# SITE INDEX MODEL FOR NATURALLY REGENERATED EVEN-AGED LONGLEAF PINE

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**Abstract**—Data from the Regional Longleaf Growth Study (339 permanent sample plots) were used to develop a site index model for naturally regenerated, even-aged longleaf pine (*Pinus palustris* Mill.). The site index equation was derived using the generalized algebraic difference approach and is base-age invariant. Using height as a measure of site productivity in naturally regenerated longleaf pine is confounded by the variability in the number of years an individual tree remains in the grass stage. This site index equation uses ring count age to model height development from 4.5 feet but can be modified to use tree age based on ring count age and years it takes trees to reach 4.5 feet.

## INTRODUCTION

Height development in naturally regenerated even-aged longleaf pine (*Pinus palustris* Mill.) under shelterwood management is complicated by the fact that ring count age at d.b.h. for a given cohort includes variability in year of germination, length of time in the grass stage, and number of years it takes a tree to reach 4.5 feet. Site index equations typically model the grass stage of longleaf pine as slow early growth and/or make assumptions about the length of the grass stage. Early height predictions and estimates of site productivity would be improved by treating early longleaf development as a discrete event before the initiation of height growth. The difficulty is that site index typically uses stand age.

The objective of this project was to improve current site index models using more recent modeling methodology. Base-age invariant site index modeling methods allow the fitting of curves using ring count age and the substitution of stand age based on measurements or assumptions about years added to ring count age. Estimates based on early height development were improved through the use of a polymorphic equation and the modeling of individual tree height trajectories instead of using plot average height and average ring count age.

## DATA

A subsample of dominant and codominant trees were measured on permanent plots since 1964 by Auburn University, Mississippi State University, and other public owners as part of a U.S. Forest Service, Southern Research Station cooperative study investigating production of thinned, even-aged, naturally regenerated stands in the east Gulf region of the Southern United States. Plots were initially selected to fill an array of cells with five 20-year classes, five 10-foot site index classes, and five 30-square-foot basal area classes (Farrar 1993). Plots were measured every 5 years and additional plots were added as the study progressed. A total of 2,014 plot measurements have been completed covering a wide range of age and height classes.

Dominant and codominant trees selected from this population of sampled trees had to have been measured at least three times, measured on at least half the number of all measurements taken on a given plot, and must have been measured at least to the second-to-the-last plot measurement. The trees must have been classified as dominant or codominant at all measurements. This resulted in a dataset with 19,527 measurements on 3,267 trees distributed over 285 plots.

## ANALYSIS

Longleaf pine height development in young stands is characterized by nearly linear and rapid height growth once trees are >4.5 feet tall. Height growth slows with age but continues at a very slow rate at ages >90 years. A model was selected that was appropriate for this height development pattern. The generalized algebraic difference approach was used to develop a base-age invariant polymorphic model as discussed in detail by Cieszewski and Bailey (2000).

The model was fit to individual tree data using a dummy variable approach. This method estimates global parameters that are the same for all trees and define the shape of the site index curve. A parameter, or random effect, was estimated for each tree to determine the instance of the site index curve for an individual tree. A first-order autoregressive error process was used to account for serial correlation of repeated measurements on a tree. Models were fit using the SAS/ETS model procedure (SAS Institute Inc. 2004).

## GENERALIZED EQUATIONS

The fitted models that describe height development >4.5 feet based on ring count age were generalized to use total height and stand age. The site index equation is:

$$S_{rc+G} = 4.5 + \frac{b_1 + X_0}{1 + \frac{b_2}{X_0}(B_{rc+G} - G)^{-b_3}} \quad (1)$$

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where

$$X_0 = 0.5\left(H - 4.5 - b_1 + \sqrt{(H - 4.5 - b_1)^2 + 4b_2(H - 4.5)(age - G)^{-b3}}\right)$$

The height equation is:

$$H = 4.5 + \frac{b_1 + X_0}{1 + \frac{b_2}{X_0}(age - G)^{-b_3}} \qquad (2)$$

where

$$X_0 = 0.5\left(\left(S_{rc+G} - 4.5\right) - b_1 + \sqrt{((S_{rc+G} - 4.5) - b_1)^2 + 4b_2(S_{rc+G} - 4.5)(B_{rc+G} - G)^{-b3}}\right)$$

In these equations, *age* is stand age in years, *G* is the age at which trees reach 4.5 feet (or stand age minus ring count age), *rc* is ring count age, *S* is site index, *B* is site index base age, and *H* is total height. Estimates of the parameters are $b_1$ = 77.080, $b_2$ = 1723.39, and $b_3$ = 1.235. The subscripts for *S* and *B* indicate how base age is referenced. $S_{43+7}$ would indicate site index base age 50 with a ring count of 43 years and 7 years to reach 4.5 feet.

These equations allow the user to clearly define height development in longleaf stands if both stand age and ring count age are known. Note that base age 50 has very different implications if stands are out of the grass stage in 2 years as opposed to 5 years. Care must be exercised when using this equation to compare management regimes or comparing longleaf height development to that of other pine species. The subscripting of site index and base age allows the clear understanding of what is being assumed.

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