LOBLOLLY PINE SITE INDEX CURVES

CONSTRUCTED FROM AGE-HEIGHT DATA

by

Richard G. Oderwald

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APPROVED: ______________________

Chairman, Harold E. Burkhart

______________________ ______________________

Robert E. Adams Alfred D. Sullivan

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CHAPTER 1: INTRODUCTION

Loblolly pine (Pinus taeda L.) is perhaps the most important of the southern pine species. Its range extends from Maryland and Delaware in the north, Florida in the south, to Texas in the west. In the southern area of the United States loblolly pine currently constitutes 45 percent of the pine growing stock.[1/]

As the demand for wood grows, loblolly pine's importance as a crop tree will increase. More and more wood per acre will have to be obtained, and increasingly better management techniques and decisions will be needed to produce these increased yields. Since the amount of wood that can be grown on an area is dependent on the site quality of that area, better and more accurate estimates of site productivity will be needed.

Site index, the height of the dominant and codominant trees at a given index age, is the most widely used estimate of forest productivity. Any increase in the accuracy of site index estimates will provide management personnel with better information on which to base decisions, and, as such, will help managers produce the extra growth needed.

Objective

The objective of this study was to construct anamorphic site index curves by standard methods, and to compare the accuracy and

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[1/] Boyce, S. G. 1971. Open letter to those on the mailing list of the Southeastern Forest Experiment Station.

precision of these curves, through use of sectioned tree data, against polymorphic site index curves computed by two alternative methods.

Literature Review

Methods of site index curve construction have fallen into two broad classifications: anamorphic and polymorphic. Anamorphic curves are constructed by determining a single guide curve and then establishing the various site index levels as a constant proportion of that guide curve. This method results in a set of harmonic curves with all curves having the same shape. The assumptions necessary to anamorphic site index curve construction are listed by Spurr (1952:311) as (1) each site class is represented equally well in all age classes, (2) height growth is affected by site factors equally well at all ages, (3) the shape of the site index curve is the same for both good and bad sites.

The first assumption is dependent on data collection, and may be violated no matter what type of curve construction is utilized. The second and third assumptions have been questioned by Bull (1931), Osborne and Schumacher (1935), Spurr (1952:311), and others. Their contention is that site factors may affect height growth differently at different ages, and that a tree on a good site will have a growth curve with a steeper initial slope and a quicker flattening of the curve at higher ages than will a tree on a poor site. If these contentions are true, polymorphic curves, which take into account differences in height growth patterns at different site index levels, are a better alternative.

Polymorphic curves may be constructed using stem analysis of trees over index age, by permanent plot data, or by establishing a guide curve from temporary age-height data and then adjusting the guide curve by some function of the data. Jones (1969) states that Huber's site index curves were based on stem analysis data. Unfortunately, the use of stem analysis to construct polymorphic curves has often been accepted as a necessary condition (DeMars, Herman and Bell, 1970); (Spurr, 1952:315).

Establishing guide curves for use in the latter method of polymorphic site index curve construction has almost exclusively involved regression techniques using the logarithm of height-reciprocal of age model. This method supposedly linearized the height-age data. Recent work by Carmean (1971) and Beck (1971) has made use of a biological growth function as an alternative to the logarithm of height-reciprocal of age model. The biological model does not assume linearity and must be fitted using nonlinear regression techniques. This model has appeared in both 3 and 5 parameter forms.

Several different methods have been utilized for adjusting the guide curves to construct polymorphic site index curves. Osborne and Schumacher (1935) used the coefficient of variation of height to adjust their curves, and suggested the use of the standard deviation of height as another alternative for adjustment. Brickell (1968) has stated, however, that this technique of adjustment will only be effective if all heights by age intervals involved are distributed normally, or all have the same amount of skewness and kurtosis from the normal. Brickell took these irregularities into account by testing the intervals for skewness and kurtosis, and fitting Pearson curves to the height-age intervals to avoid assuming normality.

Bull (1931) established polymorphic curves from temporary age-height data by assigning each tree to one of seven site index strata on the basis of an initial estimate of site index for each tree, and then calculating a guide curve for each stratum.

Various corrections have been made to make site index curves better describe stand development. Alexander, Tackle, and Dahms (1967) and Parker (1942) added a factor of density for high and low stocking in lodgepole pine (Pinus contorta Dougl.) Zahner (1962) and others have made corrections for soils groups. Zahner combined soil factors with age to construct site index curves for loblolly pine.

Other indices have been suggested for describing stand development, but site index, in spite of all its difficulties, is still the best alternative.

CHAPTER 2: PROCEDURES AND METHODS

The data for this study were obtained from several industrial forest companies as a part of the V.P.I.-Industry Cooperative Yield Study[2]. The data were taken from a total of 365 1/10-acre temporary sample plots in Virginia, North Carolina, Maryland, and Delaware. Two hundred and forty of these plots were in planted stands, while the remaining 116 plots were in natural stands. Among the plantation plots, 83 were in the Piedmont of the above states; 60 from old field plantations and 23 from stands in cutover wild land. The remaining 157 plots were from the Coastal Plain; 129 from old fields, and 28 from cutover wild lands. Ages ranged from 8 to 36 years for plantation stands, and from 13 to 77 years for natural stands. Number of trees per acre in plantations were from 200 to over 1600, and in natural stands were from 100 to 900.

Diameters were measured for all trees on each 1/10-acre plot. The tenth and twentieth trees tallied on each plot were felled for detailed measurement unless there was evidence of a broken top or other previous damage. If damage was evident, the next tree tallied was felled. Crown class for each felled tree was recorded and the trees were cut into four foot bolts. Ages at the top of each bolt were determined by ring counts. In addition, six site sample trees on or near each plot were measured for total height and age.

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[2] Virginia Polytechnic Institute and State University Research Division State Project No. 200101, "Yields of Loblolly and Virginia Pine."

There were 1273 site sample trees and 212 stem analysis trees for plantations, and 721 site sample trees and 120 stem analysis trees for natural stands available for analysis.

Anamorphic Curve Construction

Anamorphic site index curves were first constructed for plantations and for natural stands. The procedure for both types of stands was the same. The guide line for the anamorphic curves was fitted with age-height data from the site sample trees using the logarithm of height-reciprocal of age model. The model, stated in equation form, is

$$\log_{10} H = a + b(1/A)$$

where

$\log_{10} H$ = logarithm to the base 10 of the site sample tree total height in feet

A = age of the site sample tree in years

a and b = constants to be estimated by linear regression techniques.

By definition, when age (A) is equal to index age (AI), height (H) is equal to site index (SI). Thus

$$\log_{10} SI = a + b(1/AI)$$

which implies that

$$a = \log_{10} SI - b(1/AI).$$

Replacing "a" in the $\log_{10}$ of height-reciprocal of age equation with the above expression yields

$$\log_{10} H = \log_{10} SI - b(1/AI) + b(1/A)$$

which may be rearranged as follows to predict site index from average height of the dominant stand, stand age, and the arbitrarily chosen index age:

$$\log_{10} SI = \log_{10} H - b(\frac{1}{A} - \frac{1}{AI})$$

where index age was chosen to be 25 for plantations and 50 for natural stands. To obtain estimates of height directly from site index, age, and index age, the equation was algebraicly manipulated as

$$\log_{10} H = \log_{10} SI + b(\frac{1}{A} - \frac{1}{AI}).$$

Heights by age for each site index level in the anamorphic curves were predicted and site index curves generated.

A nonlinear equation form was fitted to the age-height data to provide an alternative, in the event the logarithm of height-reciprocal of age model failed to linearize the data. This equation was used by Carmean (1971) and is a three parameter biological growth function of the form

$$H = b_1 \left[1 - EXP(-b_2 A)\right]^{b_3}$$

where

A = tree age

H = tree height at age A

b_1 = asymptotic tree height

b_2 = rate of tree height growth

b_3 = initial height growth

EXP = base of the natural logarithms (e).

