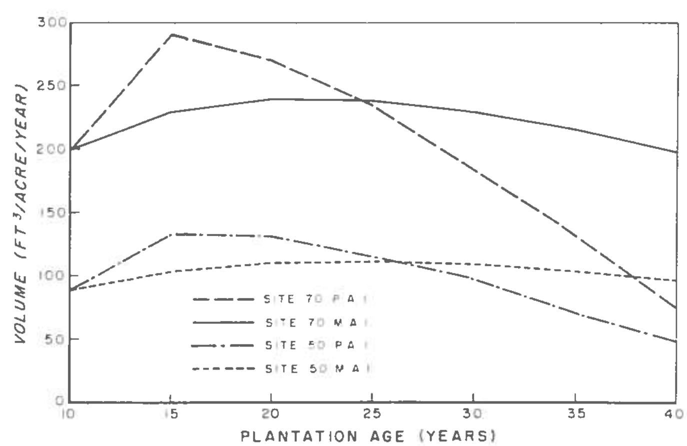

Figure 15.—*Predicted mean and periodic annual cubic foot volume increment within an unthinned loblolly pine stand (site index 50) and an unthinned loblolly pine stand (site index 70) both planted with 700 trees per acre.*

the high site (fig. 16). Notice that in the site index 70 plantation after the first thinning and in the site index 50 plantation after the second thinning mortality had nearly stabilized.

Mean Stand Diameter.—Quadratic mean diameter averaged 2.98 inches higher on the high site than on the low site. The difference was smaller in the early years but consistently increased over time (fig. 17). Since the thinning technique was a modified low thinning, as explained earlier, the average diameter increased with each thinning. The larger increases occurred in the latter thinnings, because spacing and stand clean-up would have then essentially been achieved, and a more accurate low thinning would be practiced.

Basal Area.—After each stand had been thinned at least once, basal area growth was only slightly higher in the high-site stand than in the low-site stand (fig. 18). This result was unexpected but not inconsistent with our data. The fewer larger trees did not greatly compensate in basal area for the greater number of smaller trees in the lower site index stand. There was essentially no statistical relationship between site index and basal area growth after a stand had been thinned. The linear correlation between these variables was only $r = 0.046$.

Total Stem Volume Yield.—Total cubic foot (o.b.) standing volume was always higher in the higher site plantation than in the lower site plantation (fig. 19). This was true even after all thinnings. Not only was there 1,060 cubic feet per acre more total volume on the high site at age 50, but here was 2,571 cubic feet per acre more volume removed through all of the thinnings in the higher site plantation.

UNTHINNED, THINNED PLANTATION COMPARISON

In the unthinned plantation (site index 70), the age 40 survival was 236 trees per acre as compared to 103 trees per acre (before the final thinning) in the thinned plantation at that age. The unthinned plantation had almost double the total volume of the thinned plantation—7,745 cubic feet per acre as compared to 4,278. However, the average diameter of the trees in the thinned plantation (at age 40) was about 2 inches greater than those in the unthinned plantation. If one considers the cumulative total volume removed in the first three thinnings, the total volume either used or available for use before thinning at age 40 in the high site stand was 3,627 + 4,278 = 7,905 cubic feet per acre. This is about 160 cubic feet per acre more volume than in the site index 70 unthinned stand at age 40.

An Example

To illustrate the application and utility of the prediction system, a relatively simple but realistic example should be considered. Given an existing unthinned loblolly pine plantation that is presently 15 years old, an inventory of the stand reveals there are 500 surviving trees per acre, and the average height of the dominant and codominant trees is 45 feet. The user desires full stand and stock table volume output to describe the present stand. He then wants to thin the stand back to a residual basal area per acre of 70 square feet, see what the stand looks like after the thinning, and obtain a projection of what the thinned stand will look like 5 years later. Stand and stock table volume output is desired after the thinning and at the end of the projection period. Also, a table completely summarizing the timber removed during the thinning is requested. Board-foot volume using the International 1/4-inch rule is chosen. Furthermore, the same stand and stock table information in terms of green weight is requested. A merchantable top diameter of 4 inches is selected for all the output.

