Station Paper No. 97

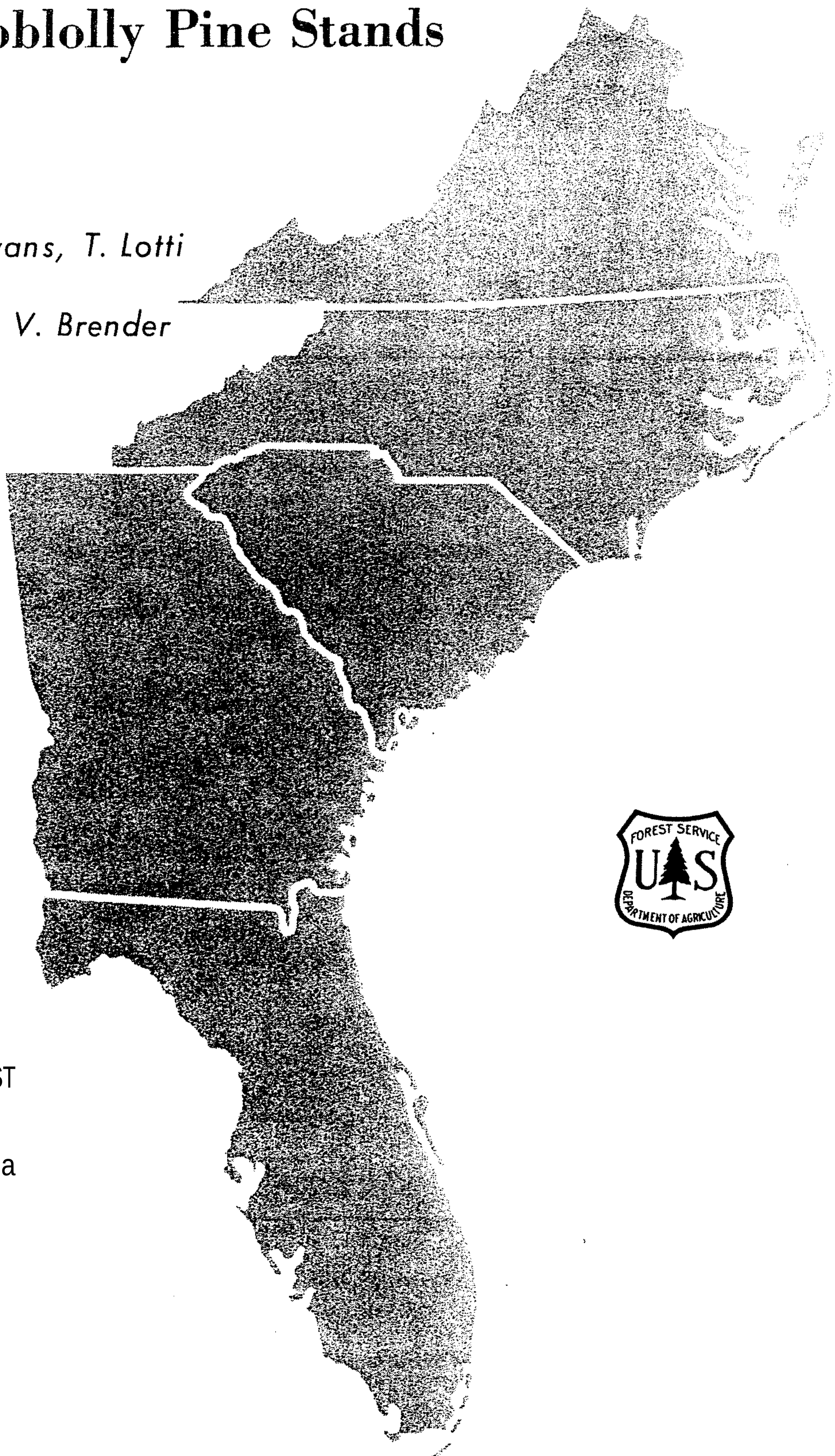
December 1958

The Relation of Growth to Stand Density in Natural Loblolly Pine Stands

by

K. F. Wenger, T. C. Evans, T. Lotti

R. W. Cooper, and E. V. Brender



SOUTHEASTERN FOREST EXPERIMENT STATION
Asheville, North Carolina

Joseph 3. Pechanec,
Director

U. S. DEPARTMENT OF AGRICULTURE · FOREST SERVICE

The Relation of Growth to Stand Density in Natural Loblolly Pine Stands

5-Year Results

by

K. F. Wenger, T. C. Evans, T. Lotti, R. W. Cooper, and E. V. Brender [1]

INTRODUCTION

This is a progress report of a regional study on growing-space requirements for natural stands of loblolly pine (*Pinus taeda* L.).

A primary objective is to measure the effects of residual stand density, obtained naturally or by cutting, during intermediate ages, upon volume yield and total production. By imposing real values and costs upon measured yields, net return may be calculated and used to determine optimum levels of stand density for various combinations of site, product, and financial goal.

The attainment of this objective obviously depends on a series of measurements taken over a long period. Only preliminary and partial results are reported herein because data are complete only for the first S-year period of the study. Nevertheless, these data indicate that a low level of stand density is optimum for growth on a poor site, at least in young loblolly pine stands. In contrast, a good site will support a relatively high stand density throughout the rotation. Because of the preliminary nature of these findings, no attempt is made to develop financial aspects of the study at this time.

METHODS

A total of 153 circular ¼-acre plots with i-chain isolation strips were selected in 20- to 60-year-old stands of a wide range of site indices and densities. Site indices ranged from a little less than 60 feet to a little more than 100; densities ranged from 40 to 130 percent of full stocking (7). Only essentially pure stands of even-aged, uniformly spaced, and insect- and disease-free loblolly pine were used. Site index could not vary more than 10 feet within plot boundaries.

