Growth of Loblolly Pine Stands After the First Five Years of Uneven-Aged Silviculture Using Single-Tree Selection

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ABSTRACT. *The effects of three levels of residual basal area (40, 60, and 80 ft^2/ac), maximum dbh (12, 16, and 20 in.) and site index (<81 ft, 81 to 90 ft, and >90 ft) on the growth of loblolly pine (*Pinus taeda *L.) stands after 5 yr of uneven-aged silviculture were determined from plots located in south Arkansas and north Louisiana. Designated levels of basal area and maximum dbh were achieved by harvesting; a q factor of 1.2 (using 1 in. dbh classes) was imposed on all plots as closely as possible. Stand-level models were developed for annual per acre net volume growth (merchantable cubic feet, sawtimber cubic feet, and sawtimber board feet, Doyle rule) and annual per acre survivor growth, ingrowth, and mortality components of basal area growth. Growth for all volume measures increased with an increase in basal area. Site index did not significantly affect merchantable cubic-foot growth but had a positive effect on sawtimber growth in both cubic feet and board feet, Doyle. Increases in maximum dbh decreased merchantable and sawtimber cubic-foot growth but increased growth for board-foot volume, Doyle. South. J. Appl. For. 18(3): 128–132.*

No information is available about the growth and yield of essentially pure loblolly pine stands that are managed under uneven-aged silviculture with single-tree selection as the reproduction cutting method. The available data pertain only to loblolly-shortleaf pine stands, where loblolly pine may be the predominant species but where shortleaf pine (*P. echinata* Mill.) is also present as a common associate. Loblolly pine in the West Gulf Coastal Plain is usually favored over shortleaf because of the reputed slower growth and more erratic and lower seed production of shortleaf pine.

Reynolds (1959, 1969) reported production averages over a 29-yr period for loblolly-shortleaf pine stands managed by single-tree selection in southeast Arkansas (loblolly pine site index 90 ft, base age 50). Growth was 84 ft^3/ac for merchantable trees (3.6 in. dbh and larger) and 432 bd ft (International 1/4-in. rule) in 24 managed stands that were harvested on 3-yr, 6-yr, and 9-yr cutting cycles. Brender (1973) reported merchantable growth of 74 ft^3 and 319 bd ft (International 1/4-in. rule) for sawtimber in loblolly-shortleaf pine stands in the Georgia Piedmont (loblolly site index 77 ft, base age 50). Although there were minor merchantability differences between the Arkansas and Georgia studies, the primary cause of the growth difference was site quality.

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More recently, Murphy and Farrar (1982a, 1983) and Farrar et al. (1984) developed stand-level growth and yield models for loblolly-shortleaf pine stands in the West Gulf region (site index 80 to 90 ft, loblolly pine). These models predict future basal areas and current and future volumes, both cubic foot and board foot. As they are stand-level models, stand or stock tables cannot be derived, and the applicable site index range is rather narrow.

Stand structure is an important adjunct of uneven-aged regulation, but knowledge about the effect of structure on growth is fragmentary. Solomon (1977) created 12 different stand structures in a northern hardwood stand in New England by varying the total basal area and percent basal area that was in sawtimber. He found that higher sawtimber production (including ingrowth) was obtained where the proportion of sawtimber basal area was reduced. Sawtimber production (excluding ingrowth) was maximized where both a high sawtimber basal area and a high total basal area were maintained. A methods-of-cutting study in south Arkansas (Baker and Murphy 1982) compared four reproduction cutting methods. Two of these methods were a 12-in. diameter-limit cut and single-tree selection. The board-foot volume production was not different between the two methods, even though much higher densities were retained in the single-tree selection.

In summary, our current knowledge of uneven-aged stand dynamics and growth potential is quite limited, even for such

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a widely studied species as loblolly pine. Consequently, a study was installed during 1983–1985 to investigate the effects of different stand and site variables on the growth and development of loblolly pine stands that were put under uneven-aged silviculture with single-tree selection. Presented here are the initial 5-yr results.

Methods

Treatment Variables

Uneven-aged stand structures are typically defined in terms of (1) basal area, (2) maximum diameter, and (3) a quotient, termed "q." This quotient is the ratio of the number of trees in a diameter class to the adjacent diameter class. For example, if there are 10 trees/ac in the 13 in. class and 12 trees/ac in the 12 in. class, the q value would be 1.2. The quotient is also affected by diameter class width: a q value of 1.2 for 1 in. classes would become 1.44 for 2 in. classes. Several guides have been published on how to use these three variables to describe stand structure (Brender 1973, Moser 1976, Murphy and Farrar 1982b). Site quality also influences growth, but its effect on uneven-aged loblolly pine stands has not been documented in a single study, although inferences can be made by comparing different investigations.

