GROWTH AND YIELD OF SHORTLEAF PINE

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ABSTRACT

A survey of available growth and yield information for shortleaf pine (Pinus echinata Mill.) is given. The kinds of studies and data sources that produce this information are also evaluated, and an example of how a growth and yield model can be used to answer management questions is illustrated. Guidleines are given for using growth and yield models, and needs for further research are outlined.

INTRODUCTION

Shortleaf pine (Pinus echinata Mill.) has the largest range of the southern pines and ranks second only to loblolly pine (Pinus taeda L.) in terms of inventory volume in the South. However, the quantity of growth and yield information for shortleaf is minuscule in relation to its importance as a resource and to the volume of information available for the other three major southern pines. Some information is available for natural stands and unthinned old-field plantations. The present data for natural stands need to be supplanted by better information, and new data must be developed for thinned plantations on both old-field and nonold-field sites. The main impediment to producing new information is the lack of data from well designed, comprehensive field investigations. Fortunately, there are efforts underway to install these desperately needed studies.

The benefits of growth and yield information are more difficult to quantify than the more tangible results from other research, such as forest genetics. Growth and yield results are used primarily as a basis for decisionmaking. But the conclusions reached with the benefit of growth and yield models can have far-reaching social and economic consequences. The selection of a rotation length, thinning schedules, harvest scheduling, choice of species, regeneration densities, growing stock levels, method of regeneration (natural, direct seeding, or planting), even mill or plant location--all depend on growth and yield data. Hopefully, the more complete and accurate the information, the more informed and accurate the final decision.

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CLASSIFYING GROWTH AND YIELD INFORMATION

Before taking a look at what information is available, it is instructive to look at how growth and yield studies can be classified. One way is to look at their purpose--descriptive, inferential, and predictive. Descriptive studies are the most elementary and are primarily observations of some unusual phenomenon, such as a description of a timber stand with exceptional stocking.

Inferential studies are statistically designed experiments for answering a question such as, "What residual basal area--60, 90, or 120 square feet per acre--results in the largest cubic-foot volume growth?" These studies are usually limited in the numbers of variables that are under investigation so that the field experiment does not become too large or expensive.

Predictive studies are designed to produce mathematical models; they are also statistically designed to observe the range of variables of interest. The models are used to project growth and yield given certain stand and site characteristics--such as stand age, stand density, and site quality. Predictive studies are more comprehensive than inferential ones; more variables are usually included. In an inferential study, site quality may be of no interest, and its effect may be controlled by blocking or some other statistical design technique. In a predictive study, site may be a primary variable, and plots will be located across the range of sites. Because predictive studies are more comprehensive, they are larger, more expensive, and require a large organizational commitment in terms of manpower, time, and money. It is not unusual for growth and yield studies to have more than 200 plots and span decades of time. Ideally, these studies should run through a rotation. Only rotation-length experiments will reveal definitively how a stand will respond over its life to a given thinning treatment. The great demand on resources is the main reason that few predictive studies have been installed. Their success depends upon the research sponsor having a long-time horizon.

Sometimes several inferential studies can be combined to produce a predictive study. But the data are usually not completely compatible, and important treatment combinations may be missing.

Both inferential and predictive studies are controlled experiments. But, as we have seen, they can be expensive and time consuming, especially predictive ones. Consequently, another strategy is to use inventory data to develop growth and yield models. These data usually come from continuous forest inventory systems that are maintained by government agencies or forest industries. Though the data may have been accurate and adequate for the original purpose, there are several limitations for growth and yield model development: (1) there are no plot isolations, (2) important variables may not have been measured, (3) a large number of plots must be available so that a sufficient number are left after they are screened to eliminate unwanted plots, (4) rare situations may not have been sampled, (5) there is usually a limited knowledge of the plot history, and (6) the growth and yield predictions of the models may not be those that can be realized from managed stands.