1/ L. E. Chaiken, now Professor of Forestry at Duke University, and T. A. McClay, now of the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, also were responsible for important portions of the study. The West Virginia Pulp and Paper Company made land available in the Westvaco Experimental Forest, Georgetown, S. C., and L. T. Easley and D. A. Harkin of the Company staff assisted in the work. The Georgia Kraft Company, Macon, Ga., supplied substantial assistance for the remeasurement of the Georgia portion of the study.

Plots were established in Georgia, Virginia, and South Carolina on the Hitchiti, Camp,[2/] Santee, and Westvaco Experimental Forests during the period 1948- 1950.

Stand measurements on the plot consisted of a tally of all pine stems 0.6 inch d. b. h. and larger by l-inch diameter classes. Only those hardwoods 4.6 inches d.b.h. and larger were tallied. Site index was determined by measuring total height and age of a sample of dominant and codominant trees, and applying the readings to Coile's (3) site index curves. These initial measurements were used to determine merchantable cubic-foot volume, board-foot volume (International f-inch log rule), and stocking per acre. Board-foot and cubic-foot volume tables based on total height were constructed from data that had been collected earlier in the Hitchiti, Santee, and Camp Experimental Forests.

About 35 percent of the number of plots were cut to specified residual densities, to provide a comparison between the growth of thinned and unthinned stands of the same age, density, and site. The thinnings were essentially from below, but modified to permit uniform spacing of residual stems and the removal of undesirable trees in all crown classes. Hardwoods 4.6 inches d. b. h. and larger were poisoned.

All of the plots were remeasured after five growing seasons. Growth was expressed in terms of the net annual increment in cubic-foot and board-foot volume per acre. Regression methods were used to determine the relation of growth to the age, site index, and density of the stand.

The form of the function fitted to the data was 'as follows:

$$Y = b_0 + b_1 \frac{1}{10A} + b_2(S) + b_3(D) + b_4(D^2) + b_5\left(\frac{S}{A}\right) + b_6\left(\frac{D}{A}\right) + b_7\left(\frac{D^2}{A}\right) + b_8(SD) + b_9(SD^2)$$

in which Y = growth

A = total age

S = site index

D = density percent

b with subscripts = coefficients derived from the data.

