DEVELOPMENT OF MATURE NATURAL EVEN-AGED STANDS OF LOBLOLLY PINE IN THE PIEDMONT

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Abstract—In 1949 a loblolly pine growing-space study was established on the Hitchiti Experimental Forest outside Macon, GA. It consisted of 72 plots varying in age from 18 to 88 years old. Of these plots, 20 were part of an embedded thinning study with 2 replications on each of 2 sites and 4 treatments plus a control. Multiple thinnings were conducted, though none in the last 39 years. Diameter, height, and volume increased while the number of trees per acre decreased and stand density index regressed toward a mean value. Generally, these trends are accelerated on plots with higher site indices. Although a density-limiting relationship is suggested by our data, we found that the slope parameter should be -2 rather than -1.605 as suggested by Reineke. This result suggests that basal area alone is a sufficient estimator of stand density.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the most important softwood species in the southern pine region, and 59 percent of this growing stock was in natural stands in 1989 (Schultz 1997). In the future, rotation length is anticipated to increase on public and some nonindustrial private lands.

When Robert Cooper established the Hitchiti growing-space study in 1949, foresters recognized the need to study the relationship between growing space and yield of a stand. Thinning studies reduce the density of a stand, and spacing studies establish a set number of trees per unit area. However, a growing-space study uses both thinning and natural establishment to evaluate the effects of the density of stands on their continued growth.

A growing-space study like this one provides information on growth rates at various densities and also helps to establish the limits of maximum density. This information can be used to construct the stand density management diagrams (Dean and Baldwin 1993, Drew and Flewelling 1979, Gingrich 1967) used for management of loblolly pine stands. The original researchers may not have expected this study to continue into the 21st century, but the longevity of the data collected has added greatly to its value. Most natural resource research organizations and scientists agree that long-term research is essential, yet few carry out studies for more than a few years because of the special problems involved (Devall and Baldwin 1998).

METHODS

Study Site

The growing-space study is located on the Hitchiti Experimental Forest, 20 miles west of Macon, GA, in the lower Piedmont region. The forest has rolling topography with elevations between 328 and 532 feet above sea level. Its soils range from shallow, poorly developed profiles of the Wilkes and Helena series to deep, well-developed soils of the Lloyd and Davidson series. The climate is temperate with a mean annual rainfall of 48 inches and spring droughts expected 1 year out of 5. Almost all of the Hitchiti Forest was previously farmed; continual row cropping caused serious erosion on all of the uplands so that today little topsoil remains. Following agricultural abandonment in the 1860s, 1880s, and 1920s, the stands in this study naturally seeded into almost pure loblolly pine with occasional shortleaf pine (*P. echinata* Mill.) (Brender 1960).

This study was an installation of a broader regional study to determine the relationship between growing space and yield in a stand of natural loblolly pine. At Hitchiti there are seventy-one ¼-acre plots and one 1/10-acre plot with ½-chain-wide isolation strips surrounding each. On 20 plots with a stand density index (SDI) > 293, a thinning study reduced SDI to 275, 225, 175, 125, or left it unaltered as a control. There were four replicates of each treatment. Our description of results concentrates on the thinning-study plots within the larger growing-space study.

At establishment, the plots in this study had ages ranging from 18 to 88 years and site indices (base age 50) ranging from 57 to 105. The plots also had a range of SDI values from 154 to 431. The subset of plots used in the thinning study ranged from age 21 to 30, site index from 65 to 85, and SDI from 293 to 464. By our latest measurement, in winter 2002, 53 years had passed since study establishment. Of the 72 original plots, 24 have been lost to harvest or damage, and the stand ages now ranged between 71 and 142. Hardwood trees were poisoned on all plots in 1956 and again partially cut in 1993.

