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Site Index for Loblolly Plantations on Cutover Sites in the West Gulf Coastal Plain

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SUMMARY

Functions used previously to derive height-age relationships for southern pines are compared in order to develop new site index curves for loblolly pine plantations on cutover sites in the lower West Gulf.

Additional keywords: *Pinus taeda,* height growth.

INTRODUCTION

Site index permits the timberland owner or manager to classify forest land by its productive capacity. Initial planting density, thinning regimes, cutting cycles, and rotation lengths can be adjusted according to the site index. Existing site index curves are not suitable for loblolly pine (*Pinus taeda* L.) planted on cutover sites in the West Gulf.

Curves for naturally regenerated loblolly (U.S. Forest Service 1929, Zahner 1962, Trousdell and others 1974) show a steady increase in estimated site index when measurement is repeated. The same is true of the Coile and Schumacher (1964) curves for planted loblolly on drainage classes d_1 - d_4. Site curves from Lenhart (1971) and Smalley and Bower (1971) are for loblolly planted on old fields. The Lenhart (1971) curve has heights greater at early ages and lower at older ages while the Smalley and Bower (1971) curve has heights lower at older ages than observed averages for plantations on cutover sites.

Myers' (1977) yield program for planted loblolly computes heights by combining Lenhart's (1971) old-field curve for ages 3 to 25 and Farrar's (1973) curve for natural stands for ages 25 and beyond. For site indices 30 to 100 (index age 25) and ages up to 70, Myers' program predicts taller trees than any of the anamorphic loblolly curves we investigated and for site indices 60 to 100 (index age 25) of the Trousdell and others (1974) polymorphic curves. Our paper presents new curves for estimating site index and height growth of loblolly pine plantations on cutover sites in the lower West Gulf Coastal Plain. The height-age relationship presented here was used in a system to generate yield tables in Feduccia and others (1979).

METHODS

A total of 787 age and height determinations were available from 293 permanent plots geographically distributed as shown in figure 1. Plots were measured from one to six times at intervals of 1 to 5 years. The height value used for each plot observation was the average of the dominant and codominant trees on the plot. Plots were located in plantations on cutover sites having no establishment problems or accidents that retarded growth. The age and site index distribution of the observations are shown in table 1.

Two basic mathematical models are frequently used to determine site index for the southern pines (table 2). Models 1a, 1b, 1c, 1d, and 2a were fitted to our data. The fitted regression of height on age