Density percent expresses the basal area of a stand of given average diameter as a percentage of the basal area of well-stocked stands of the same average diameter. Reineke's (6) stand density index (SDI), Chisman and Schumacher's (2) tree-area ratio, or other measures of stocking might have served equally well.

2/ Maintained in Surry County, Virginia, by the U. S. Forest Service in cooperation with the Union Bag-Camp Paper Corporation.

RESULTS

Cubic-Foot Volume Growth

The relations of growth in cubic feet per acre to site index, stand age, and stand density percent (7) derived from the data were as follows:

$$PAG\ (\text{thinned}) = 272.08 - 2.47(S) - 5.72(D) + 0.074(SD)$$

$$PAG\ (\text{unthinned}) = -91.36 + \frac{4908.0}{A} - 0.075(S) - 51.79\left(\frac{D}{A}\right) + 0.0289(SD)$$

in which PAG = periodic 5-year annual growth in cubic feet per acre of trees 4.6 inches d.b.h. and larger,

A = age of stand in years at the beginning of the 5-year period,

S = site index of stand,

D = percent of theoretical full stocking after thinning or at the beginning of the 5-year period.

In the thinned stands, the relation of growth to density varied with site index (fig. 1). No significant. effect of age was found. Heavier stands grew faster than lighter stands on good sites but slower on poor sites. Since the trend on poor sites is negative within the range of densities sampled, it must be positive at lower densities. Thus, the true relation must be curvilinear, and growth rate must reach a peak somewhere near or below the lower limit of the sample. The difference in trends with site also indicates, therefore, that maximum growth occurs at a higher density on good sites than on poor sites.

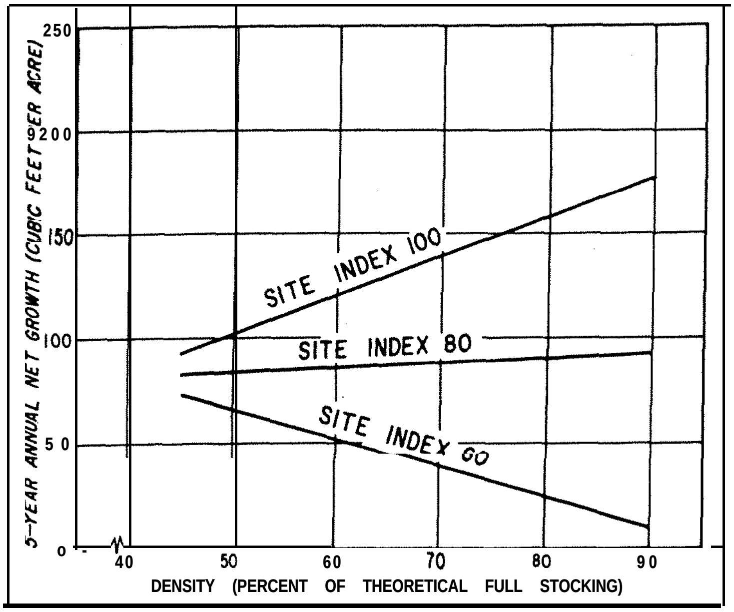


Figure 1. -- Cubic-foot volume growth of thinned stands in relation to stand density and site index.

In the unthinned stands, the relation of cubic-foot volume growth to stand density varied with age as well as with site index. At young ages, growth was related to density in essentially the same way as in thinned stands, increasing with increasing density on good sites and decreasing on poor sites, within the density range sampled (fig. 2A). In older stands, however, growth increased with increasing density on all sites, although the difference was greater on good than on poor sites (fig. 2B).