Analysis

We chose to describe stand dynamics over the 27-year period following the last thinning. Rather than testing whether the treatments were significant, we describe the subsequent development of plots that initially differed due to site and previous management. We calculated site index based on a sample of tree heights and ages taken in 1949 using the equation for loblolly pine in the South (U.S. Department of Agriculture 1929), as formulated by

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Carmean and others (1989). When we explored the limiting relationship between trees per acre and quadratic mean diameter, we supplemented the thinning study data with the data from the other plots of the growing-space study. We wanted sufficient numbers of observations near the limiting density. Our analysis examines patterns of stand development by graphing stand-level variables (including only pine trees). The variables are (1) number of trees per acre, (2) average height, (3) quadratic mean diameter, (4) SDI (Reineke 1933), (5) cumulative yield (including thinnings) in cubic-foot volume, (6) cumulative yield in board-foot volume, (7) mean annual increment in cubic-foot volume, (8) mean annual increment in board-foot volume, and (9) percent of pine (by basal area). We calculated tree volumes in cubic feet and in board-foot volume by the International ¼-inch log rule. These calculations used the taper functions of Farrar and Murphy (1987, 1988) as incorporated in an unpublished FORTRAN program by Murphy and Leduc. The cumulative yields include only volumes removed during the 53 years of the study; if previous harvests were made, that volume is missing. Each plot is connected by lines to show its individual trajectory and is identified symbolically by the level of thinning and site quality of the stand. In addition, we plotted percent of pine vs. total basal area. Plot 43 is excluded because its extreme age (144) and low percentage of pine (74) compress the remaining plot data and thus hide other potential trends. As well, hardwoods were not controlled on plot 43 in 1993. To explore a limiting density relationship, we plotted the logarithm of trees per acre vs. the logarithm of quadratic mean diameter and estimated a limiting density line for that data.

We modeled the limiting density relationship as trees per acre vs. quadratic mean diameter, which is the standard Reineke (1933) relationship.

$$N = aD_q^{\,b}\,, \qquad (1)$$

where

N = number of trees per acre

Dq = quadratic mean diameter

a and b = parameters to be estimated.

Reineke set b to be -1.605. Equation 1 is often represented by the log-log transformation:

$$\log(N) = \log(a) + b * \log(D_q), \qquad (2)$$

We estimated equation 2 using a weighted regression to provide a line near the limits of the data. Specifically the weighting function was

$$wt = \left(\frac{ba - ba_{\min}}{ba_{\max} - ba_{\min}}\right)^{1000}, \qquad (3)$$

where

wt = the weight

ba = basal area

ba_{min} = the minimum basal area among the data

ba_{max} = the maximum basal area among the data.

The exponent of 1000 was chosen as the largest power of 10 that could be used without causing overflows on the computer. The idea was to give large weight to observations near the boundary line.

RESULTS AND DISCUSSION

We present the relationship of higher hardwood basal area with increasing age and decreasing basal area in figure 1. There is a slight tendency for percent of pine to decrease

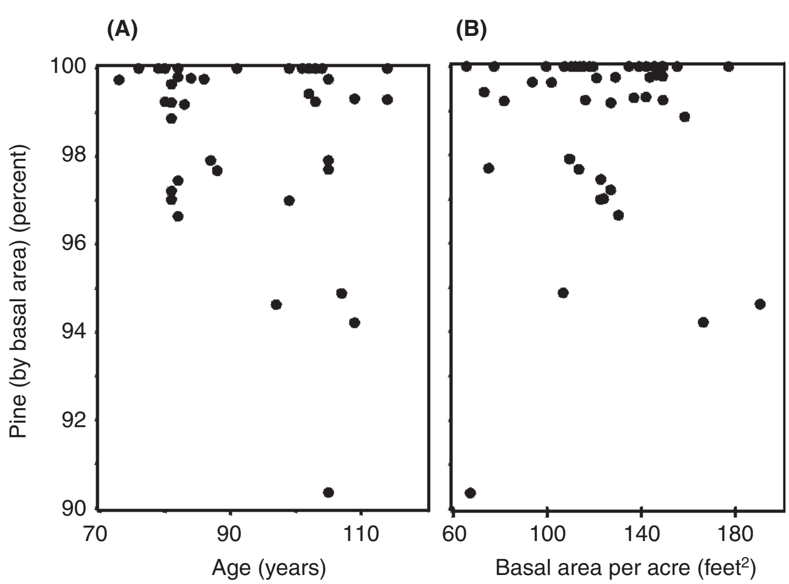

Figure 1—Hardwood encroachment on all study plots as illustrated by (A) percent of pine basal area vs. age and (B) percent of pine basal area vs. total basal area.

with increasing age. Either relationship could exist, but prior removals, the relatively poor sites, or other factors may have eliminated any meaningful age–basal area relationships.