Using a non-linear, least squares regression program, b_1, b_2, and b_3 were estimated. The substitution procedure was again used to obtain site index as a function of average height of the dominant stand, stand age, and index age. The site index equation

$$SI = \left[\frac{H}{\frac{1 - EXP(-b_2A)}{1 - EXP(-b_2AI)}}\right]^{b_3}$$

may be rearranged as

$$H = SI\left[\frac{1 - EXP(-b_2A)}{1 - EXP(b_2AI)}\right]^{b_3}$$

to obtain estimates of height directly from site index, stand age, and index age. This equation was also used to predict heights at various ages for each site index level and to generate a second set of anamorphic site index curves.

Polymorphic Curves: Coefficient of Variation Method

Construction of the first set of polymorphic site index curves involved the Osborne-Schumacher coefficient of variation technique. To perform this procedure, a guide curve for the site curve set must first be established. The data are then divided into intervals of age with all intervals having approximately the same number of age height pairs. Average height for each interval is determined and the coefficient of variation for heights in each interval calculated.

The guide curve used for the construction of the polymorphic curves was the same as that established for the anamorphic site curves. For the anamorphic curves, for both plantation and natural stands, a linear model and a non-linear model guide curve was established. The guide curves for these four different anamorphic site curve sets were used as guide curves for their polymorphic counterparts.

The Osborne-Schumacher technique for constructing polymorphic site index curves requires the guide curve to be unbiased, that is, in the sample data site index should not be correlated with age. To see if the data for this study fulfilled the assumption, site index for both plantation and natural stands was predicted using an equation independent of the data and a simple linear correlation coefficient, r, for site and age was calculated. A site index equation from Gaiser (1950) was used to predict site index for the natural stands, and an equation from Lenhart and Clutter (1971) was used to predict site index for the plantation stands. The r for the plantation stands was -.1333. Although this value is statistically significant, it is of no practical significance. The r value, -.4506, of the natural stands was statistically significant, and bordered on being of practical significance. This correlation may be due to a bias in Gaiser's equation, with which site index was predicted, or a genuine inverse correlation between site and age. If an inverse relation does exist, any site index curve construction method involving regression techniques will be considerably weakened.

Coefficient of variation for the age intervals selected for use was computed using the formula

$$CV = S/\bar{X}$$

where

CV = coefficient of variation of height in any given age-class interval

$\bar{X}$ = average height in the interval

S = standard deviation of heights in the interval.

An equation from Alemdag (1971) was used to predict coefficient of variation of height from age. The equation form is

$$\log CV = a + bA$$

where

CV = coefficient of variation of height in the age interval

A = average age of sample trees in that interval

a and b = regression constants.

The base of the logarithm used in the equation varied depending on the base of the logarithm used in the guide curve equation. For use with the linear guide curve logarithms were taken to the base 10, for the non-linear to the base e.

Since the prediction of coefficient of variation is such an important part of the height by site equation, several different class interval systems of height by age were constructed for both natural and plantation stands. For each separate system a prediction equation for coefficient of variation of height by age was developed.

The predictions for coefficient of variation, the particular guide curve required for each situation, the desired site index, and ages were combined in an equation suggested by Chapman and Meyer (1949:378) and used by Alemdag (1971) of the form

$$H = HG \cdot \left[\frac{SI - HG_{AI}}{HG_{AI}} \cdot \frac{CV_A}{CV_{AI}} + 1 \right]$$

where

H = height of given site index curve at age A

HG = height of guide curve at age A

SI = site index

CV_A = coefficient of variation of heights at age A

CV_{AI} = coefficient of variation of heights at index age AI

Each interval within each set of height by age intervals was tested for differences of height distribution from the normal distribution.

The statistics calculated to measure these differences were Fisher's K statistics for skewness and kurtosis as presented by Pearson and Hartley (1954). The measure of skewness, m_3, is calculated using the formula

$$m_3 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^3}{n}$$

where

x_i = each observed value of height in the interval

$\bar{x}$ = mean height in the interval

n = number of observations in the interval.

The measure of kurtosis, m_4, is calculated using

$$m_4 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^4}{n}$$

where x_i, $\bar{x}$, and n are as defined above.

Computation of the test statistics for departures from normality due to skewness and kurtosis requires determination of the measure of dispersion in the interval, m_2. This measure is computed from

$$m_2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}$$

where x_i, $\bar{x}$, and n are as defined above. B_1, the test statistic for skewness is

$$B_1 = m_3 \,/\, m_2^{3/2}$$

where the expected value of B_1 is zero. The test statistic for kurtosis, B_2, with an expected value of 3, is

$$B_2 = m_4 \,/\, m_2^2$$

Tables of significance of B_1 and B_2 are found in Pearson and Hartley. A further discussion of tests for nonnormality may be found in Bliss (1967).

Polymorphic Curves: Data Stratification Method

A second set of polymorphic site index curves were constructed using a method similar to that of Bull (1931). This procedure requires an initial site prediction for each tree from which age-height data was obtained, division of the age-height data into various strata by initial predicted site, and a separate guide curve construction for each strata.

Initial site predictions of each age-height pair must be performed by an equation independent of the data set. An equation from Gaiser (1950) was used to predict site for age-height data from natural stands, and an equation from Lenhart and Clutter (1971) was used to predict site for plantation data.

On the basis of these initial site predictions, the data were split into three site strata for both plantation and natural stands. An effort was made to place one-third of the data from each stand type into each strata, subject to the condition that the mean initial site for each stand type be contained in the middle strata for each type. For plantations, all data having an initial site prediction base age 25, less than 55 feet were classified as low site data, from 55 feet to 75 feet as middle site data, and greater than 75 feet as high site data. For natural stands, all data with an initial site prediction base age 50, of less than 75 feet were classified as low site data, from 75 feet to 85 feet as middle site data, and greater than 85 feet as high site data.

The guide curves for each site strata were fitted using the linear equation

$$\log_{10} H = a + b(1/A)$$

where

$\log_{10} H$ = logarithm to the base 10 of the site sample tree total height in feet

A = age of the site sample tree in years

a and b = constants to be estimated by linear regression techniques.

Through the same algebraic manipulation performed on the linear model ananamorphic site index curves, the equation

$$\log_{10} H = \log_{10} SI + b(\frac{1}{A} - \frac{1}{AI})$$

was obtained to predict heights by age and site index level and to generate site index curves in each stratum.

After the logarithm of height-reciprocal of age model had been fitted to each site stratum, the slopes of the three regression lines for plantation stands and natural stands were tested among themselves for differences. No significant difference between the slopes of the guide curves for different levels of site within either plantations or natural stands would indicate that the three guide curves for that particular type of stand were no different from a single anamorphic guide curve.

Evaluation Procedures

Stem analysis data from the two trees felled and sectioned on each plot were available to evaluate the predictive ability of individual sets of anamorphic and polymorphic site index curve sets.

Before the evaluation could be carried out, however, a bias inherent in the stem analysis data pointed out by Carmean (1971) was corrected using Carmean;s suggested adjustment procedure. The bias occurs because the sectioning cuts at four-foot intervals rarely fall at the end of the terminal leader for the year of tree growth determined by ring counts. Thus, at the second sectioning cut, for example, the ring count might indicate that six years of tree growth were required to bring the tree height to this level. This would be recorded as tree height eight feet at six years of age. Since the tree section probably did not fall at the exact end of the terminal leader for the sixth year of growth, a bias is introduced. This is corrected by assuming that the sections, on the average, will fall at the halfway point of the terminal leader for a given year. The adjustment is made by adding one half the terminal leader length for that year.

The terminal leader length for one year is estimated by finding the tree growth for each ten years of tree life, 0 - 10, 11 - 20, 21 - 30, etc. and dividing by the age interval, ten years. This determines the average annual leader length for a ten year period. Average annual leader length is divided by two to obtain one half the average annual leader length, and this value is added to all bolt heights having ages which place them into the ten year period the correction value represents. All stem analysis data used for evaluation were corrected in this manner.