The effect of cutting on stand structure may be the reason why age was a significant factor in the growth of the unthinned stands but not of the thinned stands. In an unthinned stand on a given site, the size of trees is related to the number per acre and the stand age. Thinning destroys this relation, and in thinned stands the number per acre is determined mainly by the heaviness of the thinning. Thus, any effect of age is likely to be obscured in the early years after thinning. As the prescribed densities are maintained for extended periods, growth may again be more strongly related to age.

<u>Board-Foot Volume Growth</u>

In thinned stands, the relations of board-foot volume growth per acre to age, site, and density were as follows:

$$PAG = -484.09 + \frac{14657.86}{A} + 3.68(S) - 407.75\,\frac{D}{A} + 0.204(SD)$$

In unthinned stands, they were:

$$PAG = -1054.61 + \frac{47971.81}{A} + 4.04(S) - 154.68\left(\frac{S}{A}\right) - 602.99\left(\frac{D}{A}\right) + 0.259(SD)$$

in which PAG = periodic 5-year annual volume growth per acre of trees 9.6 inches d.b. h. and larger to a ‘I-inch top diameter inside bark, in terms of the International $\frac{1}{4}$-inch log rule.

In both thinned and unthinned stands, the relation of board-foot volume growth to density varied with age as well as with site index. In young stands, growth increased with increasing density on good sites, but decreased on poor sites within the density range sampled (fig. 3). But in older stands, growth increased with increasing density on all sites, although the increase in growth was not as great on poor as on good sites (fig. 4). This difference with age in the relation of board-foot volume growth to density indicates, therefore, that the density for maximum growth is higher in older than in younger stands.