We present basic stand growth relationships in figure 2. Over time the number of trees per unit area decreases (fig. 2A). The plots with higher site index have already completed much of their thinning. The Sukatschew effect suggests stand development progresses faster on better sites (Harper 1977). Average stand height increases as stands get older (fig. 2B). As expected, the plots with higher site index are generally taller than those with lower site index.

Diameter increases as trees get older. On better sites and with lower densities, the absolute diameter is greater. However, the rate of increase is about the same for all sites and densities (fig. 2C). This result suggests that the plots are currently within a relatively narrow band of stand density. Trends in SDI are somewhat masked by a general regression toward the mean (fig. 2D). The plots with higher SDI (> 250) at age 50 to 60 tend to decrease in density, while the plots that have lower SDI (< 200) tend to increase over time.

In figure 3 we present trends in volume growth as total yields and increments. As expected, total yield (board foot and cubic foot) increases with age. The plots thinned to 175 SDI have the greatest volume yield. Volume mean annual increment trends suggest that a rotation of around 70 years would maximize production. Plots thinned lightly on poor sites have (MAI) trends in board-foot volume that are still increasing at age 85.

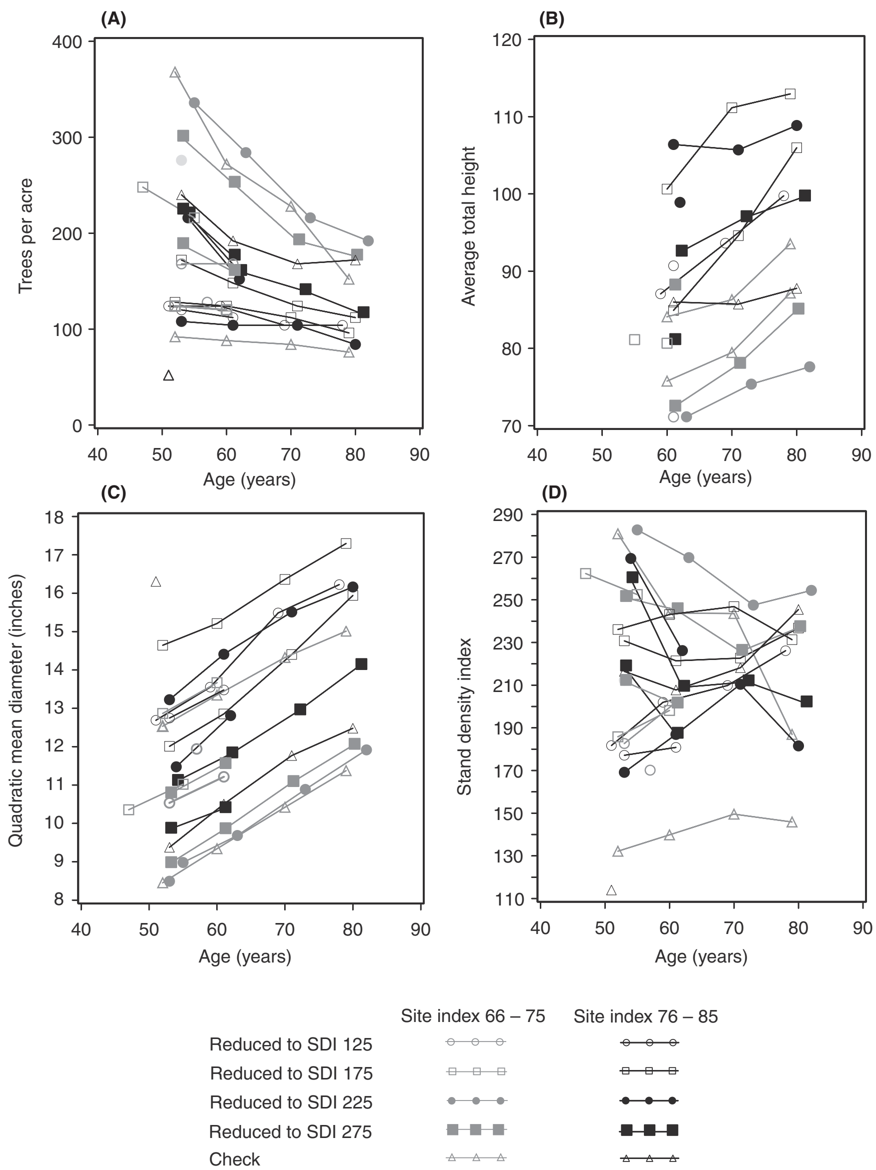

Figure 2—Basic stand growth relationships in the thinning study as related to age including (A) trees per acre, (B) average total height, (C) quadratic mean diameter, and (D) stand-density index (SDI).