To minimize the error involved in estimating the site index of trees younger than index age, only those trees twenty years or older were applied to plantation site curve evaluation, and only those trees forty years or older were applied to natural stand site curve evaluation. Also, only those trees, both planted and natural, in a dominant or codominant position in the stands were utilized.

The site index of trees younger than index age for natural and plantation stands was estimated by comparing each tree with those trees index age or older from the same data set. More specifically, all trees in the plantation stand stem analysis data set were arbitrarily stratified by early height growth into high, medium, and low site index classes. Stratification was accomplished by arbitrarily dividing site levels 40 through 90 into three groups: lower than 53 for low sites, 53 through 67 for medium sites, and 67 up for high sites. Trees index age or older from the plantation stem analysis data set were chosen such that the trees selected from each level had site indexes near the midpoint of that level. In this manner two trees were chosen from the low site stratum, two trees were chosen from the medium site stratum, and one tree was chosen from the high site stratum due to a lack of data in that stratum. The growth curves for the selected trees in the low site stratum were averaged, and their average site index obtained. The same was done for the trees selected from the medium site level. The tree selected from the high site level was not adjusted.

Since only break points for classification of index age or older data had been established, it was necessary to construct break point lines for sample trees younger than index age. This was accomplished by considering the distances between consecutive growth curves as intervals, and determining what percentage of these interval distances the break points at age 25 represented. These percentages were then used to extend the break point lines back as constant proportions of the average growth curves.

Each age-height pair was checked against the break point lines. Any pair falling on or below the 53 break line was placed in the low site stratum, any pair falling between the 53 and 67 break lines was placed in the medium site stratum, and any pair falling on or above the 67 break line was placed in the high site stratum.

Due to a lack of trees older than index age in the natural stand stem analysis data, no stratification of the data was performed and only one tree could be chosen to represent the natural stands as an average tree curve.

To estimate the site index for those trees under index age the average tree curves for each stratum were used as standard tree curves for age-height data falling in the stratum. Sites were estimated using

$$HT_{AI} = \frac{HT_A \times HS_{AI}}{HS_A}$$

where

HT_A = height of the sample tree at age A

HT_{AI} = estimated height of the sample tree at index age AI, and therefore site index of the sample tree

HS_A = height of the standard tree for the site stratum the sample tree has been assigned to, at age A

HS_{AI} = height of the standard tree at index age AI.

When all of the above estimations, corrections, and predictions had been made, the evaluation procedure began.

Using the true site index of the sectioned trees, height was predicted for the age of each bolt and compared against the observed height. From these observed and predicted heights two measures of accuracy of the equations were calculated.

The first of these measures was

$$d = H_o - H_p$$

where

H_o = observed height of the sample tree at a given age

H_p = predicted height of the sample tree at the given age

d = difference between observed and predicted height.

A mean difference and a standard deviation of the differences was calculated for each set of site index equations.

The second measure, the simple linear correlation (r), was calculated for each site index curve set from the formula

$$r = \frac{\sum_{i=1}^{n} H_o H_p - (\sum_{i=1}^{n} H_o)(\sum_{i=1}^{n} H_p)_{n}}{\sqrt{\sum_{i=1}^{n} H_o^2 - (\sum_{i=1}^{n} H_o)^2/n)(\sum_{i=1}^{n} H_p^2 - (\sum_{i=1}^{n} H_p)^2/n)}}$$

where H_o and H_p are as defined above

and

n = total number of comparisons made for each set of site index equations.

CHAPTER 3: RESULTS AND DISCUSSION

Anamorphic site index curves from the logarithm of height-reciprocal of age model and the biological growth function were constructed for plantation stands and natural stands.

The logarithm of height-reciprocal of age transformation served to linearize the age-height data except in the lower ranges of the age-height pairs. A graphical comparison of the guide curves from different equation forms for both plantation and natural stands showed very little difference between the two curve forms for either type of stand (Fig. 1). The parameters estimated for the different equations and equation forms, and the r^2 and standard deviations for these equations are shown in Table 1.

Four different systems of height by age intervals were constructed for natural stand data. The intervals in each system contained approximately equal numbers of age-height pairs, although in some schemes the lowest and highest intervals were smaller than average. The intervals and tieir respective sample sizes appear in Table 2.

Sturges (1926) has suggested an equation for choosing the optimum number of class intervals for a given data set. The equation

$$K = 1 + 3.3 \log_{10} N$$

where

K = optimum number of intervals

$\log_{10} N$ = logarithm to the base 10 of total sample

was utilized as a check to see if the theoretically optimal number of intervals was employed in each data set. The sample size for

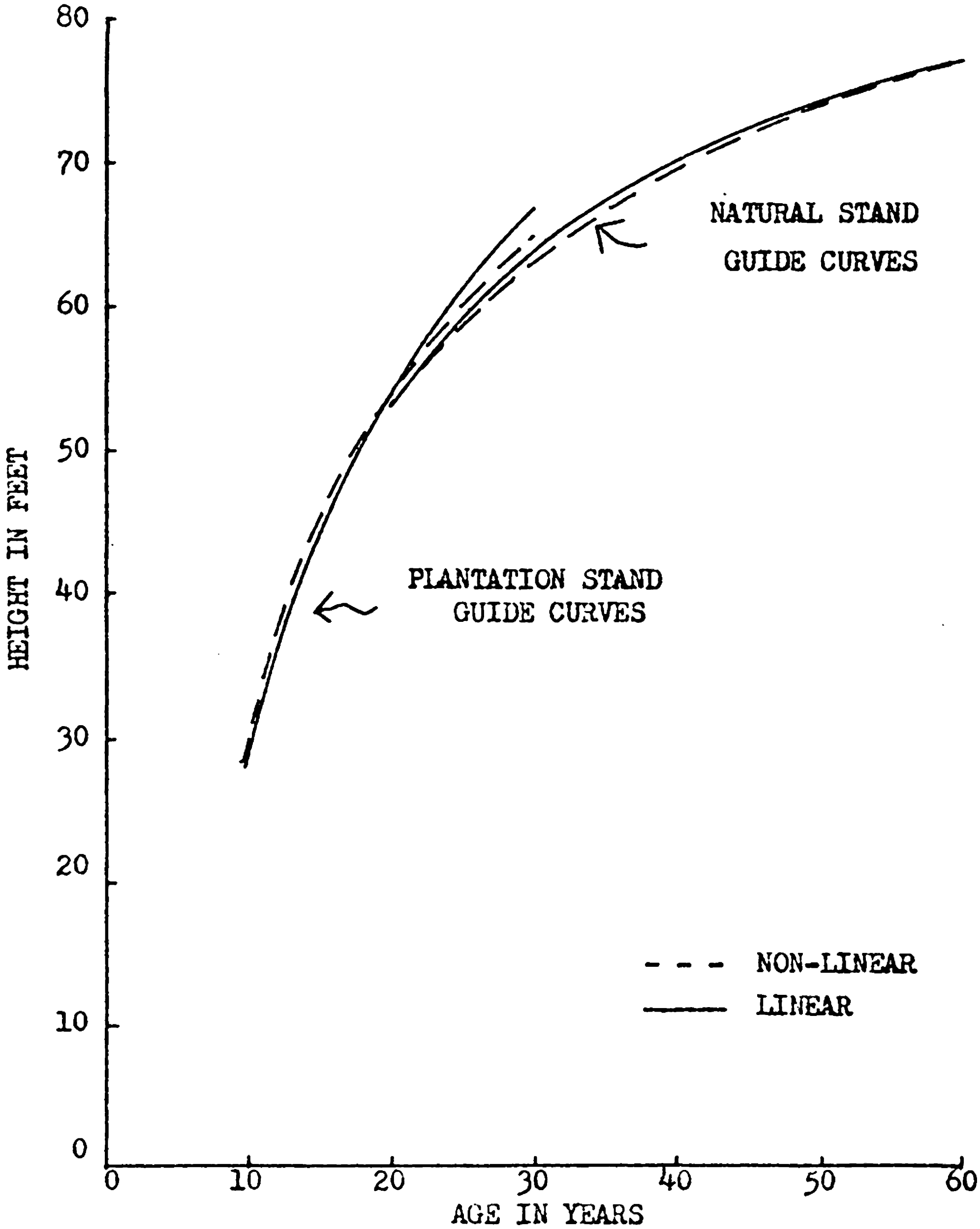

Fig. 1. Comparison of linear and nonlinear guide curves for plantation stands and natural stands.