Despite these limitations, these data are invaluable for obtaining interim results. Models can be developed immediately for conditions for which there are no installed studies, and subsequent controlled studies can be designed better using the knowledge gained by developing these interim models. There is a considerable time lag from when a study is installed until growth information is available. If the remeasurement period is 5 years and the study is installed over a 3-year period, then it may be 8 to 10 years before results are available. Models developed from inventory plots can be used during the interim.

Another topic related to data is that some models have been developed using temporary plot data, while others have used permanent plots. You have to make judicious and sometimes heroic assumptions (to borrow a phrase from the economists) to use these models for projections.

Models can be classified into three main types--stand level, size-class distribution, and individual tree. Stand-level models need only a few variables but usually give yields on a aggregate stand basis. For example, a natural even-aged model might require input values of age, site, and density, but will project only cubic- and board-foot volumes on a per-acre basis.

Size-class distribution models may require more input variables, but will provide more detailed information in terms of stand and stock tables. Individual tree models are the most data demanding. Individual-tree measurements--such as diameter and height--must be provided, but individual tree identities are maintained and their attributes are projected. More detail is provided than is probably needed by the casual user. Size-class and individual-tree models do possess an advantage over the stand-level ones with regard to model development. It is much easier to expand the models to include other variables--such as the effects of genetics, disease, or fertilization.

AVAILABLE INFORMATION

The following discussion will be confined to either comprehensive predictive studies or long-term inferential studies as outlined in table 1. Williston's selected growth and yield bibliography (1975) gives a good account of growth and yield information up to about 1974, but this publication is almost out-of-print. Thus, for the reader's convenience, Williston's citations for shortleaf pine are included in the reference section at the end of the paper with some exceptions: references in which loblolly pine was the predominant species have been deleted. An effort was also made to include all papers published since 1974 to provide a current, comprehensive bibliography on shortleaf pine growth and yield.

Natural Even-aged Stands

The grandfather of all southern pine growth and yield information for natural even-aged shortleaf pine is the venerable USDA Forest Service Miscellaneous Publication 50 (USDA Forest Service 1929). It is based on the concept of normal stocking, which is the density at which a stand is producing the maximum cubic-foot volume of wood. Yields are given by age and site index classes in a series of tables. The information is from 188 temporary plots scattered across the South (table 1). Miscellaneous Publication 50 (Misc. Publ. 50) has been supplanted by more recent studies, but its site index curves are still used and it also serves as a valuable reference for research purposes.

The second major growth and yield model for shortleaf was Schumacher and Coile (1960). The equations were much easier to use than the tabular data of Misc. Publ. 50, but there were also some weaknesses. Like Misc. Publ. 50, it uses a somewhat subjective stocking standard that Schumacher and Coile called "well stocked". The data are from 74 temporary plots from a small geographic locality (table 1). It can be used for projections provided you are willing to make some assumptions about how stocking percentages develop over time. Despite its limitations, it has been widely used since its availability to the public.

The use of a stocking standard, such as normality, was abandoned by growth and yield researchers in favor of presenting yields by an array of densities instead of an idealized one. Until Murphy and Beltz (1981) and Murphy (1982), variable density yield information for a variety of sites and ages had not been available for natural even-aged shortleaf pine. The data came from permanent inventory plots maintained in Arkansas, Louisiana, east Oklahoma, and east Texas by the Forest Inventory and Analysis Unit of the Southern Forest Experiment Station (table 1). Given stand basal areas, stand age, and site index, the equations can give projected basal areas and current and projected stand volumes. The models have the limitations of those based on inventory data, which have already been described.

The preceding models have been stand level ones. An individual tree model has been developed by the USDA Forest Service, North Central Forest Experiment Station, 1992 Folwell Avenue, St. Paul, MN 55108, for Indiana, Illinois, and Missouri. Available in a microcomputer software package called TWIGS (table 1), it was also developed from inventory data.