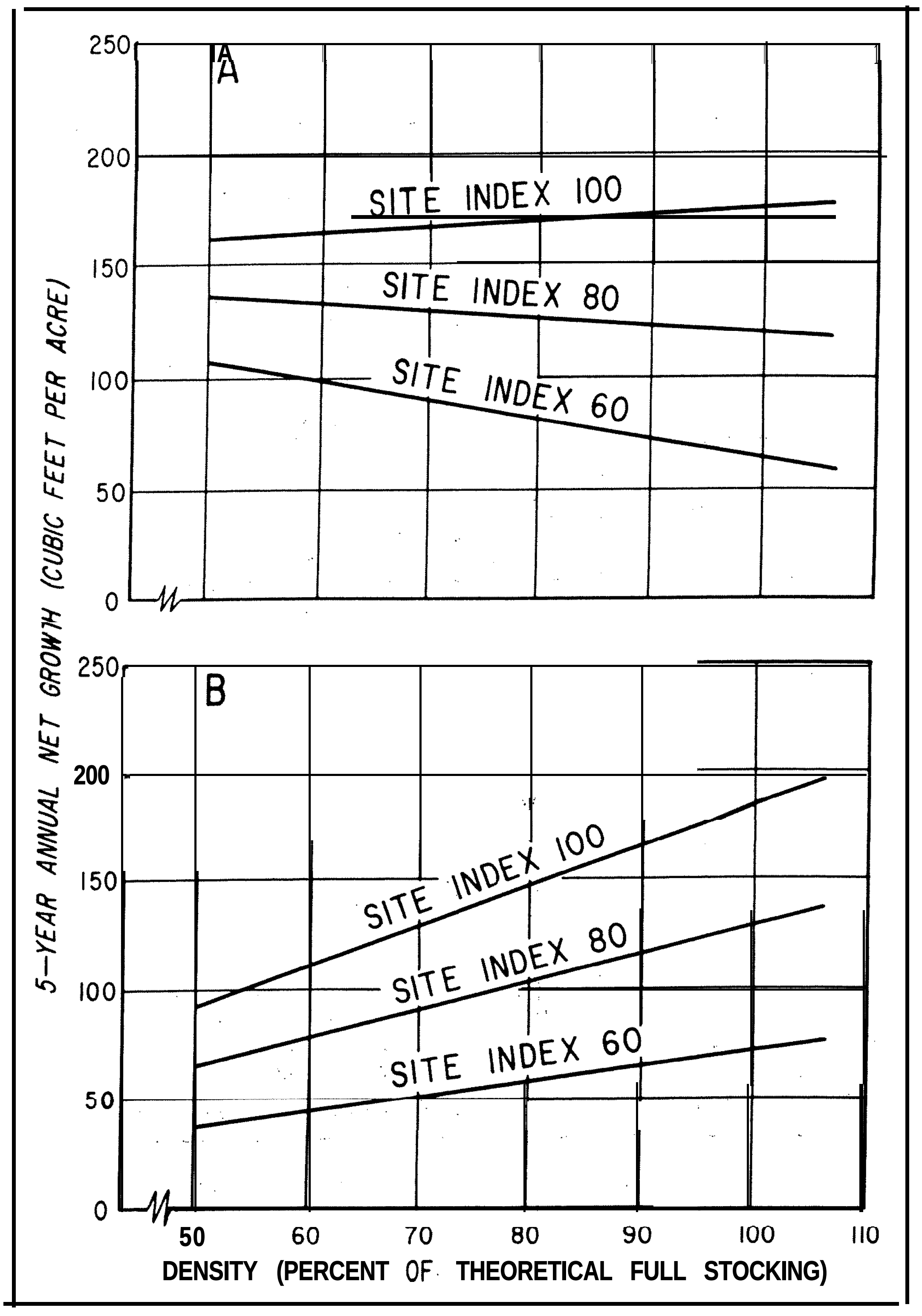


Figure 2. --Cubic-foot volume growth of unthinned stands in relation to stand density and site index. A, at 20 years; B, at 50 years.