Table 1. Estimates of parameters, r^2, and standard deviations of guide curves for the different curve construction methods.

Anamorphic curves and polymorphic curves by the coefficient of variation method

	Linear Model			Nonlinear Model	
	Plantation	Natural		Plantation	Natural
a	2.026	1.966	b_1	69.529	80.222
b	-5.865	-4.879	b_2	0.122	0.052
r^2	0.833	0.612	b_3	2.660	0.967
$s_{y \cdot x}$	0.051	0.049	r^2	0.836	0.620
			$s_{y \cdot x}$	0.164	0.362

Polymorphic curves by the data stratification method

	Plantation			Natural		
	Low stratum	Middle stratum	High stratum	Low stratum	Middle stratum	High stratum
a	1.970	2.036	2.057	1.957	2.008	2.037
b	-6.932	-6.914	-5.989	-5.747	-5.408	-4.946
r^2	0.836	0.962	0.881	0.928	0.977	0.950
$s_{y \cdot x}$	0.032	0.015	0.027	0.033	0.023	0.017

Table 2. Interval systems and their sample sizes.

Plantation Stands Number of intervals							
5		10		11		13	
Interval	Size	Interval	Size	Interval	Size	Interval	Size
6 - 10	196	6 - 9	88	6 - 9	88	6 - 9	88
11 - 12	230	10	108	10	108	10	108
13 - 14	246	11	119	11	119	11	119
15 - 17	264	12	111	12	111	12	111
18+	337	13	136	13	136	13	136
		14	109	14	109	14	109
		15 - 16	162	15 - 16	162	15	84
		17	102	17	102	16	78
		18 - 19	158	18 - 19	158	17	102
		20+	179	20	78	18	86
				21+	101	19	72
						20	78
						21+	101

Table 2. Interval systems and their sample sizes (continued).

Natural Stands Number of Intervals									
6		7		9		10		15	
Interval	Size	Interval	Size	Interval	Size	Interval	Size	Interval	Size
13 - 19	108	13 - 19	108	13 - 17	60	13 - 17	60	13 - 14	12
20 - 22	127	20 - 22	127	18 - 20	95	18 - 20	95	15 - 17	48
23 - 26	126	23 - 26	126	21 - 22	80	21 - 22	80	18 - 19	48
27 - 31	108	27 - 31	108	23 - 24	90	23 - 24	90	20 - 21	64
32 - 35	102	32 - 35	102	25 - 28	90	25 - 28	90	22	63
36 - 55	114	36 - 55	114	29 - 31	54	29 - 31	54	23	60
		56+	36	32 - 33	66	32 - 33	66	24 - 25	54
				34 - 36	54	34 - 36	54	26 - 27	36
				37 - 41	48	37 - 41	48	28 - 29	60
						42+	84	30 - 32	66
								33 - 34	36
								35 - 36	42
								37 - 40	36

Table 2. Interval systems and their sample sizes (continued).

Natural Stands Number of Intervals									
6		7		9		10		15	
Interval	Size	Interval	Size	Interval	Size	Interval	Size	Interval	Size
								41 - 45	36
								46+	60

plantation 1273, and the sample size for natural stands, 721, were substituted for N in the equation yielding values of K of 11.25 and 10.43 respectively. Both values agree well with one of the intervals constructed for each data set as shown in Table 2.

Since there was very little difference between the guide curves established for anamorphic site curves for the linear model and the exponential model, for either plantations or natural stands, there was little difference between the polymorphic site curve sets constructed using these curves as guide curves.

Coefficient of variation was predicted from the equation

$$\log CV = a + bA$$

using logarithms to the base 10 and e. Although the estimates of a and b did not change greatly from one interval set to the next, in some cases the polymorphic site index curves generated using the intervals differed radically, especially among those curves constructed for the natural stands.

The selection of the number of intervals into which the data is divided therefore makes a great deal of difference in the predictive ability of the site index curves. A reduction of only one class interval from 10 classes to 9 classes, in the natural stand data caused the resulting curves to go from reasonable descriptions of stand height to ridiculous curves for which the site 50 curve is negative until sixteen years of age (Fig. 2). The same condition exists for curves from 7 and 6 intervals for natural stands. The plantation curve also exhibited this tendency

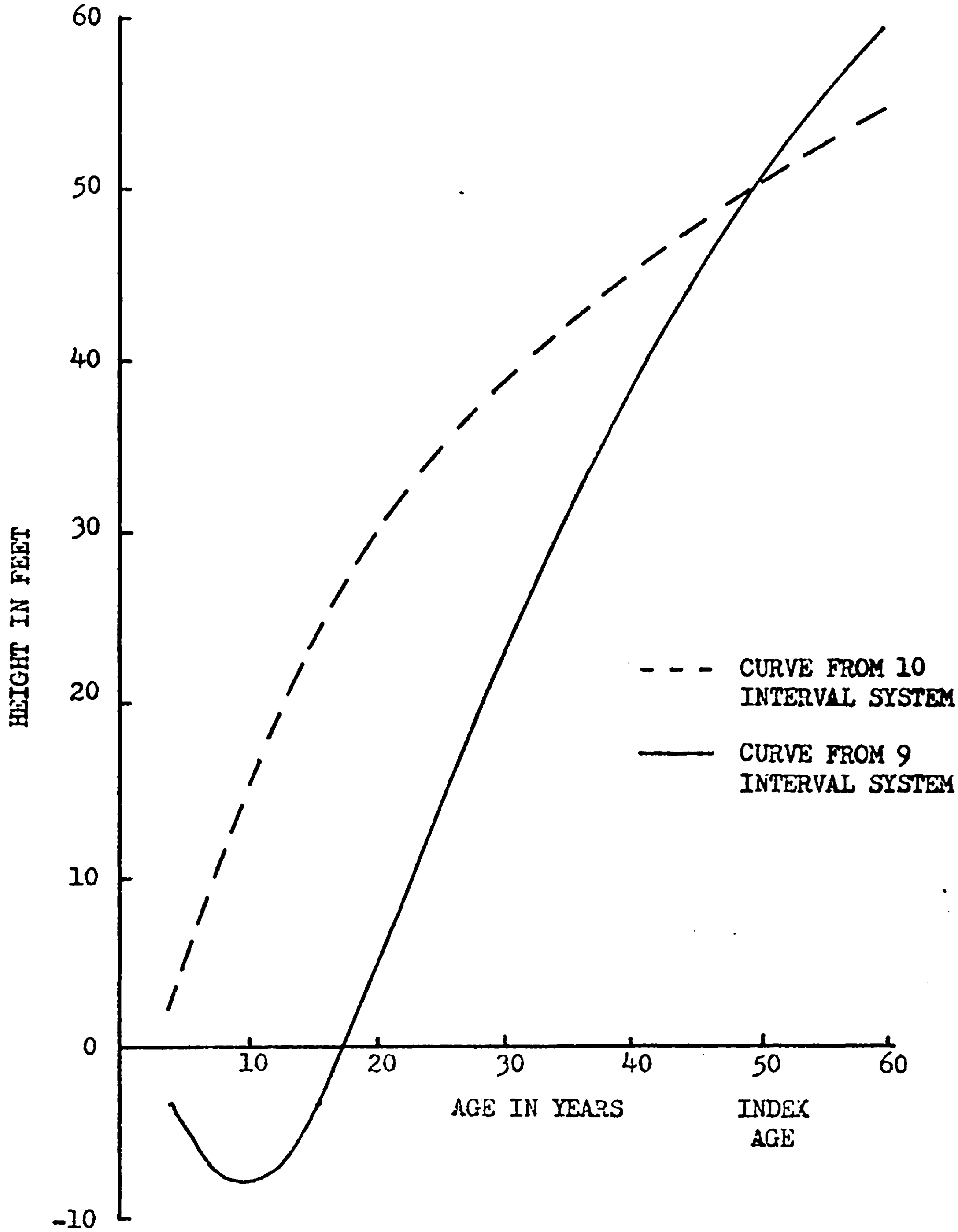

Fig. 2. Comparison of site 50 curves for natural stand polymorphic curves from 9 and 10 interval systems.

but to a lesser degree.