The effects of basal area, maximum diameter, and site quality on growth and development of uneven-aged loblolly pine stands were investigated in this study. Although q is one of the principal variables used to define uneven-aged stand structure, experience has shown it to be the least amenable to management, at least initially. A stand can easily be cut to a specified basal area, and maximum diameter is not a difficult goal to achieve. However, q is a more difficult goal. If deficits occur in particular diameter classes, one must wait for these deficits to be erased by ingrowth from smaller size classes. If cutting is ruthlessly applied to eliminate surpluses in some diameter classes, the residual basal area will probably be lower than desired. In addition, stands that have not been under uneven-aged management are probably overstocked and have severe deficits in the smaller size classes, because conditions were not favorable for pine regeneration. Thus, structural goals may be attained only after a lengthy period. Therefore, the other variables were selected in this first effort and q was fixed. A q of 1.2 was used for this study; Reynolds (1959, 1969) and Reynolds et al. (1984) have observed and used this value in several decades of uneven-aged management of loblolly–shortleaf pine stands.

We chose treatment levels of 40, 60, and 80 ft^2/ac in trees larger than 3.5 in. dbh for basal area; 12, 16, and 20 in. dbh for maximum diameter; and site index ranges of less than 81 ft, 81 to 90 ft, and 91 ft and above (loblolly pine base age 50). Basal area levels are lower than those encountered in even-aged stands to favor the development of pine reproduction. Reynolds (1959) recommended that a stand have 75 ft^2/ac of basal area just before a cycle cut to allow pine regeneration to develop. Uneven-aged loblolly pine stands, therefore, should probably not be much above this level at any time during a cutting cycle. A slightly higher basal area (80 ft^2) was chosen to investigate growth and the long-term effects on loblolly pine regeneration. The lowest basal area treatment level of 40 ft^2 probably represents the lower acceptable density limit for management. Lower densities approach understocked conditions for uneven-aged stands, and growth is being lost without any concomitant gain in regeneration.

Maximum dbh is somewhat akin to rotation age in even-aged stands. Selection of a larger maximum dbh represents a longer term investment than selection of a smaller maximum dbh. A residual maximum dbh of 20 in. probably represents an upper limit for both economic and product-size goals. Likewise, 12 in. dbh represents a lower limit for an adequate seed source. The site index classes of this study adequately capture the range of site quality that is encountered in the West Gulf Coastal Plain. Each treatment combination was replicated three times for a total of 81 plots.

Field Installation and Measurements

Candidate stands for plot installation had to have at least 70% of the basal area in loblolly pine; no evidence of cutting within the last 10 yr; no evidence of catastrophic loss from insects, disease, weather, or fire; and a site index that did not vary more than 10 ft over the plot area. Stands that exhibited a reverse J-shaped stand structure were preferred if available.

The stands represented a gamut of conditions: some already exhibited a reverse J-shaped stand structure, while others had a mound-shaped structure typical of even-aged stands. Most stands had more than one plot installed in them. All 81 study plots are located in the Coastal Plain of south Arkansas and north Louisiana (Figure 1). Plots were assigned to a residual basal area and maximum dbh treatment as randomly as possible.

Square 1.6 ac gross plots were installed with an interior square 0.5 ac net plot. Before harvest, all loblolly pine trees greater than 3.5 in. dbh were inventoried by 1 in. dbh classes

Figure 1. Locations of uneven-aged loblolly pine study plots in south Arkansas and north Louisiana.

separately for the 0.5 ac net plot and 1.1 ac isolation strip. Plots were then marked for harvest to attain their assigned residual structure as defined by residual basal area, maximum dbh, and a q of 1.2 for 1 in. dbh classes. Any shortleaf pines occurring on the plots were cut. All hardwoods with a groundline diameter of 1 in. or larger were injected with herbicide prior to harvest, if possible, or no later than the first growing season after treatment. All cutting was completed during the early part of the dormant season of each year, with about one-third of the plots established each year. Plot installation and harvest occurred over a 3-yr period beginning in the fall of 1983.