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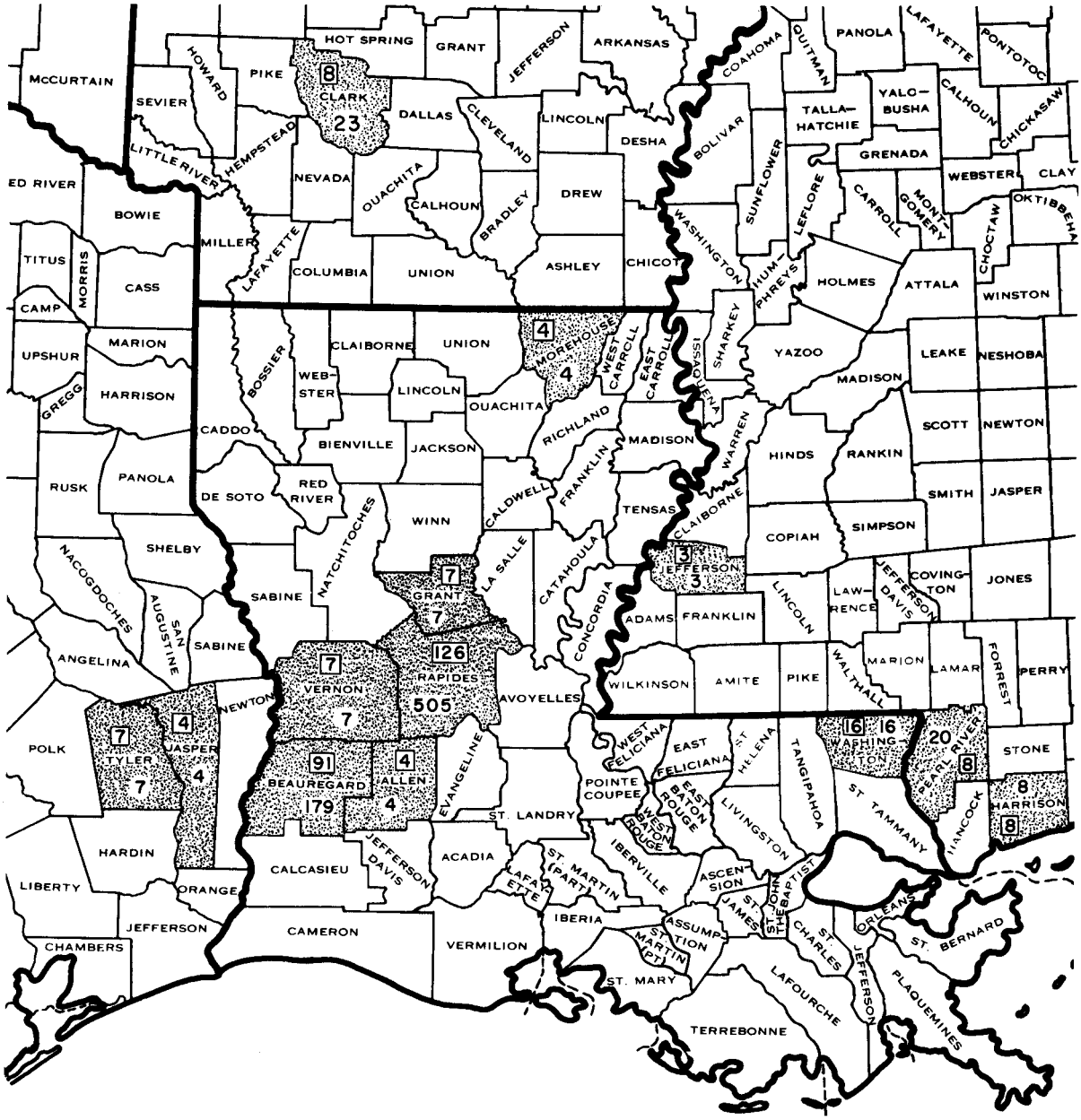

Figure 1—*Geographic location of 293 plots (numbers enclosed in boxes); 787 observations (numbers not enclosed in boxes).*

Popham is Mathematical Statistician; Feduccia, Research Forester; Dell, Mathematical Statistician; Mann, Chief Silviculturist; and Campbell, Silviculturist. All are employed by the Southern Forest Experiment Station, Forest Service—USDA, except Feduccia, who is assigned to the Southern Station by the Louisiana Office of Forestry.

Table 1.—*Number of observations classified by age and site index (index age 25)*

	Site Index							
Age	< 45	45-50	50-55	55-60	60-65	65-70 >	70	Total
5-7	6	----	1	1	7	7	9	31
8-12	7	1	9	16	5	8	14	60
13-17	7	3	17	46	62	11	3	149
18-22	1	9	16	74	40	46	9	195
25	2	10	28	27	9	----	----	76
30	----	2	16	38	11	2	----	69
35	----	2	10	39	15	3	----	69
40	----	----	13	34	19	3	----	69
45	----	----	4	41	23	1	----	69
Total	23	27	114	316	191	81	35	787

was required to approximate the data center of mass over the range of ages. Also, on plots measured more than once, site index of plots when they were older had to be consistent with the site index estimated when the plots were younger. This consistency was evaluated for each model by a combination of statistical procedures. The site index computed for a plot when it was older was plotted over the index computed for an earlier age in pairs of successive observations on a plot. A simple linear regression was fitted through the points to give a visual impression of possible bias. A chi-square procedure (Freese 1960) was used to evaluate the consistency of site index determination at progressing ages.