An inferential study that has provided valuable information over the years has been one maintained by the North Central Forest Experiment Station on the Sinkin Experimental Forest in Missouri (Brinkman and others 1965, Sander and Rogers 1979, Rogers and Sander 1985). Four residual basal area treatments and a control were replicated three times on a 30-year-old natural shortleaf pine stand (table 1).

Natural Uneven-aged Stands

Until recently, information was very skimpy for growth and yield of uneven-aged stands of either pure shortleaf pine or where shortleaf pine predominated. Gibbs (1958) reported on the 10-year growth of mixed shortleaf-loblolly pine stands in east Texas. Other reported information has been for Coastal Plain stands in which loblolly predominates by a wide margin. Murphy and Farrar (1985) have recently published an uneven-aged shortleaf growth and yield stand-level model. Given site index and initial merchantable and sawtimber basal areas, one can obtain projected basal areas and current and projected cubic- and board-foot volumes. It was developed from inventory data and should be used with this fact in mind.

Plantations

Models for plantations can generally be categorized by being for old-field versus nonold-field (or forest) sites and for thinned versus unthinned stands. The first models were for unthinned old-field plantations. Large acreages of abandoned agricultural fields were planted to pine, but were not usually thinned. We are just beginning to see models being developed for thinned plantations on nonold-field sites.

The first plantation model was developed by Ralston and Korstian (1962) for predicting pulpwood volumes of unthinned plantations in the North Carolina Piedmont. Only 18 of the 66 plots in the study were from shortleaf plantations: the rest were loblolly plantations. The combined data from the two species were used to derive the model. It is a stand-level model and uses number of trees, basal area, average stand diameter, and cordwood/basal-area ratios associated with different dominant stand heights.

The most comprehensive shortleaf pine plantation model was developed by Smalley and Bailey (1974) for unthinned old-field stands in the Tennessee, Alabama, and Georgia Highlands. It is a size-class distribution model and gives stand and stock tables for different sites, planting densities, and ages from seed.

In addition to these two models, results from a variety of inferential studies have been published over the years. Arnold (1975, 1981), Boggess (1958), Boggess and Gilmore (1963), Boggess and McMillan (1953), Boggess et al. (1963), Gilmore and Boggess (1969), Gilmore and Gregory (1974), and Gilmore and Metcalf (1961) have reported on studies in southern Illinois. Williston has written of studies in Tennessee and north Mississippi (1959, 1963, 1967, 1972, 1983, 1985). Williston and Dell (1974) provide periodic annual increment equations for plantations in north Mississippi for ages 20 to 35 based upon two 5-year remeasurements of a field survey established by the Yazoo-Little Tallahatchie Flood Prevention Project in 1959.

Tree Volume and Biomass Equations

Determining individual tree product volumes and biomass is a necessary adjunct to growth and yield. Several references about this subject are listed in the bibliography. Baldwin (1982), McNab and others (1982), and Phillips (1982) provide excellent bibliographies on biomass estimation of individual trees. Walters (1982) gives taper, green weight and volume equations for shortleaf pine in east Texas. A comprehensive taper function will be published soon for shortleaf pine in natural stands for Louisiana, Arkansas and east Oklahoma (Farrar and Murphy in preparation).

AN EXAMPLE

Some possible applications of growth and yield information have already been mentioned. The following example shows how a growth and yield model can be used in decisionmaking. The recently published uneven-aged model (Murphy and Farrar 1985) for shortleaf pine will be used as an illustration. The input variables are initial merchantable and sawtimber basal areas and elapsed time (or cutting cycle).

Many private nonindustrial timberlands brought under management are understocked. The problem is to increase stocking while simultaneously providing the landowner a periodic income under a variety of constraints. One common harvesting constraint is that there must be an operable cut of, say, at least a 1,000 board feet per acre (Doyle rule). The models can be used to derive a management strategy with these objectives and constraints.