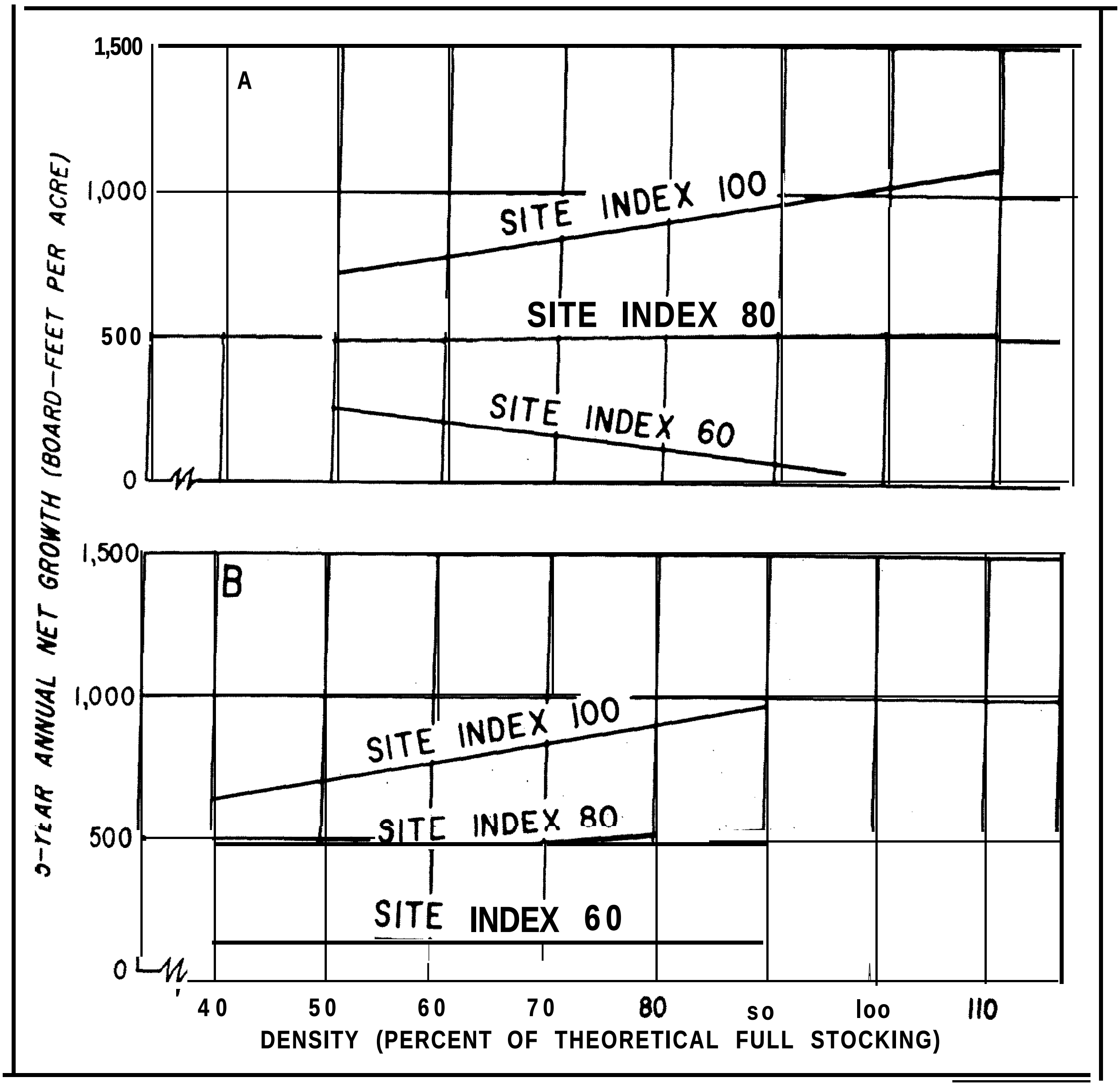


Figure 3. -- Board-foot volume growth of 30-year-old stands in relation to stand density and site index. A, unthinned; B, thinned.