The site index curves constructed from the number of intervals chosen as optimal by Sturges' formula behaved well and appeared to be a reasonable indicator of stand development.

For the polymorphic site index curves constructed by the data stratification method, a test for slope coefficient differences among each group of guide curves for plantations and natural stands was performed. The test showed significant differences between the slope coefficients for both types of stands. Thus, the three guide curves for each stand are different from a single guide curve form and will result in polymorphic site index curves.

Evaluation Results

Evaluation results are shown in Table 3. The results of the evaluation differed between plantation stand curves and natural stand curves.

For the plantation stands the anamorphic site index curves constructed from the linear model guide curve had the lowest average difference and standard deviation of differences and the highest correlation coefficient.

For the natural stands, the polymorphic curves from the data stratification method proved to have the best predictive ability of the three curve types constructed. Differences in mean difference and correlation coefficient from those in the other models were sharply evident. The next best site curve type was the anamorphic curve form from both linear and nonlinear guide curves. The

Table 3. Evaluation results from the three curve construction methods.

	Plantation Stands					
	Linear Model			Nonlinear Model		
	$\bar{d}$	s_d	r	$\bar{d}$	s_d	r
Anam[a]	-0.151	3.134	0.959	-0.823	3.432	0.948
CV5[b]	-0.170	3.996	0.933	-1.001	4.297	0.918
CV10	-0.168	3.907	0.939	-0.975	4.111	0.925
CV11[d]	-0.167	3.768	0.941	-0.969	4.072	0.927
DSM[c]	-1.365	3.209	0.949	---	---	---
	Natural Stands					
	Linear Model			Nonlinear Model		
	$\bar{d}$	s_d	r	$\bar{d}$	s_d	r
Anam[a]	-10.439	6.562	0.492	-10.298	6.585	0.505
CV6[b]	-12.419	9.335	*	-11.795	9.152	*
CV7	-10.613	6.658	0.467	-10.429	6.659	0.487
CV9	-13.018	10.637	*	-12.244	10.409	*
CV10[d]	-10.990	6.991	0.393	-10.717	6.945	0.433
CV15	-10.828	6.829	0.428	-10.594	6.802	0.458
DSM[c]	- 6.157	5.053	0.827	---	---	---

[a]Anam = Anamorphic construction method

[b]CVX = Polymorphic construction by coefficient of variation method with X number of intervals

[c]DSM = Polymorphic construction by data stratification method

* = r values were not calculated for curves that showed negative heights

[d] Interval scheme selected as optimal by Sturges (1926)

polymorphic site curves from the coefficient of variation method were the poorest in predictive ability, with no interval system being particularly better than the others.

Analysis of the various height-age interval schemes for both natural and plantation stands showed that all intervals in all schemes had a significant amount of skewness and kurtosis as shown in Figs. 3 and 4. Furthermore, few of the intervals in each system had the same amount of skewness and kurtosis. Thus, the evaluation results agree well with the statement by Brickell (1968) that the Osborne-Schumacher coefficient of variation technique will not work well unless all intervals in a system are either normal, or have the same amount of deviations from the normal.

The failure of the Osborne-Schumacher technique in this case is significant because of the recent trend toward construction of site index curves by this technique. Chaiken and Nelson (1959) and Alemdag (1971) have used the Osborne-Schumacher method, but no mention is made in either publication of alternatives in the number of intervals used to predict coefficient of variation of height from age, nor is there any evidence that the chosen intervals were tested for skewness and kurtosis within the intervals. Since the addition or reduction of only one interval can greatly change the resulting curves, anyone using the Osborne-Schumacher technique should be cognizant of the importance of the selection of interval numbers.

When irregular skewness and kurtosis are found in the intervals,

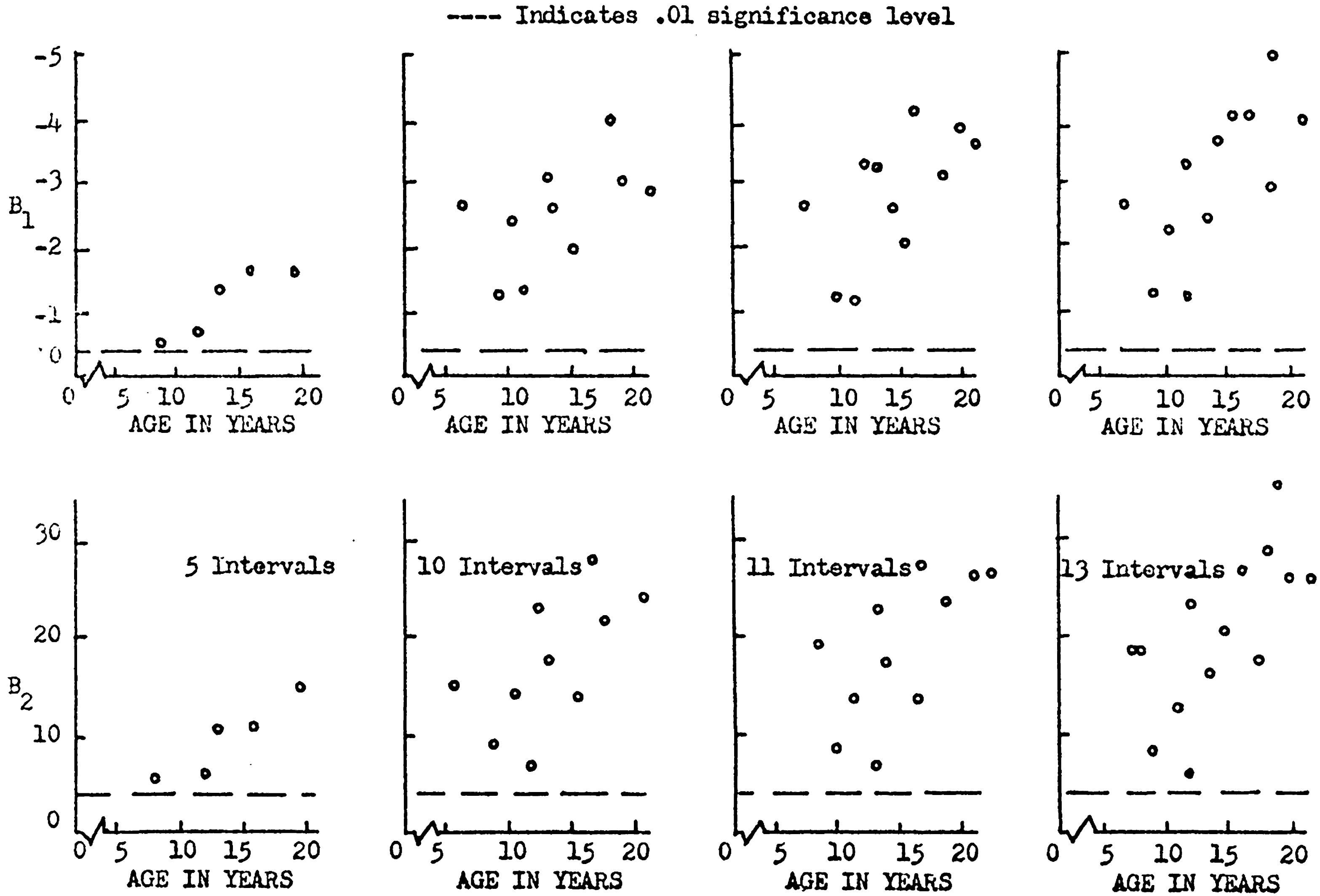

Fig. 3. Results of tests for B_1, the measure of skewness, and B_2, the measure of kurtosis plotted against mean age for the age intervals.