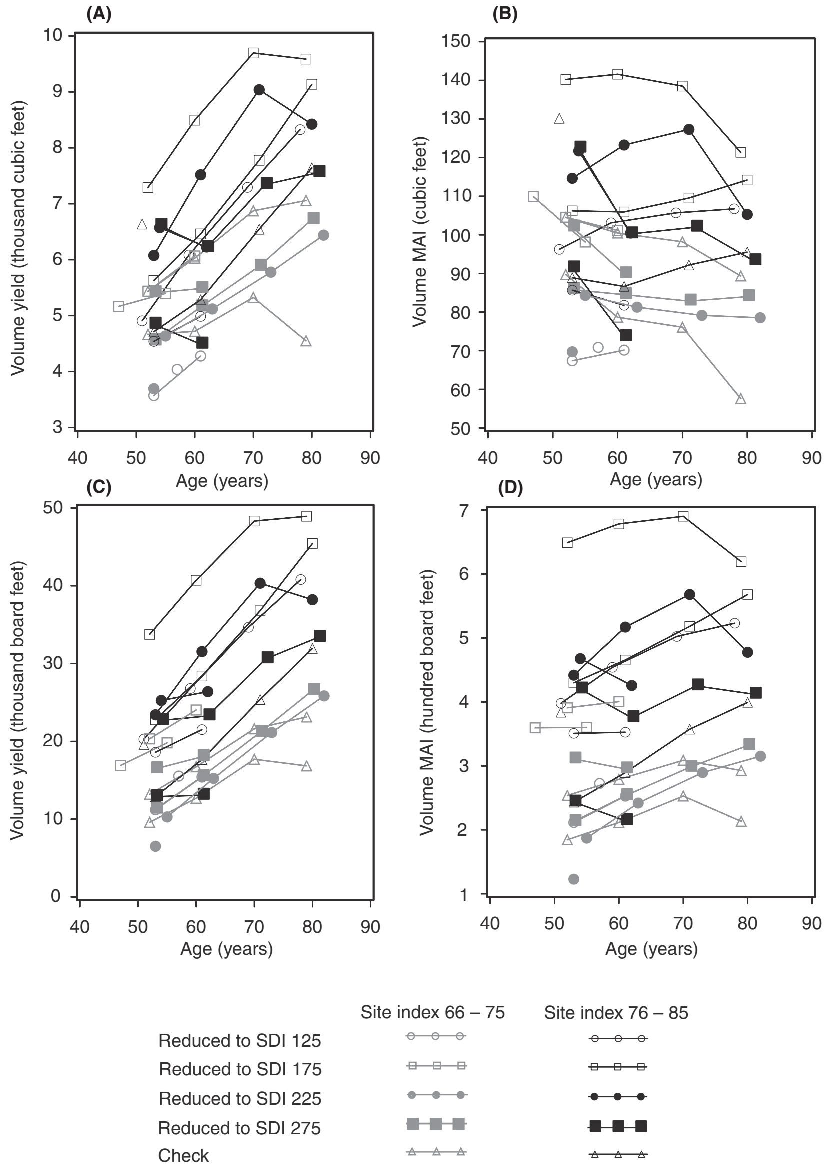

Figure 3—Volume-growth relationships in the thinning study as related to stand age including (A) cubic-foot volume yield, (B) mean annual increment of cubic-foot volume, (C) board-foot volume yield in International ¼-inch scale, and (D) mean annual increment of board-foot volume in International ¼-inch scale (stand-density index = SDI, MAI = mean annual increment).