Following harvest, all residual loblolly pine trees larger than 3.5 in. dbh on the net plot were numbered, mapped, and measured. Dbh was measured to the nearest 0.1 in. using a tape. A dbh mark was painted on each tree to ensure consistency in subsequent measurements. Total height and height to the crown base were measured to the nearest foot on a sample of 20% of the trees in each 1 in. dbh class. Five to ten height-sample trees suitable for site index calculation were selected for age determination by increment coring. If no past suppression occurred, site index was computed using the function by Farrar (1973).

The plots were remeasured after 5 yr of growth. The same measurements, except tree age, were taken on both surviving trees and ingrowth trees.

Calculations and Modeling

Net plot summaries were calculated for merchantable basal area, merchantable and sawtimber cubic-foot volume, and board-foot volume for the Doyle log rule. To calculate individual tree volumes, height/dbh regressions for each plot and measurement were developed and used to calculate heights for trees with no height measurements. Tree volumes were calculated from taper curves for natural loblolly pine (Farrar and Murphy 1988). Merchantable cubic-foot volumes were calculated for a 1-ft stump to a 4-in. top, outside bark; sawtimber ft^3 and bd ft volumes, for a 1-ft stump to a 7-in. top, outside bark.

Annual net growth was determined by subtracting the initial volume from the final one and dividing by the length of the growth interval. Basal area growth was divided into three components—growth of initial trees that survived du ing the entire period (survivor growth), the basal area of tre that died during the period (mortality), and the basal area trees that grew past the 3.5-in. threshold (ingrowth). The components were expressed on an annual basis by dividin by the length of the growth period.

After evaluating several candidate models, we selecte the following form for the growth analysis:

$$Y = \exp(b_0 + b_1B + b_2S + b_3D)$$

where Y is the response variable of interest, B is initial bas area (ft^2/ac), S is site index (ft) for loblolly pine (base age 50 D is initial maximum diameter (in.), and the b_i's are coeff cients to be determined. Nonlinear seemingly unrelated r gressions (SAS Institute 1988) were calculated for merchan able and sawtimber cubic-foot volume growth, board-fo volume growth (Doyle rule), and the components of bas area growth—survivor growth, ingrowth, and mortalit Variables included in the model had coefficients whos calculated approximate "t" values had calculated probabi ties of 0.10 or less.

Results

Table 1 lists the regression coefficients and associate statistics for the growth models developed in this study. Th coefficient b_1 is positive for all the volume growth variable which indicates that increasing basal area will increase growt for the volume variables and basal area ranges studied her The coefficient b_2, associated with site index, did not contrib ute to merchantable volume growth and was not included i the equation for this variable. However, the coefficient b was positive for sawtimber volume growth, indicating a increase for stands on the better sites.

A more complex pattern occurs in volume growth with th coefficient b_3, which is associated with maximum diamete the coefficient is negative for all variables except board-fo growth. Although stand age is meaningless in an uneven aged context, there is a positive relationship between the siz of a tree and its age in uneven-aged stands (Shelton an Murphy 1991). This relationship also apparently become

Table 1. Coefficient values and associated statistics for volume and basal area growth equations.

Variable	Coefficients[1]				Fit index[2]	Root mean square erro
	b_0	b_1	b_2	b_3		
Merchantable ft^3 volume growth	4.4548	0.014522	0.0	-0.035473	0.51	27.5
Sawtimber ft^3 volume growth	4.1901	0.015707	0.0027677	-0.040077	0.48	31.2
Bd ft volume growth, Doyle rule	4.0595	0.014962	0.0087398	0.020744	0.51	115.
Basal area, survivor growth	1.6745	0.0092927	0.0	-0.065752	0.38	1.01
Basal area, ingrowth	5.0763	-0.013659	-0.079917	0.0	0.41	0.16
Basal area, mortality	-7.1667	0.014940	0.063312	0.0	0.24	0.24

[1] $Y = \exp(b_0 + b_1B + b_2S + b_3D)$, B = basal area, S = site index, and D = maximum dbh.

[2] Fit index $= 1 - \Sigma(y_i - \hat{y}_i)^2 / \Sigma(y_i - \bar{y})^2$.

more pronounced the longer a stand has been under uneven-aged silviculture. Tubbs (1977) reported on the change in age structure of a virgin northern hardwood stand after it was managed by single-tree selection. The correlation between dbh and tree age was 0.40 before management in 1929 but increased to 0.94 after 47 yr of management. In even-aged stands, growth increases, reaches a maximum, and then decreases in relation to age. Moreover, the region of decreasing growth dominates the latter portion of stand development. Therefore, if maximum dbh can be used as a surrogate for age in uneven-aged stands, some measures of growth would logically decrease as maximum dbh increases.