For example, suppose a tract of uneven-aged shortleaf pine is to be brought under management. The site index for shortleaf is 70 feet (base age 50) on the property, and the current stand has 45 square feet per acre in merchantable basal area and 25 square feet per acre in sawtimber basal area. The desired management regime is a 7-year cutting cycle and residual densities of 60 and 45 square feet for merchantable and sawtimber basal areas, respectively. How might this property be managed to bring the stand up to these stocking goals while providing a periodic cut that is at least 1,000 board feet (Doyle rule)?

A proposed strategy is to maintain a 7-year cutting cycle, cut 75 percent of growth, and see if the harvesting constraint is observed. To use the model for this problem, future basal areas are projected first. The basal area that can be cut is computed from growth, and then residual basal area is found by subtraction. Before- and after-cut stand volumes are calculated using basal area and site index in the stand volume equations. A table of before-cut, cut, and after-cut basal areas and volumes can then be calculated for the planning period.

The stand will be allowed to grow for 7 years before the first harvest. The periodic growth for the first 7-year period is 61.1 minus 45.0, or 16.1 square feet. If 75 percent of periodic growth is to be harvested, then 12.1 square feet of merchantable basal area will be cut, with 49.0 square feet remaining. The whole process is repeated for subsequent cutting cycles until the stocking goal is reached. The following tabulation summarizes the cyclic harvests and residual densities for merchantable basal area:

	Merchantable Basal Area		
Growth period	Before cut	Cut	After cut
years	----------------	ft^2	----------
0	45.0	-	45.0
7	61.1	12.1	49.0
14	64.9	11.9	53.0
21	68.7	11.8	56.9
28	72.3	12.3	60.0
35	75.1	15.1	60.0

The residual stocking goal for merchantable basal area is reached in 28 years, and regular cyclic cuts for merchantable basal area and volume take place after that.

The cutting schedule for sawtimber basal area is computed next. The projected sawtimber basal area in 7 years, given initial basal areas of 45 square feet for merchantable trees and 25 square feet for sawtimber trees, is 39.1 square feet. The periodic growth is 39.1 minus 25.0, or 14.1 square feet per acre, and the first cycle cut for sawtimber basal area is 75 percent of periodic growth: 10.6 square feet. Values for subsequent cutting cycles are determined in the same manner. The following tabulation may be constructed,

Sawtimber Basal Area			
Growth period	Before cut	Cut	After cut
years	ft^2		
0	25.0	-	25.0
7	39.1	10.6	28.5
14	42.9	10.8	32.1
21	46.6	10.9	35.7
28	50.3	11.0	39.3
35	53.9	11.0	42.9
42	57.6	12.6	45.0
49	59.7	14.7	45.0

The residual stocking goal for sawtimber basal area is reached in 42 years, two cutting cycles later than for merchantable basal area. The cyclic harvest for maintaining sawtimber basal area is 14.7 square feet after the stocking goal is reached.

Now that merchantable and sawtimber basal areas have been determined, volumes can be calculated. With an initial volume of 853 cubic feet, the volume in 7 years would be 1,201, and the residual volume would be 938 cubic feet. The harvest is determined by subtracting after-cut from before-cut volumes. The remaining values are determined in a like manner. The following tabulation can now be constructed for merchantable cubic-foot volume:

Merchantable Cubic-foot Volume			
Growth period	Before cut	Cut	After cut
years	ft^3, i.b.		
0	853	0	853
7	1,201	263	938
14	1,285	260	1,025
21	1,370	261	1,109
28	1,451	274	1,177
35	1,514	337	1,177

After the stocking goal is reached in year 28, the cyclic harvest for merchantable volume would approximate 337 cubic feet; periodic annual growth, 48 cubic feet.