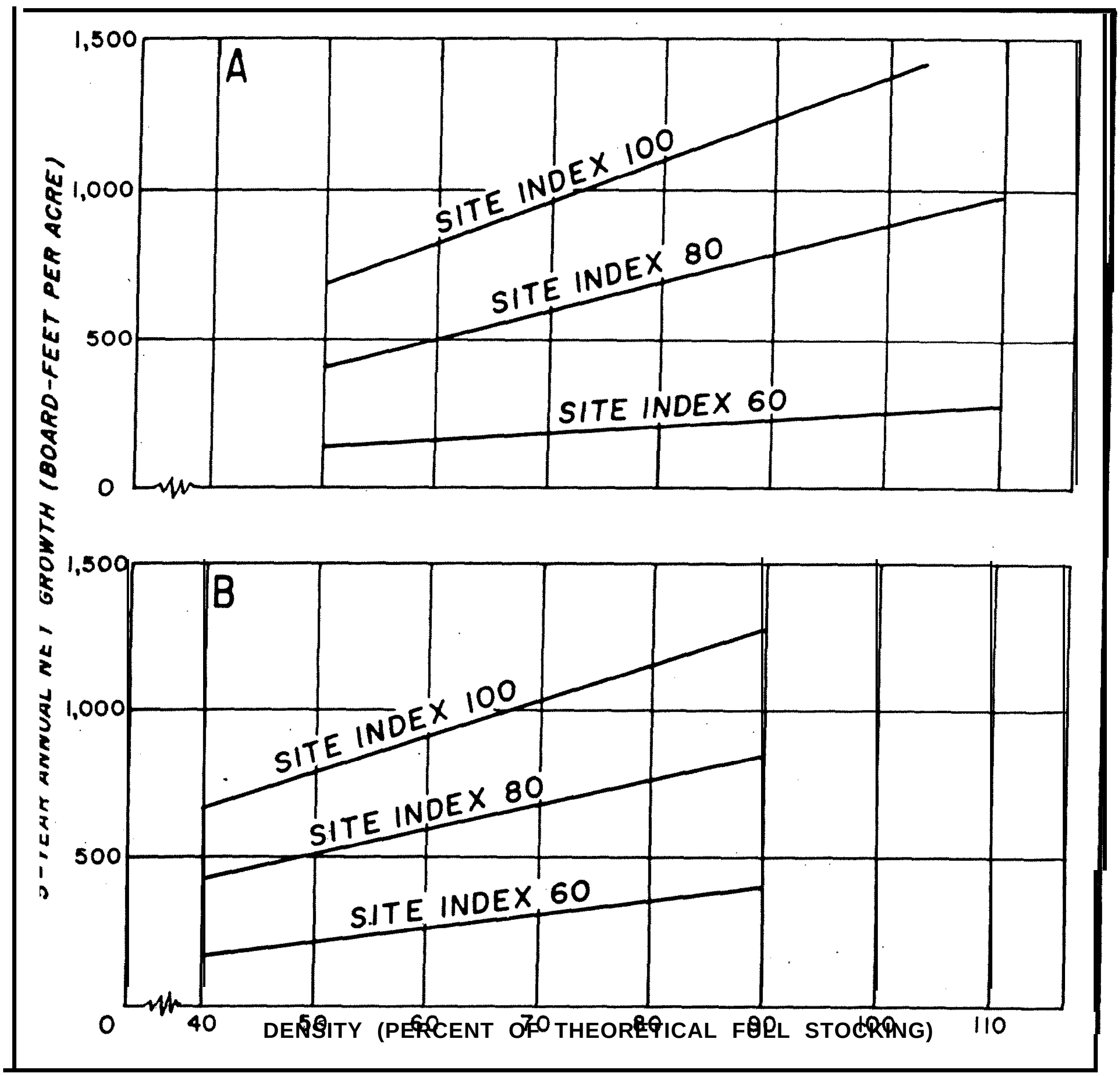


Figure 4. --Board-foot volume growth of 50-year-old stands in relation to stand density and site index. A, unthinned; B, thinned.

DISCUSSION

None of the relations found accounted for more than 40 percent of the variation in growth. The large, unaccountable variation may be related to the effect of mortality on net growth and the short growth period of 5 years. On small plots, net growth is greatly affected by the death of only a few trees because their entire volume is subtracted from the growth of the live trees in the net growth computation. Mortality occurred in the plots in this study, but it could not be taken into account because trees were not permanently marked when first measured and the dead trees could not be identified. The remeasurements were made by the progressive azimuth method, which will permit the identification of individual trees in the future so that mortality can be taken into account.

The second factor, which applies only to the thinned plots, is that 5 years is probably not enough time for the growth of the thinned stand to fully reflect the increased growing space. Stands that were reduced from a high initial density to a comparatively low density were probably especially slow to respond. However, this effect was not significant in these data when expressed as the reduction in density.

In young stands on poor sites, the decrease in volume growth per acre with increasing density is probably due mainly to slow growth of individual stems and mortality, which are expressions of the inability of the site to support the heavy stocking. However, an additional factor may be the difference in the diameter limits for density percent and volume growth. Density percent is based on all stems larger than 0.5 inch d. b. h., while cubic-foot and board-foot volumes begin at 4.6 and 9.6 inches, respectively. Because of the effect of stand density on diameter growth, ingrowth into volume size classes occurs at a later age in dense stands than in lighter stands. Thus, at certain young ages, measured growth would be less in denser stands because fewer trees contribute to volume growth. The period of fast ingrowth is also earlier on good sites than on poor sites. Apparently 20 years, the lower age limit in this study, is within the period of fast ingrowth for 60- and 80-foot sites but beyond that period for 100-foot sites (fig. 2A). The magnitude of this effect on cubic-foot volume growth can be determined in future analyses by extending the volume table to smaller diameters and including the small stems in the growth determinations. The inclusion of smaller stems is not, of course, appropriate in board-foot volumes.