The effects of maximum dbh on board-foot growth for the Doyle rule differ from the other volume growth measurements. However, the Doyle rule underestimates volume in smaller dbh classes, and Doyle volume increases more dramatically with an increase in dbh than the other principal log rules at smaller dbh's. Thus, this volume underestimation for smaller diameters apparently offsets the decline in growth usually attributed to age.

The components of basal area growth—survivor growth, ingrowth, and mortality—are affected differently by basal area, site index, and maximum dbh as seen in Table 1. Survivor growth is affected by initial basal area and maximum diameter; the implicit effect of tree age is expressed in the negative term for maximum diameter. Ingrowth is adversely affected by basal area and site index. It seems reasonable that higher basal areas would inhibit ingrowth of smaller stems. The effect of site index is not as straightforward. Two causes appear plausible. First, the development of seedlings and saplings is probably more suppressed on the better sites because of the more vigorous competing vegetation. Second, the plots on the better sites probably had fewer submerchantable pine stems before the study was installed because of this competition. Basal area mortality is also influenced by site index and basal area. Mortality probably increases with basal area because of the greater competition for growing space. Stand development probably proceeds faster on better sites, which might cause more mortality.

The fit indexes, analogous to coefficient of determination, range from 0.24 to 0.51, which are not very high. Growth is a much more difficult variable to predict than accumulated basal area or volume. Ingrowth, a significant and continuous factor in uneven-aged stands, also makes growth more variable and difficult to predict. In contrast, ingrowth is a transitory phenomenon in even-aged stands. Productivity in uneven-aged stands is sustained by ingrowth, and if ingrowth stops, the stand will lose its uneven-aged character as time passes.

The current model predicts an annual merchantable growth of 117 ft^3/ac for an initial basal area of 60 ft^2/ac and maximum diameter of 16 in. This growth is greater than the 80 ft^3/ac/yr average previously reported (Murphy and Farrar 1982a) for stands located on the Crossett Experimental Forest in south Arkansas. However, this prediction is close to a mean of 107 ft^3/ac/yr for industrially managed uneven-aged loblolly pine stands in southeast Arkansas (Farrar et al. 1989).

Site index has a small but perceptible effect on sawtimber cubic-foot growth. An uneven-aged loblolly pine stand with an initial basal area of 60 ft^2/ac, a maximum dbh of 16 in., and a site index of 85 ft will have a periodic annual growth in sawtimber of 113 ft^3/ac. At times sawtimber ft^3 growth can exceed merchantable growth, which is an artifact of the ingrowth-outgrowth relationships that occur between the sawtimber and subsawtimber components of merchantable growth. The subsawtimber component can experience an outgrowth into the sawtimber component, which may result in negative net growth for that component. The outgrowth may not be compensated for by ingrowth from submerchantable trees or growth of the remaining subsawtimber component. In contrast, the sawtimber component has no outgrowth into a larger size class, receives ingrowth as long as stand structure is maintained, and also experiences growth of the existing sawtimber component.

Figure 2 illustrates board-foot growth, Doyle rule, for different initial basal areas, maximum diameters, and site indexes. Site index affects growth to some extent, and a stand with a larger maximum diameter will have more growth than a stand with a smaller one. For site indexes of 85 ft and above, moderate densities of about 60 ft^2/ac, and maximum diameters of at least 16 in., annual production should be about 400 bd ft/ac or more. This level compares favorably with the long-term annual production of the Farm Forestry Forties on the Crossett Experimental Forest of 404 bd ft/ac (Reynolds et al. 1984).