The following scenario demonstrates how this system obtains the desired information.

Since HD = 45 feet is given, equation (8) is solved for SI obtaining 61 feet.

Equations (11), (12), and (13) are solved next giving $X_1 = 2.9$ inches, $X_{qmd} = 6.4$ inches, and $X_{93} = 8.4$ inches.

This information is then used in equations (5), (6), and (7), following the procedure explained on p. 5, 6. This produces Weibull parameter estimates of $a = 1.718$, $b = 5.010$ and $c = 3.357$.

Given the Weibull parameters and TS, equation (2) is used to distribute TS into 1-inch diameter classes. Now assuming each diameter class represents the midpoint diameter (i.e., the quadratic mean diameter) for that class, equation 23, rearranged to estimate BA, is invoked within each class to obtain BA for each of those diameter classes.

The average height of the trees within each class is obtained from equation (28) in this case.

Given all of this information, equations (30), (31), and (32), with appropriate coefficients from tables 8 through 10, are used to obtain cubic-foot volume, board-foot volume, and green-weight estimates within each diameter class.

Finally, the stand totals for each output category are obtained by summation. Figures 20 and 21 are outputs from a computer program, COMPUTE_P-LOB (Ferguson and Baldwin 1987), which performed the calculations for this procedure. The tables describe the initial stand before thinning. Note that due to rounding of fractional to whole numbers, some columns of figures do not add to the totals indicated in the output tables.

Next, the stand is thinned. This is accomplished by

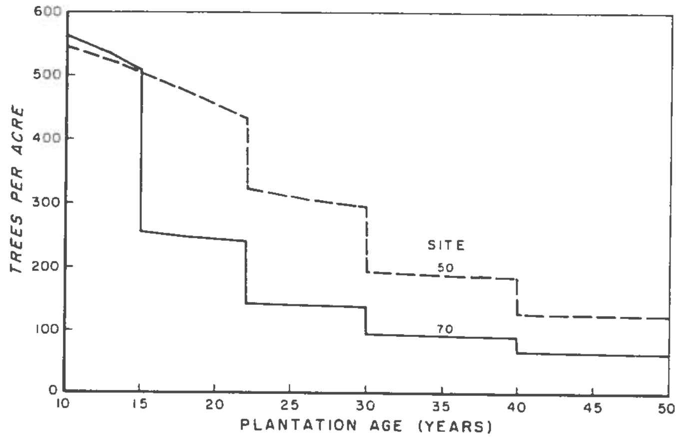

Figure 16.—*Predicted survival trends within a loblolly pine stand (site index 50) and a loblolly pine stand (site index 70) both planted with 700 trees per acre and thinned back to 80 square feet per acre of basal area at ages 15, 22, 30 and 40.*

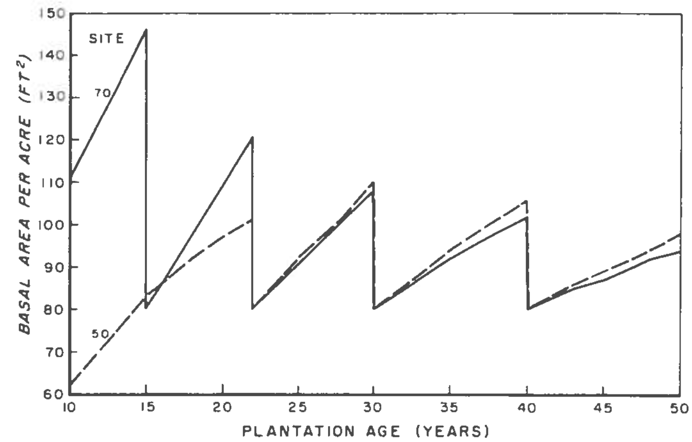

Figure 18 .—*Predicted basal area per acre trends within a loblolly pine stand (site index 50) and a thinned loblolly pine stand (site index 70) both planted with 700 trees per acre and thinned back to 80 square feet per acre of basal area at ages 15, 22, 30 and 40.*