Thus, because of the low correlations obtained, the optimum densities and growth rates for various sites and ages cannot yet be specified. Nevertheless, the indications that the optimum density is lower on poor than on good sites are probably correct. Cruschow and Evans 3/ combined data

---

3/ Gruschow, G. F., and Evans, T. C. The relation of cubic-foot volume growth to stand density in young slash pine stands. Publication pending in Forest Science. 1958.

from a number of earlier studies and found that the curves of cubic-foot volume growth culminated at low densities on poor sites, and at higher densities on better sites in 10- and 20-year-old natural slash pine stands. McClay (4) also found that the curve of cubic-foot volume growth culminated at a higher residual basal area on 80-foot than on 70-foot sites in partially cut 25- to 35-year-old loblolly pine stands. In Germany, Assman (1) reviewed data from many years of thinning and concluded that optimum stocking increased with site quality. But after summarizing data from many thinnings of beech and *Norway* spruce in Denmark, Möller (5) believed that 50 percent of the maximum possible stocking was best on all sites. These divergent opinions in Europe will undoubtedly be reconciled in time, but most of the evidence to date indicates that optimum density varies with site quality.

No curves were apparent in this study. This failure to show optimum densities may have been due to the limited range of densities sampled. To correct this condition, additional plots *were* thinned at the beginning of the second 5-year period, extending the range of residual densities to a very low level. With a wider range of residual densities, the chance of determining the optimum level should be much better.

SUMMARY

In order to determine the relations of growth, variously expressed, to the age, site index, and density of thinned and unthinned, even-aged loblolly pine stands, 153 circular ¼-acre plots were selected in 20- to 60-year-old stands of a wide range in site index and density. About 35 percent of these plots were thinned to a range of residual densities.

Cubic-foot volume growth was found to be significantly related to age, site index, and density of unthinned stands, but only site index and residual density were significant factors in the growth of thinned stands. However, age will probably be important in thinned stands in the future as they are maintained at the prescribed densities. Board-foot volume growth was significantly related to age, site index, and density in both thinned and unthinned stands.

In young stands, volume growth increased with increasing density on good sites but decreased with increasing density on poor sites, indicating that the optimum density for growth was near the lower end of the sampled density range on poor sites and near the upper end of the range on good sites. In older stands, volume growth increased with increasing density on all sites, but not so much on poor sites as on good sites. Thus, the optimum density for volume growth increases with age of stand on poor sites, while good sites will support a high density throughout the rotation.

LITERATURE CITED

1. Assman, E.
   BESTOCKUNGSDICHTE UND HOLZERZEUGUNG. Forstwiss. Centbl. 72(3/4): 69-101. (U. S. Dept. Agr. translation.)

2. Chisman, H. H., and Schumacher, F. X.
   1940. ON THE TREE-AREA RATIO AND CERTAIN OF ITS APPLICATIONS. Jour. Forestry 38: 311-317.

3. Coile, T. S.
   1952. SOIL PRODUCTIVITY FOR SOUTHERN PINES. Part I. SHORTLEAF AND LOBLOLLY PINES. Forest Farmer 11(7): 10, 11, 13.

4. McClay, T. A.
   1955. THE RELATION OF GROWTH TO SITE AND RESIDUAL DENSITY IN LOBLOLLY PINE PULPWOOD STANDS. U. S. Forest Serv. Southeast. Forest Expt. Sta. Res. Note 78, 2 pp., illus. (Processed.)

5. Möller, Carl Mar:
   1954. THE INFLUENCE OF THINNING ON VOLUME INCREMENT. In THINNING PROBLEMS AND PRACTICES IN DENMARK. N. Y. State Col. Forestry, Syracuse Univ. Tech. Paper 76, 92 pp.

6. Reineke, L. H.
   1933. PERFECTING A STAND DENSITY INDEX FOR EVEN-AGED FORESTS. Jour. Agr. 'Res. 46: 627-638.

7. Stahelin, R.
   1949. THINNING EVEN-AGED LOBLOLLY AND SLASH PINE STANDS TO SPECIFIED DENSITIES. Jour. Forestry 47: 538-540.