In figure 4 we show the relationship between trees per acre and quadratic mean diameter on a log-log scale. The limiting density relationship has a slope of -2.005 rather than the -1.605 assumed in the Reineke relationship. Statistically, this slope of -2.005 is not significantly different ($\alpha = 0.05$) from -2, indicating that these stands are limited by basal area since basal area is proportional to the square of diameter. Contrary to most density management tools (Dean and Baldwin 1993, Gingrich 1967, Reineke 1933), this result suggests that, for natural stands of loblolly pine, the same maximum basal area applies regardless of age or average tree size. Thus basal area alone is an adequate measure of stand density.

We fit equation 2 while fixing *b* to be 2.0, using the same weighting function. Thereby we hope to determine the value of the limiting basal area (with *b* as -2.005, the limiting basal area varies very slightly with increasing quadratic mean diameter). There is once again a clear boundary, as shown in figure 5, which we have calculated as 183.2 square feet (1/183.2 = 0.005458).

Nelson and Brender (1963) indicated that basal area was a better predictor variable for estimating future volume growth than was SDI and the Hitchiti plots were a subset of their data. However, Nelson and Brender's (1963) results prove little; standing volume was greatly superior to basal area as a predictor variable. SDI is intended as an estimate of density, not as an estimate of future volume growth. SDI will not be an effective predictor variable unless other predictor variables contribute information regarding age and average tree size. A more appropriate statistical test would be

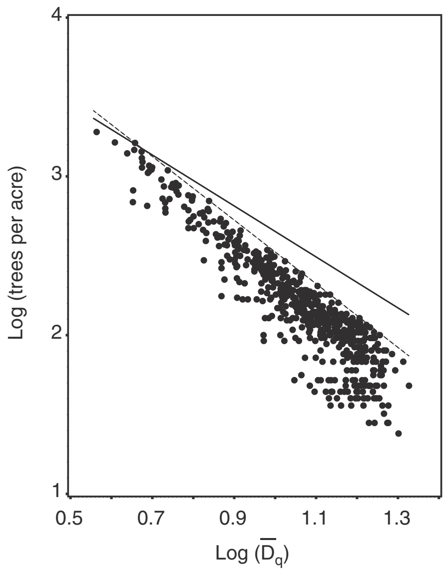

Figure 4—The relationship between the number of trees per acre and the quadratic mean diameter on a log-log scale. Superimposed on this graph is the line for the Reineke slope of -1.605 (solid line) and an apparently better-fit line with a slope of -2.005 (dashed line).

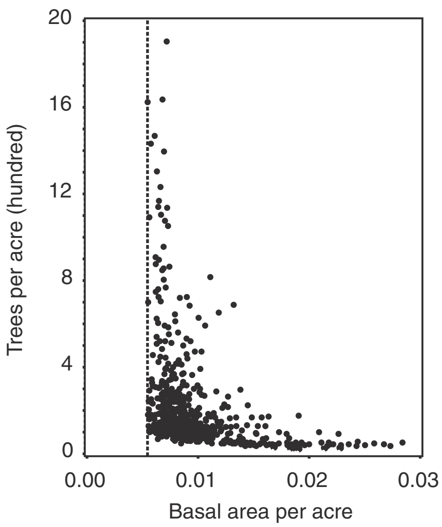

Figure 5—The relationship between trees per acre and the inverse of basal area per acre. Superimposed on this graph is a dotted line showing the hypothesized basal area limit of 183.2 square feet per acre.

whether SDI was a significant predictor variable in an equation that already had basal area as a predictor.

The idea of a limiting basal area also suggests other processes in stand dynamics. As the proportion of sapwood basal area to total basal area declines with age, and as sapwood basal area is related to foliage mass, foliage mass would be lower in an older stand than a younger stand, even though both were at the boundary of maximum density.

CONCLUSIONS

The Hitchiti plots in our report are rare in their age range and the length of recorded data, but they appear to behave mostly as one would expect a natural stand of loblolly pine to behave. The small percentage of hardwood encroachment and the relatively late culmination of MAI are probably related to the relatively poor sites. The indication that basal area defines the limiting density of these stands could be related to the site quality, or it could be more significant. We intend to follow up on basal-area limitation with other research data in the near future. Finally, we will continue to collect data from these stands for as long as the plots avoid catastrophic mortality. The trends may not be surprising, but do provide hard numbers for use in judging the results of the increasingly long rotations in public forests.

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