Remeasurement data were insufficient for a polymorphic approach to site curves as recommended by Curtis (1964), so anamorphic curves were used.

RESULTS AND DISCUSSION

The regression lines were well below the average height of the older plots when the models were fitted using unweighted regression. The longer a stand occupies a site the more accurately it represents the growth potential of the site. Obtaining data from age classes 30 to 50 years is difficult because of the scarcity of older plantations. Logically, the oldest data collected should have the greatest weight in fitting the relationship of height to age. Farrar (personal communication)[1] suggests weighted regression with the square of age as the weight. When fitting the relationship with the square of age as weight, it was impossible to distinguish between the models by using statistical criteria. Model 1c was selected because it best approximated the data center of mass for the older plots.

The coefficients for model 1c, fitted by weighted regression, are:

$$b_0 = 2.24283$$

$$b_1 = -21.0977$$

$$b_2 = 316.282$$

$$b_3 = -2443.84$$

$$b_4 = 6318.86$$

Site index for a given height and age is computed by equation 1 (fig. 2) and height for a given site and age is computed by equation 2 (fig. 2).

Estimates of site index or height beyond 45 years

[1]Robert M. Farrar, Jr. Research Forester, Southern Forest Experiment Station, Monticello, Ark.

Table 2.—*Frequently used models for relating height to age in southern pines*

MODEL	REFERENCE
1. Height$=10^{[b_0+b_1\,(\text{function of Age})]}$ or $\text{Log}_{10}\text{Height}=b_0+b_1$ (function of Age)	
(1a) $H=10^{(b_0+b_1/A)}$ or $\text{Log}_{10}H=b_0+b_1/A$; b_0 and b_1 parameters to be estimated; H is observed height at age A.	Zahner (1962), Coile & Schumacher (1964), Lenhart (1971)
(1b) $H=10^{(b_0+b_1/\sqrt{A})}$ or $\text{Log}_{10}H=b_0+b_1/\sqrt{A}$; b_0, b_1, H, and A same as model (1a)	Smalley & Bower (1971)
(1c) $H=10^{(b_0+b_1/A+b_2/A^2+b_3/A^3+b_4/A^4)}$ or $\text{Log}_{10}H=b_0+b_1/A+b_2/A^2+b_3/A^3+b_4/A^4$; b_0, b_1, H, and A same as model (1a).	Farrar (1973)
(1d) $H=b_0+b_1(\text{Log}_{10}A)$; b_0, b_1, H, and A same as model (1a).	Larson & Moehring (1972)
2. Height$=a(1-e^{-b(\text{Age})})^c$; a, b, and c parameters to be estimated. Chapman-Richards generalization of Von Bertalanffy's equation.	Pienaar & Turnbull (1973)
(2a) $H=a(1-e^{-b(A)})^c$; a, b, and c parameters to be estimated, H is observed height at age A.	Bailey and others (1973)
(2b) $H=a(1-e^{-bA})^c$; Where $a=b_1+b_2S$, $b=b_3+b_4S+b_5S^2$, H and A are same as model (2a) and S=site index, 5 parameters to be estimated.	Graney & Burkhart (1973)
(2c) $H=a(1-e^{-bA})^{\frac{1}{1-m}}$; where $a=b_1+b_2S$, $b=b_3+b_4S+b_5S^2$, $m=b_6+b_7S+b_8S^2$, H and A are same as model (2a), and S=site index, 8 parameters to be estimated.	Trousdell and others (1974)

are an extrapolation beyond our data. The model cannot be used below age 6. The function reaches a minimum between 5 and 6 and goes to infinity as age approaches 0. Evaluation of site quality from observations of plots less than 10 years old cannot take into account long-term environmental conditions. Some situations, such as computer simulation, require computing a height for a specific site index regardless of age. The FORTRAN computer subprogram (fig. 3) provides for computing height when the age is less than 6 by linear interpolation between 0 height at age 0 and height at age 6 for the specific site index.