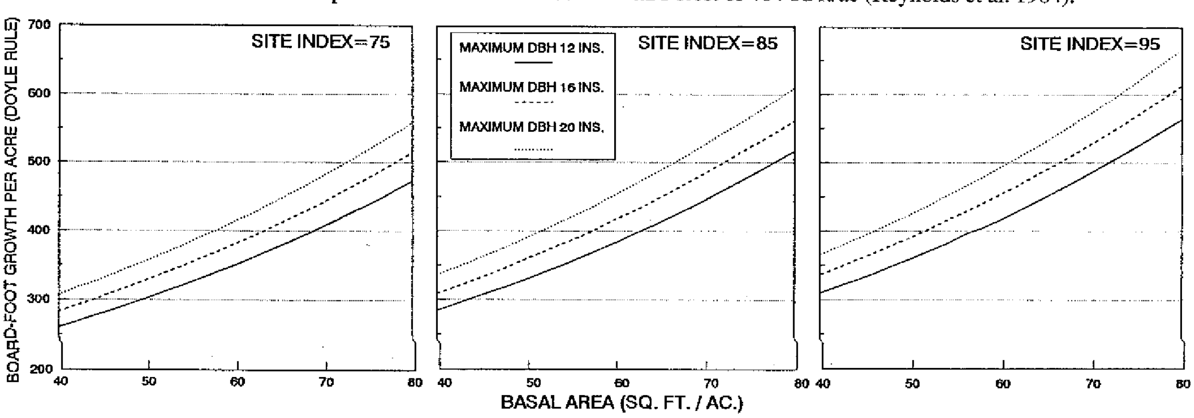

Figure 2. Net annual board-foot volume growth, Doyle rule, as affected by initial basal area, maximum diameter, and site index in uneven-aged loblolly pine stands.

Net basal area growth—the sum of survivor growth and ingrowth—varies from a little more than 2 ft^2/ac to more than 5 ft^2/ac annually (Figure 3). Note that the effect of site index on net basal area growth is very small. This growth range agrees with the overall average of 3 ft^2/ac of annual growth reported by Murphy and Farrar (1982a) for uneven-aged loblolly–shortleaf pine stands in south Arkansas.

Conclusion

Uneven-aged silviculture using single-tree selection is a viable option for loblolly pine, but little information has been available for the growth characteristics of these stands, particularly as they are affected by site index and maximum dbh. The results presented here provide an initial glimpse into the growth dynamics of these stands to managers. Although this study evaluates a residual basal level of 80 ft^2/ac, experience to date indicates that loblolly pine cannot be sustained in uneven-aged stands at this level, because this density is too high for reproduction to become established and to develop into merchantable sizes. As this study continues, evidence will accumulate as to the feasible operating ranges for growing and sustaining uneven-aged loblolly pine stands. It is also not known whether the adverse effect of site index on ingrowth will persist as the study progresses. The reader is reminded that these results are from the first 5 yr remeasurement of a new study and should be regarded as preliminary.

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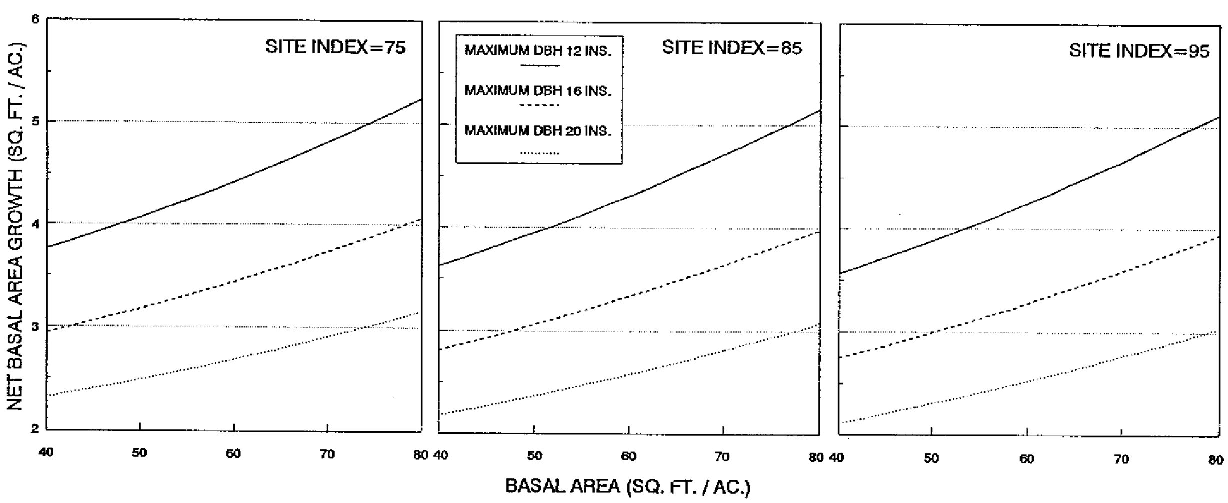

Figure 3. Net annual merchantable basal area growth as affected by initial basal area, maximum diameter, and site index in uneven-aged loblolly pine stands.