Figure 17.—*Predicted quadratic mean diameter trends within a loblolly pine stand (site index 50) and a loblolly pine stand (site index 70) both planted with 700 trees per acre and thinned back to 80 square feet per acre of basal area at ages 15, 22, 30 and 40.*

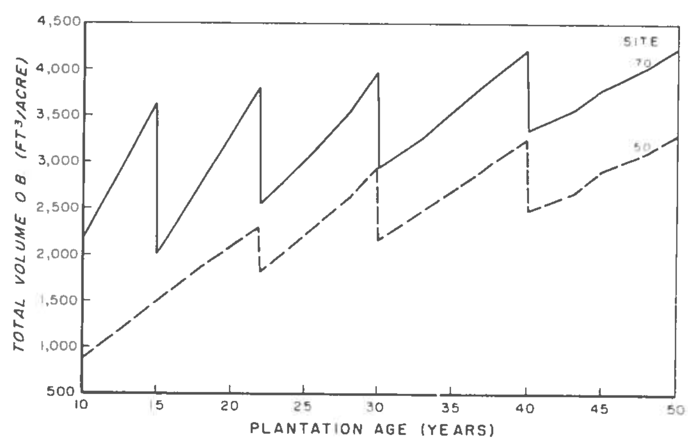

Figure 19.—*Predicted total cubic-foot volume per acre trends within a loblolly pine stand (site index 50) and a loblolly pine stand (site index 70) both planted with 700 trees per acre and thinned back to 80 square feet per acre of basal area at ages 15, 22, 30 and 40.*

taking the values of X_1, X_{qmd}, X_{93}, TS, and BA, which are now defined as $X_{1,b}$, $X_{qmd,b}$, TS_b, and BA_b, and placing them into equations (15), (16), (17), and (23) to obtain $X_{1,a}$ = 3.4 inches, $X_{qmd,a}$ = 6.6 inches, $X_{93,a}$ = 8.6 inches, TS_a = 293 trees per acre, and BA_a = 70 square foot per acre (the given target basal area). Then equations (5), (6), and (7) are solved again to obtain new Weibull parameter estimates of a = 2.057, b = 4.897, and c = 3.363. Finally, the stand and stock tables (figs. 22, 23) are generated in the same manner as explained previously. The desired tables to summarize the volume and green weight of the trees removed in the thinning (figs. 24, 25) are simply obtained by term-by-term subtraction of the comparable after-thin tables from the before-thin tables.

In the final step the values of $X_{1,a}$, $X_{qmd,a}$, $X_{93,a}$ and TS_a (now defined as $X_{1,1}$, $X_{qmd,1}$, $X_{93,1}$, TS_1) are placed in equations (24), (25), (26), and (27), respectively. Given that A = 15 and the projections of these values are desired at time A = 20, $X_{1,2}$ = 4.8 inches, $X_{qmd,2}$ = 8.0 inches, $X_{93,2}$ = 10.4 inches, and TS = 272 trees per acre were obtained. Once again equations (5), (6), and (7) are solved to obtain Weibull parameter estimates of a = 2.877, b = 5.563 and c = 3.254. The stand and stock tables (figs. 26, 27) are then generated and completely describe the predicted stand at age 20.