The initial cubic volume for sawtimber is 469 cubic feet. When subsequent volumes and cuts have been calculated, the following table can be developed:

Sawtimber Cubic-foot Volume			
Growth period	Before cut	Cut	After cut
years	---------ft^3, i.b.-----------		
0	469	0	469
7	786	241	545
14	875	249	626
21	962	255	707
28	1,051	260	791
35	1,139	264	875
42	1,230	306	924
49	1,281	357	924

After the stocking goal for sawtimber is reached in year 42, the periodic cut would be about 357 cubic feet for sawtimber; periodic annual growth, about 51 cubic feet.

When the board-foot volumes (Doyle rule) for the the planning period are calculated, the following tabulation can be assembled:

Doyle Board-foot Volume			
Growth period	Before cut	Cut	After cut
years	-------------fbm-------------		
0	1,722	0	1,722
7	3,072	1,032	2,040
14	3,464	1,084	2,380
21	3,855	1,124	2,731
28	4,256	1,164	3,092
35	4,655	1,191	3,464
42	5,072	1,387	3,685
49	5,313	1,628	3,685

After the residual stocking goal is reached, the periodic cut would be 628 board feet (Doyle rule), and the periodic annual growth would approximate 233 board feet per acre. Notice that all the cuts are more than 1,000 board feet, so the harvesting constraint is satisfied by this management strategy.

The following harvest schedule is for sawtimber volume using the Scribner rule:

Scribner Board-foot Volume			
Growth period	Before cut	Cut	After cut
years	-----------------	fbm	-----------
0	2,734	0	2,734
7	4,746	1,533	3,213
14	5,321	1,600	3,721
21	5,892	1,650	4,242
28	6,474	1,698	4,776
35	7,051	1,730	5,321
42	7,652	2,008	5,644
49	7,998	2,354	5,644

The periodic cut would be 2,354 board feet (Scribner rule) after the residual stocking goal is reached, and periodic annual growth would average 336 board feet.

The board-foot volumes, International 1/4-inch rule, are:

International 1/4-inch Board-foot Volume			
Growth period	Before cut	Cut	After cut
years	---------------	fbm	-------------
0	3,084	0	3,084
7	5,361	1,736	3,625
14	6,013	1,812	4,201
21	6,660	1,869	4,791
28	7,320	1,925	5,395
35	7,973	1,960	6,013
42	8,655	2,277	6,378
49	9,047	2,669	6,378

After the cyclic harvest levels are stabilized, the periodic cut would average 2,669 board feet (International 1/4-inch rule). Periodic annual growth would approximate 381 board feet.

A variety of other strategies could have been used to rehabilitate the stand. For example, half the growth could be cut provided that the harvest were at least 1,000 board feet (Doyle rule). If an operable volume were not present, the cycle cut could be deferred. The cutting cycle length in this case would be variable. This example is only one of infinitely many ways that growth and yield models can be used.

CAVEATS FOR THE USER

Some users have become disappointed or disillusioned after using models that predict yields greater than what can be expected in practice or what they may consider unrealistic. These shortcomings can be rectified by following certain practices.

Before using a model, read the instructions and carefully observe which variables are being used. Is site index or height of the dominant stand used for the site quality variable? For plantations, is the age calculated from planting or from seed? Are the data used in the model from your geographic area or are they from another part of the South? If the study was done elsewhere, beware. Validate some of the predictions before you place your trust in the model.

Remember that models predict averages, not for the individual. Hopefully, as the number of cases increase, the average will be close to that predicted for the model.

If models are going to be applied to specific stands, you should do the following (Burkhart 1982): (1) stratify the area into reasonably homogeneous stands according to the variables used by the model (for example, age, site, and basal area), (2) make your growth and yield projections separately for each stand, (3) observe the same merchantability standards that are used by the model, (4) deduct nonproductive areas (like large openings) before expanding per-acre estimates to a stand basis, and (5) deduct for cull and defect since estimates are for gross volumes.

INFORMATION NEEDS

It is obvious that much remains to be done. The published data for natural even-aged stands comes from inventory data or temporary plots: there is a serious need for the establishment of a permanent plot growth and yield study for predictive purposes in managed stands of shortleaf pine. This same need exists for uneven-aged conditions. There is also an acute need for the same kind of study in both old field and nonold-field thinned plantations.