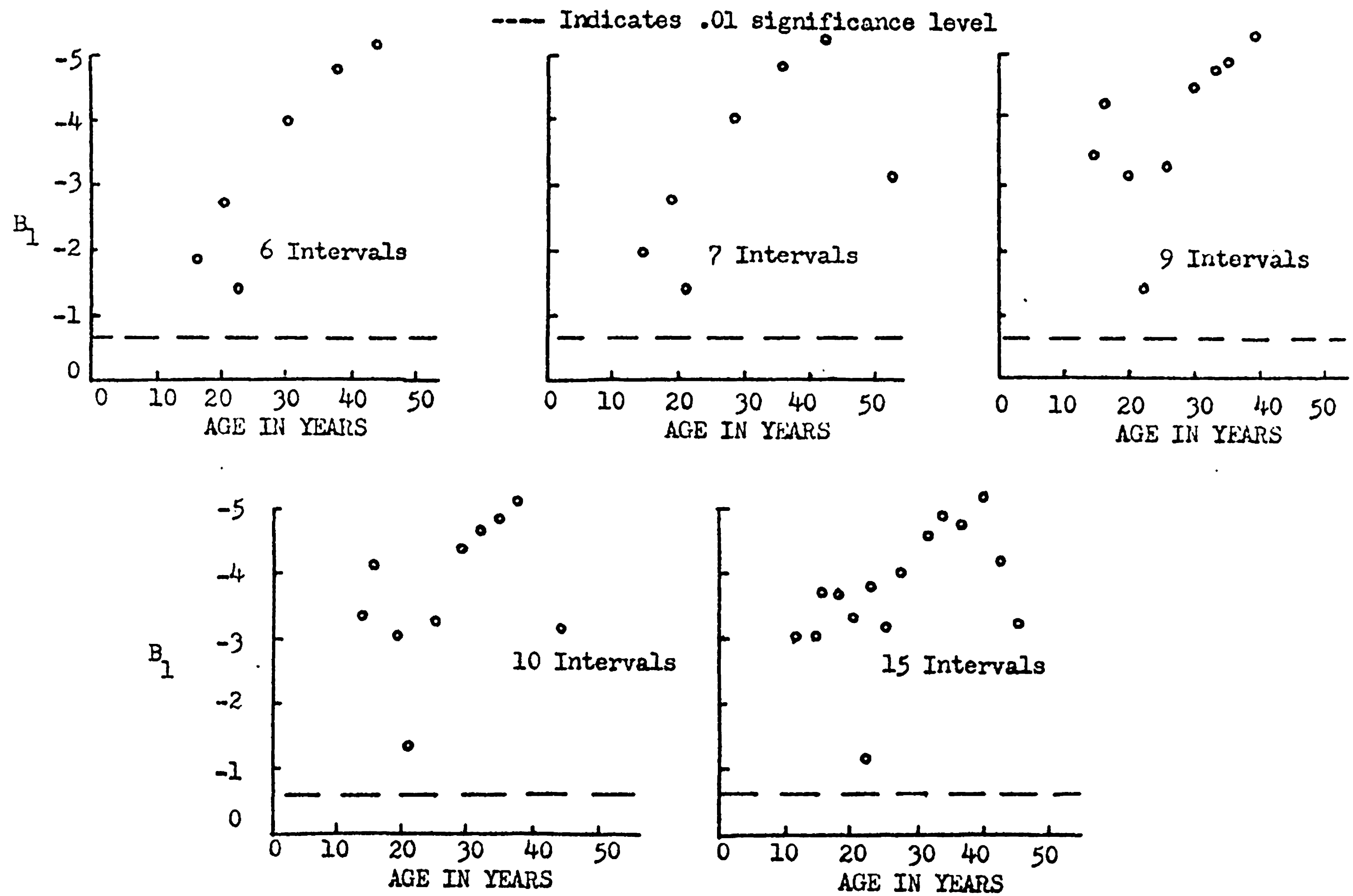

Fig. 4a. Results of tests for B_1, the measure of skewness, plotted against mean age for the age intervals.

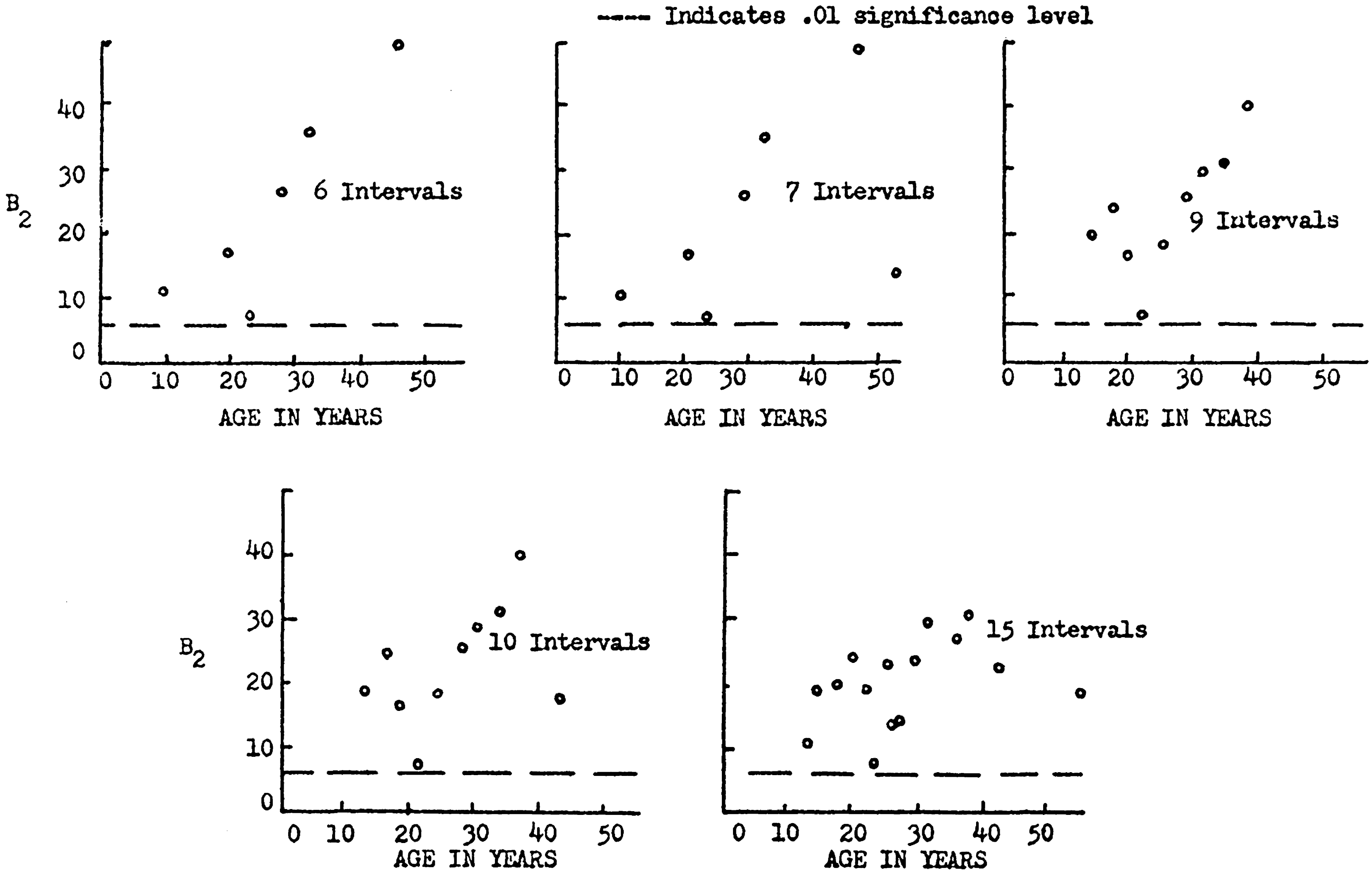

Fig. 4b. Results of tests for B_2, the measure of kurtosis, plotted against mean age for the age intervals.