LOBLOLLY PINE
BEFORE THINNING INFORMATION
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.0 FEET
QUADRATIC MEAN DBH= 6.389 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF: 0 INCHES		4 INCHES		8 INCHES		INTER. 1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
3	15	.7	29	12.	8.	0.	0.	0.	0.	0.
4	52	4.5	35	85.	60.	0.	0.	0.	0.	0.
5	99	13.5	39	275.	200.	181.	126.	0.	0.	0.
6	127	24.9	42	537.	397.	449.	327.	0.	0.	0.
7	112	29.9	44	665.	496.	610.	452.	0.	0.	0.
8	65	22.7	46	520.	392.	497.	372.	0.	0.	0.
9	24	10.6	48	251.	190.	244.	185.	108.	78.	0.
10	5	2.7	49	65.	50.	65.	49.	39.	29.	155.
11	1	.7	50	16.	12.	16.	12.	11.	9.	47.
	500	110.3		2426.	1805.	2061.	1523.	158.	116.	202.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 8.423
WEIBULL PARAMETERS: "A"= 1.718; "B"= 5.010; "C"= 3.357

Figure 20.—*Predicted volume measure (per acre) stand/stock table for an unthinned loblolly pine plantation.*

LOBLOLLY PINE
BEFORE THINNING INFORMATION
GREEN WEIGHT(POUNDS)
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.0 FEET
QUADRATIC MEAN DBH= 6.389 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	TOTAL CROWN WEIGHT W/FOL.	TOTAL WEIGHT OF WOODY COMPONENT		TOTAL WEIGHT OF BOLE		WEIGHT OF MERCH STEM 4" TOP DIA.	
in.	no.	sq. ft.	ft.	o.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	15	.7	29	173.	651.	525.	561.	465.	2.	1.
4	52	4.5	35	1175.	4792.	3959.	4141.	3510.	927.	774.
5	99	13.5	39	3969.	15912.	13334.	13616.	11705.	8082.	6950.
6	127	24.9	42	8293.	31857.	26959.	26889.	23356.	21570.	18775.
7	112	29.9	44	11292.	40535.	34524.	33577.	29387.	30188.	26465.
8	65	22.7	46	9494.	32455.	27808.	26454.	23312.	24997.	22057.
9	24	10.6	48	4839.	15967.	13758.	12835.	11382.	12425.	11029.
10	5	2.7	49	1377.	4261.	3682.	3352.	2985.	3287.	2929.
11	1	.7	50	365.	1069.	926.	824.	737.	814.	728.
	500	110.3		40977.	147499.	125475.	122249.	106839.	102292.	89711.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 8.423
WEIBULL PARAMETERS: "A"= 1.718; "B"= 5.010; "C"= 3.357

Figure 21.—*Predicted weight measure (per acre) stand/stock table for an unthinned loblolly pine plantation.*

LOBLOLLY PINE
RESIDUAL STAND -- AFTER THINNING
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.0 FEET
QUADRATIC MEAN DBH= 6.613 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
3	5	.2	29	4.	3.	0.	0.	0.	0.	0.
4	23	2.0	35	38.	27.	0.	0.	0.	0.	0.
5	52	7.1	39	144.	105.	95.	66.	0.	0.	0.
6	74	14.5	42	313.	231.	262.	190.	0.	0.	0.
7	71	19.0	44	422.	315.	387.	286.	0.	0.	0.
8	45	15.7	46	360.	271.	344.	258.	0.	0.	0.
9	18	8.0	48	188.	143.	183.	139.	81.	58.	0.
10	4	2.2	49	52.	40.	51.	39.	31.	23.	124.
11	1	.7	50	16.	12.	16.	12.	11.	9.	47.
	293	69.3		1537.	1147.	1338.	990.	123.	90.	171.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 8.607
WEIBULL PARAMETERS: "A"= 2.057; "B"= 4.897; "C"= 3.362

Figure 22.—*Predicted volume measure (per acre) stand/stock table of a loblolly pine plantation following its first thinning.*