The data used in exploring the height-age relationship represent a broad area and a variety of conditions. The chosen function should, on the average, be good. Computer programs capable of linear and non-linear least-squares regression with weighting are readily available. Development of specific relationships using local data sets is more feasible than in the past.

To generate site index or height tables with our model, a computer program by Farrar (1975) can be modified easily by substituting the coefficients b_1, b_2, b_3, b_4 for those in line SOH 123. Also, line PRT 106 should be changed to remove M. P. 50 from the printed output.

Curves for site indices 30 to 80 (index age 25) where generated using equation 2 (fig. 2). The curves are shown in figure 4.

Equation 1.

$$S_I = H_D (10)^{\left[b_1\left(\frac{1}{I} - \frac{1}{A_p}\right) + b_2\left(\frac{1}{I^2} - \frac{1}{A_p^2}\right) + b_3\left(\frac{1}{I^3} - \frac{1}{A_p^3}\right) + b_4\left(\frac{1}{I^4} - \frac{1}{A_p^4}\right)\right]}$$

Equation 2.

$$H_D = S_I (10)^{\left[b_1\left(\frac{1}{A_p} - \frac{1}{I}\right) + b_2\left(\frac{1}{A_p^2} - \frac{1}{I^2}\right) + b_3\left(\frac{1}{A_p^3} - \frac{1}{I^3}\right) + b_4\left(\frac{1}{A_p^4} - \frac{1}{I^4}\right)\right]}$$

where:

A_p =plantation age (the number of growing seasons since the seedlings were planted),

H_D =average height of dominant and codominant trees at any given A_p,

I =reference or index age (plantation age to which site quality is referenced),

S_I =site index, the average height of dominant and codominant trees at a given reference age.

Figure 2.—*General equations for computing site index given height and age (equation 1) or height given site index and age (equation 2).*

```
      SUBROUTINE HTSI (CO,AI,X,SH,I,AL)
C--
C-- COEF IS A REAL ARRAY OF SIZE 4 WHICH CONTAINS THE MODEL COEFFICIENTS
C-- AI IS THE INDEX AGE
C-- X IS AGE AS A REAL VARIABLE
C-- SH IS EITHER THE SITE INDEX OR THE HEIGHT
C-- I IS AN INDICATOR VALUE, 1. COMPUTATION OF HEIGHT GIVEN SITE INDEX
C--                          -1. COMPUTATION OF SITE INDEX GIVEN HEIGHT
C-- AL IS THE LEAST INTEGRAL AGE AT WHICH FUNCTION SHOULD BE EVALUATED
C--      WITHOUT INVOKING INTERPOLATION OPTION.
C-- ALL ARGUMENTS ARE REAL VARIABLES.
C--
      REAL CO(4),AI,X,SH,I,AL
      V1=CO(1)/AI+CO(2)/AI**2+CO(3)/AI**3+CO(4)/AI**4
      IF (X.GE.AL) GO TO 10
      IF (I.LT.0)  GO TO 20
      V2=CO(1)/AL+CO(2)/AL**2+CO(3)/AL**3+CO(4)/AL**4
      TSH=(X*(SH*10.**(V2-V1)))/AL
      SH=TSH
      RETURN
10    V2=CO(1)/X +CO(2)/X**2 +CO(3)/X**3 +CO(4)/X**4
      TSH=SH*10.**(I*(V2-V1))
      SH=TSH
      RETURN
20    SH=0.
      RETURN
      END
```

Figure 3.—*Computer subprogram to compute height or site index given the other and age. CO(1), CO(2), CO(3), CO(4) should be set equal to b_1, b_2, b_3, b_4 respectively. AL should be set equal to 6.*