a correction such as that of Brickell's (1968) should probably be made. Brickell found significant skewness and kurtosis in most of his intervals. Since the mean would not fall at the same percentage level in each interval, Brickell fitted a guide curve to the interval medians and described the distribution of heights in each interval with Pearson curves.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

One investigation of this study concerned a comparison between guide curves from the linear model

$$\log_{10} H = a + bA$$

and a nonlinear growth function

$$H = b_1 \left[1 - \mathrm{EXP}\,(-b_2 A)\right]^{b_3}$$

which has been shown to work well in describing tree height growth. The comparison of the two guide curve models derived from the data showed essentially no difference between them. Either curve form should work equally well.

Anamorphic site index curves for this data proved to have better predictive ability than polymorphic site index curves constructed using the Osborne-Schumacher technique. Selection of the proper number of intervals and tests for normality within intervals for the Osborne-Schumacher technique are necessary parts of any attempt to use this procedure. Since the curves developed using the number of intervals deemed optimal by Sturges' (1926) formula appeared the number of intervals deemed optimal by Sturges' (1926) formula appeared the best of the interval classes used, this formula may be an effective way of selecting the proper number of intervals. The selection of intervals is critical and more work in this area needs to be done.

When significant departures from normality among the intervals exist, it appears that the methods outlined by Osborne and Schumacher (1935) will not work well without modifications such as those applied by Brickell (1968).

A polymorphic alternative to the Osborne-Schumacher technique and its modifications is the data stratification method of curve construction. This method worked well for both plantation and natural stands for this study, and among the natural stands was the best alternative.

Site Curve Recommendations

For plantation stands of loblolly pine in the middle-Atlantic states the site index curves generated from the equation

$$H = 10^{[(\mathrm{Log}_{10}\ SI - 5.86537\ (\frac{1}{A} - \frac{1}{25}))]}$$

and shown in Fig. 5 are recommended.

For natural stands of loblolly pine in the middle-Atlantic states the recommended site index curves, shown in Fig. 6, are generated from the equations

$$H = 10^{[(\mathrm{Log}_{10}\ SI - 6.93220\ (\frac{1}{A} - \frac{1}{50}))]}$$

for trees with an initial site prediction of less than 75 feet

$$H = 10^{[(\mathrm{Log}_{10}\ SI - 6.91444\ (\frac{1}{A} - \frac{1}{50}))]}$$

for trees with an initial site prediction of between 75 and 85 feet, and

$$H = 10^{[(\mathrm{Log}_{10}\ SI - 5.98935\ (\frac{1}{A} - \frac{1}{50}))]}$$

for trees with an initial site prediction of greater than 85 feet. The initial site index prediction is made from the curve resulting from all data combined, i.e.

$$SI = 10^{[(\mathrm{Log}_{10}\ H + 5.86537\ (\frac{1}{A} - \frac{1}{25}))]}.$$

To establish site index of loblolly pine in plantations or natural stands, determine the age and the average height of the dominant and codominant trees in the stand and enter the proper set of curves (Fig. 5 or Fig. 6).

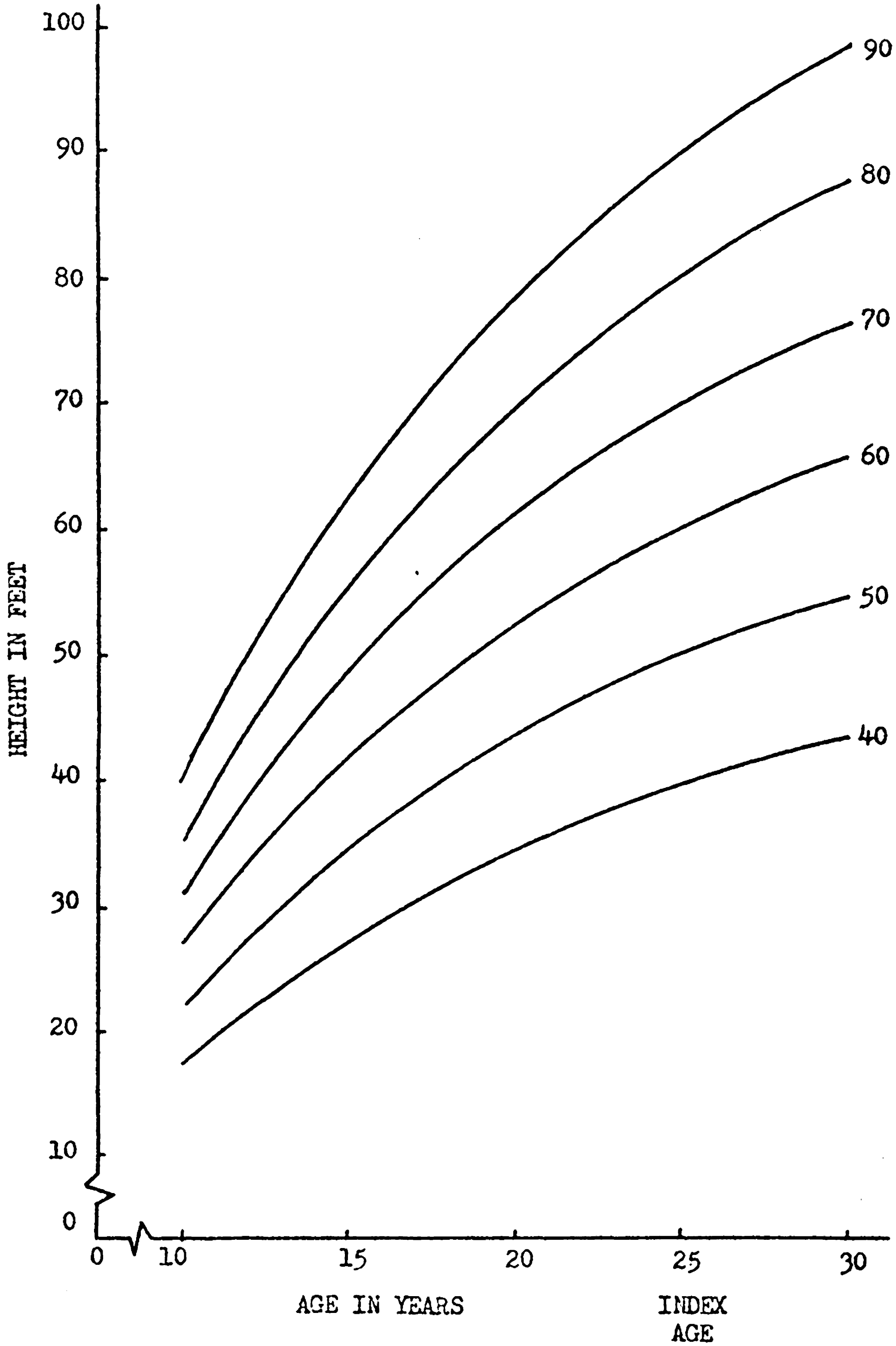

Fig. 5. Site index curves for plantation stands of loblolly pine.