LOBLOLLY PINE
RESIDUAL STAND -- AFTER THINNING
GREEN WEIGHT(POUNDS)
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.0 FEET
QUADRATIC MEAN DBH= 6.613 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	TOTAL CROWN WEIGHT W/FOL.	TOTAL WEIGHT OF WOODY COMPONENT		TOTAL WEIGHT OF BOLE		WEIGHT OF MERCH STEM 4" TOP DIA.	
in.	no.	sq. ft.	ft.	o.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	5	.2	29	58.	217.	175.	187.	155.	1.	0.
4	23	2.0	35	520.	2119.	1751.	1832.	1553.	410.	342.
5	52	7.1	39	2085.	8358.	7004.	7152.	6148.	4245.	3650.
6	74	14.5	42	4832.	18562.	15708.	15668.	13609.	12568.	10940.
7	71	19.0	44	7159.	25696.	21885.	21286.	18629.	19137.	16779.
8	45	15.7	46	6573.	22469.	19252.	18314.	16139.	17306.	15270.
9	18	8.0	48	3629.	11975.	10319.	9626.	8537.	9319.	8272.
10	4	2.2	49	1102.	3408.	2946.	2682.	2388.	2629.	2343.
11	1	.7	50	365.	1069.	926.	824.	737.	814.	728.
	293	69.3		26323.	93873.	79966.	77571.	67895.	66429.	58324.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 8.607
WEIBULL PARAMETERS: "A"= 2.057; "B"= 4.897; "C"= 3.362

Figure 23.—*Predicted weight measure (per acre) stand/stock table of a loblolly pine plantation following its first thinning.*

LOBLOLLY PINE
STAND COMPONENT REMOVED BY THINNING
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.0 FEET
QUADRATIC MEAN DBH= 6.024 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
3	10	.5	29	8.	5.	0.	0.	0.	0.	0.
4	29	2.5	35	47.	33.	0.	0.	0.	0.	0.
5	47	6.4	39	131.	95.	86.	60.	0.	0.	0.
6	53	10.4	42	224.	166.	187.	137.	0.	0.	0.
7	41	11.0	44	243.	181.	223.	166.	0.	0.	0.
8	20	7.0	46	160.	121.	153.	114.	0.	0.	0.
9	6	2.7	48	63.	47.	61.	46.	27.	20.	0.
10	1	.5	49	13.	10.	13.	10.	8.	6.	31.
	207	41.0		889.	658.	723.	533.	35.	26.	31.

Figure 24.—*Volume measure (per acre) stand/stock table of the bole wood and bark material removed during the first thinning of a loblolly pine plantation.*

LOBLOLLY PINE
STAND COMPONENT REMOVED BY THINNING
GREEN WEIGHT(POUNDS)
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.0 FEET
QUADRATIC MEAN DBH= 6.024 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	TOTAL CROWN WEIGHT W/ FOL.	TOTAL WEIGHT OF WOODY COMPONENT		TOTAL WEIGHT OF BOLE		WEIGHT OF MERCH STEM 4" TOP DIA.	
in.	no.	sq. ft.	ft.	o.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	10	.5	29	115.	434.	350.	374.	310.	1.	1.
4	29	2.5	35	655.	2673.	2208.	2309.	1957.	517.	432.
5	47	6.4	39	1884.	7554.	6330.	6464.	5557.	3837.	3300.
6	53	10.4	42	3461.	13295.	11251.	11221.	9747.	9002.	7835.
7	41	11.0	44	4133.	14839.	12639.	12291.	10758.	11051.	9689.
8	20	7.0	46	2921.	9986.	8556.	8140.	7173.	7691.	6787.
9	6	2.7	48	1210.	3992.	3439.	3209.	2845.	3106.	2757.
10	1	.5	49	275.	853.	736.	670.	597.	658.	586.
	207	41.0		14654.	53626.	45509.	44678.	38944.	35863.	31387.