New models that will be developed should be capable of producing stand and stock tables, similar to Smalley and Bailey (1974), for merchantability standards specified by the user. There will also be an increasing demand for models that can predict the effects of more intensive management, such as the use of genetically improved planting stock and fertilization. The recent concern over atmospheric deposition has highlighted the need to produce models that can incorporate additional variables so that atmospheric deposition and other effects can be addressed. Permanent plots from controlled studies can also provide valuable baseline data for investigating these kinds of problems.

Despite the past neglect of shortleaf by the research community, some encouraging trends should be noted. The USDA Forest Service has a cooperative study underway between Region 8, headquartered in Atlanta, GA, and the Southern Forest Experiment Station, headquartered in New Orleans, LA, to establish a long-term growth and yield study for natural even-aged shortleaf pine in the Ozark and Ouachita National Forests. There is also an effort by Southern Forest Experiment Station researchers to combine shortleaf plantation data from several older studies in an attempt to develop a model for thinned stands. Southern Forest Experiment Station researchers involved in shortleaf pine reforestation studies are designing their outplantings of families and mixed families so that growth and yield information may also be gathered.

With these and other efforts, perhaps the forgotten species of the major southern pines will attain a much deserved better status in terms of research knowledge.

Table 1.--Summary of major growth and yield studies of shortleaf pine.

Author or publication[1]	Location	Plots[2]	Study type	Model type
		---Natural even-aged---		
Misc. Publ. 50 (1929)	12 southern states	188-T	Controlled Predictive	Tables
Schumacher & Coile (1960)	NC Piedmont	74-T	Controlled Predictive	Stand level
Murphy (1982) Murphy & Beltz (1981)	AR, LA, OK, TX	153-P	Inventory Predictive	Stand level
TWIGS	IN,IL,MO	1500 trees	Inventory Predictive	Individual tree
Brinkman et al. (1965) Sander & Rogers (1979) Rogers & Sander (1985)	Missouri thinning study	5-P	Controlled Inferential	
		---Natural uneven-aged---		
Gibbs (1958)	East Texas	5-P	Controlled Inferential	
Murphy & Farrar (1985)	Central Arkansas	149-P	Inventory Predictive	Stand level

[1]See the text for the appropriate citation.
[2]Number denotes number of plots; P=permanent plots; T=temporary plots.

Table 1.--Summary of major growth and yield studies of shortleaf pine (continued)

Author or publication[1]	Location	Plots[2]	Study type	Model type
		---Plantation---		
Ralston & Korstian (1962)	NC Piedmont	66-T	Controlled Predictive	Stand level Unthinned, old-field
Smalley & Bailey (1974)	AL,GA,TN Highlands	104-T	Controlled Predictive	Size-class Unthinned, old-field
Arnold (1975, 1981) Boggess (1958) Boggess & Gilmore (1963) Boggess et al. (1963) Gilmore & Boggess (1969) Gilmore & Gregory (1974) Gilmore & Metcalf (1961)	Southern Illinois	P	Controlled Inferential	
Williston (1959, 1963 1967, 1972 1983, 1985)	north MS, TN	P	Controlled Inferential	
Williston & Dell (1974)	MS, YLT	88-P	Inventory Growth survey	Growth equations

[1]See the text for the appropriate citation.
[2]Number denotes number of plots; P=permanent plots; T=temporary plots.

REFERENCES

The following is an up-to-date list of publications relating to shortleaf pine growth and yield and related topics--such as tree volumes, tree biomass, and site quality. Citations preceded with a caret (^) are cited in the text and those followed by an asterisk (*) appeared in Williston's (1975) bibliography.

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PROCEEDINGS

of

Symposium on the Shortleaf Pine Ecosystem

LITTLE ROCK, ARKANSAS

MARCH 31 - APRIL 2, 1986

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