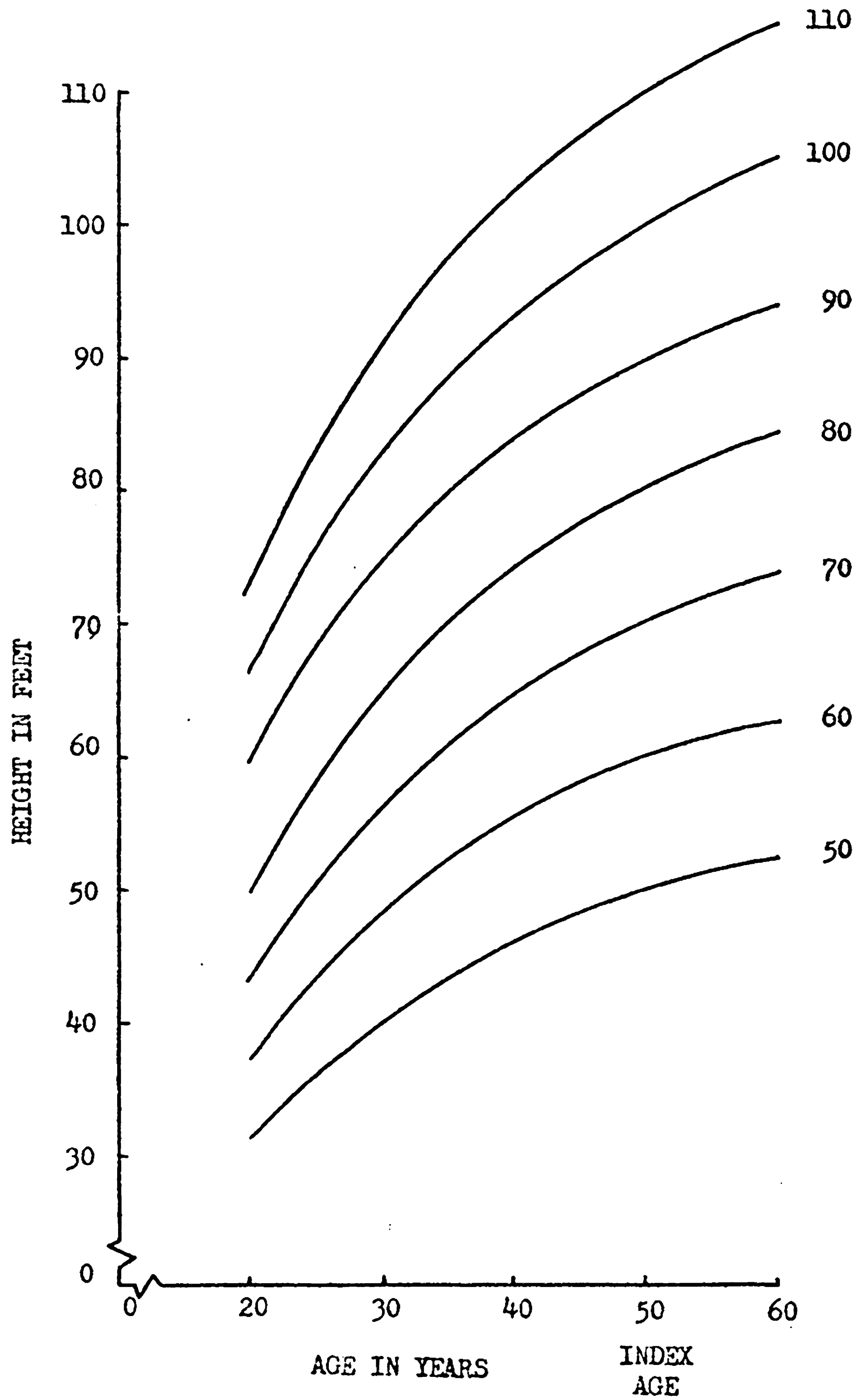

Fig. 6. Site index curves for natural stands of loblolly pine.

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APPENDICES

Appendix Table 1. Comparison of recommended plantation stand site index curves with some published curves.

Site Index	Reference	10	15	20	Base Age	30
		Heights of dominant trees at age (in years)				
40	A	15	25	33	40	45
	B	18	28	35	40	44
	C	21	29	35	40	44
	D	24	32	37	40	42
50	A	21	33	42	50	56
	B	22	35	44	50	55
	C	26	36	44	50	55
	D	30	40	46	50	53
60	A	27	41	51	60	67
	B	27	42	52	60	66
	C	31	43	52	60	66
	D	36	48	55	60	64
70	A	34	49	61	70	77
	B	31	49	61	70	77
	C	36	50	61	70	77
	D	42	56	64	70	74
80	A	42	57	70	80	88
	B	36	56	70	80	88
	C	41	58	70	80	88
	D	48	64	73	80	85
90	A	50	66	79	90	98
	B	40	63	79	90	98
	C	47	65	79	90	99
	D	54	72	83	90	95

A Clutter, J. L. and J. D. Lenhart. 1968. Site index curves for old-field loblolly pine plantations in the Georgia piedmont. Ga. For. Res. Coun. Rep. No. 22-Series 1. 4 pp.

B Recommended plantation stand site index curves.

C Smalley, G. W. and D. R. Bower. 1971. Site index curves for loblolly and shortleaf pine plantations on abandoned fields in Tennessee, Alabama, and Georgia highlands. U.S.D.A. For. Serv. Res. Note SO-126, 6 pp. Southern Forest Exp. Sta., New Orleans, La.

Appendix Table 1. (continued).

D	Lenhart, J. D. 1971. Site index curves for old field loblolly pine plantations in the Interior West Gulf Coastal Plain. Texas For. Pap. No. 8, 4 pp. Stephen F. Austin State University, Nacogdoches, Texas.

Appendix Table 2. Comparison of recommended natural stand site index curves with some published curves.

		Heights of dominant trees at age (in years)								
Site Index	Reference	20	25	30	35	40	45	Base Age	55	60
60	A	37	43	48	52	55	59	60	62	63
	B	37	44	48	52	55	58	60	62	63
	C	32	38	44	49	54	57	60	62	64
	D	39	44	49	53	56	58	60	62	63
70	A	43	50	56	61	64	67	70	72	74
	B	43	51	57	61	65	68	70	72	74
	C	38	45	52	57	63	67	70	73	75
	D	45	52	57	62	65	68	70	72	74
80	A	49	58	64	69	74	77	80	82	84
	B	50	58	65	70	74	77	80	82	84
	C	43	52	60	66	72	76	80	83	85
	D	51	59	66	71	74	78	80	82	84
90	A	55	65	72	78	83	87	90	93	95
	B	60	68	75	80	84	87	90	92	94
	C	48	58	67	75	81	86	90	93	96
	D	57	66	74	80	84	87	90	92	94
100	A	61	72	80	87	92	96	100	103	106
	B	66	76	83	89	93	97	100	103	105
	C	54	65	75	83	90	95	100	104	107
	D	64	74	82	88	93	97	100	103	105
110	A	67	79	88	96	101	106	110	113	116
	B	73	83	92	98	103	107	110	113	115
	C	58	71	82	90	99	105	110	114	117
	D	71	81	90	97	102	107	110	113	116

A Gaiser, R. N. 1950. Relation between soil characteristics and site index of loblolly pine in the coastal plain region of Virginia and the Carolinas. J. of Forest. 48:4, pp. 271-275.

B Recommended natural stand site index curves.

C U.S.D.A., Forest Service. 1929. Volume, yield and stand tables for second-growth southern pines. U.S.D.A. Misc. Pub. 50. 202 pp.

Appendix Table 2. (continued).

D Schumacher, F. X. and T. S. Coile. 1960. Growth and yields of southern pines. Durham, N. C.: T. S. Coile, Inc.

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LOBLOLLY PINE SITE INDEX CURVES

CONSTRUCTED FROM AGE-HEIGHT DATA

by

Richard G. Oderwald

ABSTRACT

Site index curves for natural stands and plantation stands of loblolly pine in the Southeast were constructed from temporary age-height data by an anamorphic technique and two polymorphic techniques. These different systems of site index curves were evaluated using sectioned tree data. Evaluation results showed the anamorphic site index curves were best for the plantation stands, and the polymorphic curves constructed using a data stratification method were best for the natural stands.