Figure 25.—*Weight measure (per acre) stand/stock table of the wood and bark material removed during the first thinning of a loblolly pine plantation.*

LOBLOLLY PINE
NO THINNING THIS YEAR
(PER ACRE)

AGE= 20
DOMINANT HEIGHT= 53.5 FEET
QUADRATIC MEAN DBH= 8.042 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
4	4	.3	39	7.	5.	0.	0.	0.	0.	0.
5	19	2.6	44	55.	40.	33.	22.	0.	0.	0.
6	38	7.5	48	174.	129.	142.	103.	0.	0.	0.
7	56	15.0	51	373.	280.	341.	253.	0.	0.	0.
8	61	21.3	53	553.	418.	529.	398.	0.	0.	0.
9	49	21.6	55	585.	446.	571.	434.	232.	164.	0.
10	29	15.8	56	436.	334.	430.	329.	257.	189.	1111.
11	12	7.9	57	223.	171.	221.	170.	162.	122.	701.
12	3	2.4	58	68.	52.	67.	52.	55.	42.	240.
13	1	.9	59	27.	21.	27.	21.	24.	18.	103.
	272	95.3		2501.	1896.	2361.	1782.	730.	535.	2155.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 10.391
WEIBULL PARAMETERS: "A"= 2.877; "B"= 5.563; "C"= 3.254

Figure 26.—*Predicted volume measure (per acre) stand/stock table of a loblolly pine plantation 5 years after its first thinning.*

LOBLOLLY PINE
NO THINNING THIS YEAR
GREEN WEIGHT(POUNDS)
(PER ACRE)

AGE= 20
DOMINANT HEIGHT= 53.5 FEET
QUADRATIC MEAN DBH= 8.042 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	TOTAL CROWN WEIGHT W/FOL.	TOTAL WEIGHT OF WOODY COMPONENT		TOTAL WEIGHT OF BOLE		WEIGHT OF MERCH STEM 4" TOP DIA.	
in.	no.	sq. ft.	ft.	o.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	4	.3	39	78.	405.	338.	361.	308.	52.	44.
5	19	2.6	44	646.	3378.	2870.	2998.	2601.	1629.	1417.
6	38	7.5	48	2068.	10619.	9122.	9355.	8209.	7377.	6492.
7	56	15.0	51	4616.	22720.	19674.	19813.	17536.	17801.	15789.
8	61	21.3	53	7343.	33855.	29473.	29114.	25934.	27593.	24613.
9	49	21.6	55	8204.	35972.	31473.	30554.	27378.	29675.	26614.
10	29	15.8	56	6658.	27085.	23764.	22607.	20339.	22227.	20010.
11	12	7.9	57	3659.	13969.	12288.	11465.	10355.	11347.	10252.
12	3	2.4	58	1183.	4279.	3773.	3456.	3132.	3433.	3112.
13	1	0.9	59	499.	1722.	1522.	1370.	1246.	1364.	1241.
	272	95.3		34954.	154004.	134297.	131093.	117038.	122498.	109584.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 10.391
WEIBULL PARAMETERS: "A"= 2.877; "B"= 5.563; "C"= 3.254

Figure 27.—*Predicted weight measure (per acre) stand/stock table of a loblolly pine plantation 5 years after its first thinning.*

Computer Program

A computer program, COMPUTE_P-LOB Comprehensive Outlook For Managed Pines Using simulated Treatment Experiments-Planted Loblolly Pine, does all of the required calculations and produces the desired yield tables. It is written in FORTRAN 77 and in BASIC. At the time of this publication, compiled or text versions in FORTRAN are available for Digital Equipment Corporation PDP11/series computers, Data General MV series computers, IBM and IBM compatible personal computers, and Hewlett Packard 9800 series computers using the FORTRAN software. Compiled and text BASIC versions are available for the IBM and IBM compatible personal computers. Copies of the program are available from the authors.

A companion publication to this one (Ferguson and Baldwin 1987) is a User's Manual for the prediction system. It completely describes the computer software and gives more examples of program uses. A complete listing of the FORTRAN code is given.

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Complete description, including tables, graphs, computer output, of a growth and yield prediction system providing volume and weight yields in stand and stock table format. An example of system use is given along with information about the computer program, COMPUTE_P-LOB, that operates the system.

Additional keywords: *Pinus taeda* L., volume predictions, weight predictions, unthinned or thinned plantation yields, Weibull distribution, taper curves, site-index prediction, survival prediction, diameter distribution moments, parameter recovery, problem-free sites.