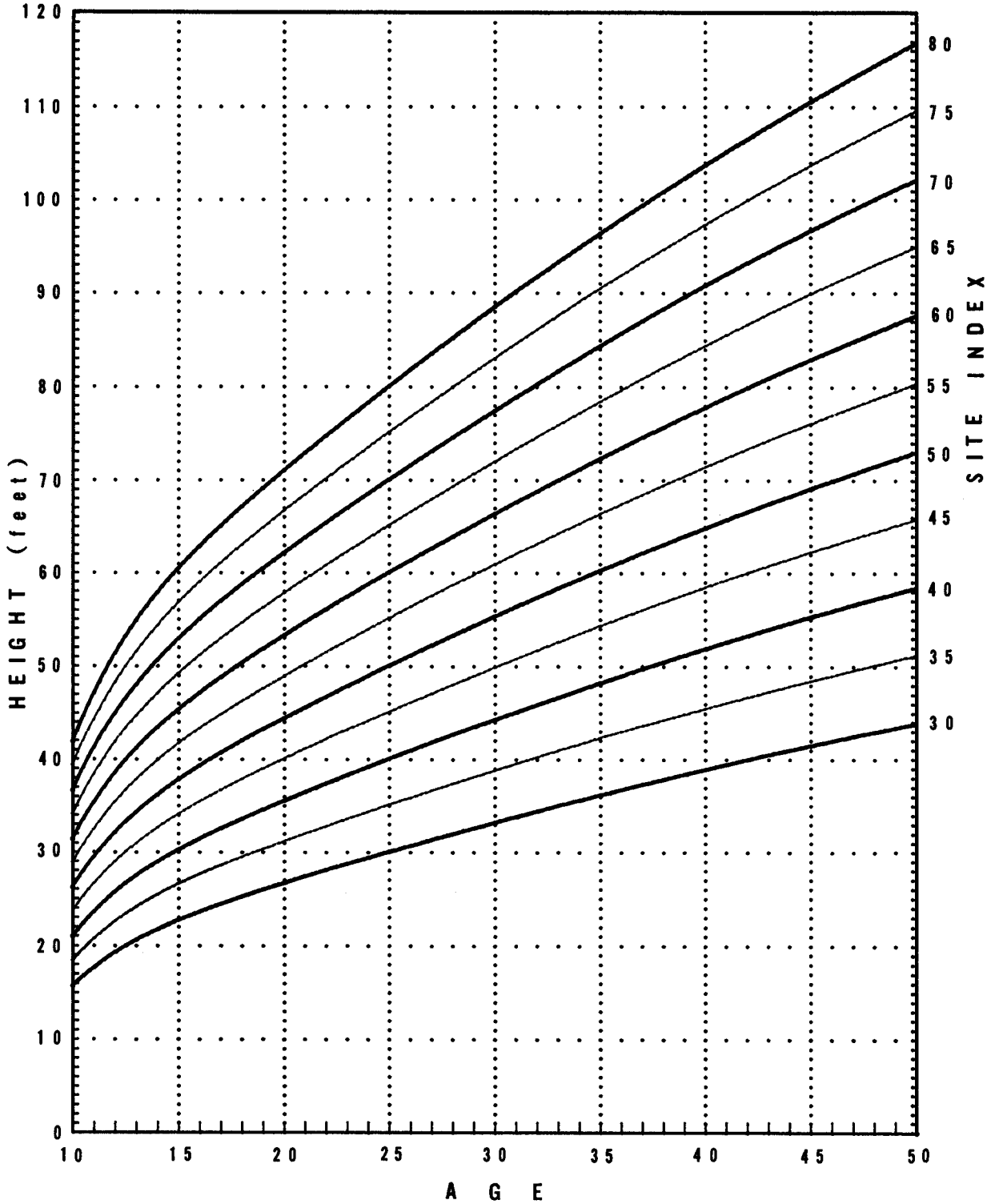

Figure 4.—*Loblolly site index curves (index age 25); plantations on cutover sites.*

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