RESTORING THE SHORTLEAF PINE–BLUESTEM GRASS ECOSYSTEM ON THE OUACHITA NATIONAL FOREST: AN ECONOMIC EVALUATION

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PREFACE

This dissertation quantifies some of the economic consequences of attempting to augment the red cockaded woodpecker population on the Ouachita National Forest in western Arkansas by restoring the ecosystem that emphasizes their habitat. It provides greater detail than previously published works regarding the tradeoffs of restoring an entire ecosystem. The goal of the analysis is to provide the USDA Forest Service with a framework for estimating the effects of this ecosystem restoration on 1) stand growth and yield, 2) timber sale values and revenue, 3) the regional economy, and 4) management costs.

The analysis begins by combining a system of growth and yield equations for shortleaf pine and hardwoods into a stand simulator. This simulator predicts the volume of wood available for harvest from both traditional even-aged management and the new management system, called the shortleaf pine-bluestem grass management. Comparing the harvest volumes forecast under both scenarios provides a sense of how the forested stands will respond to the new management regime.

In the second phase of the analysis, historical timber sales serve as the foundation for deriving values for the harvest volumes forecast by the stand simulator. Again, comparing the timber sale values predicted for each regime gives an indication of the amount of revenue that the Forest Service will forego by converting to the new scenario.

The third aspect of the analysis uses input-output analysis to estimate the regional economic impact caused by the adoption of the new management scenario. The regional

analysis also identifies the economic sectors most likely to be affected by the reduction in economic activity.

Finally, forest management – particularly timber sale marking and prescribed burning – costs are explored. The intent is to predict the amount by which costs may change as a result of adopting the new management scenario.

ACKNOWLEDGEMENTS

Proverbs 3:6 (KJV) states, “In all your ways acknowledge [the LORD], and He will direct your paths.” It has been both humbling and encouraging to review the past decade, and see how God has led me to this juncture. I am honored to have been in the company of Drs. Thomas Lynch, Robert Wittwer and David Lewis – as well as the rest of the Forestry Department faculty. Their desire for my advancement allowed me to pursue this degree. Dr. Daniel Tilley, my major professor, patiently supplied advice and constructive criticism. The other committee members – Drs. Thomas Lynch, David Lewis and Dean Schreiner – provided invaluable aid and often lightened my load by recommending simpler analysis techniques.

To Meredith, my wife, you have been a real blessing. You, Kathryn and John have made the greater sacrifice in this endeavor. Thank you for putting up with an often-absent husband and father. To my parents and in-laws, thank you for your ceaseless prayers and boundless generosity.

Special appreciation is extended to Dr. James Guldin, and the USDA Forest Service-Southern Research Station, for arranging the grant (Agreement No. SRS 33-CA-99-615) that helped make this research project possible.

I also owe a debt of gratitude for the Forestry Department’s commitment to development by the professional staff. Financial assistance from the Agricultural Economics Department was also greatly appreciated. Finally, the institutional support of

the Oklahoma Agricultural Experiment Station allowed me to complete the requirements of the Ph.D. program while employing me full time. Thank you for considering me worthy of the investment.

While I don't consider myself to be a great man, and I doubt graduate students were in mind when this poem was written, the words certainly have a familiar ring:

> *The heights by great men reached and kept*
> *Were not attained by sudden flight,*
> *But they, while their companions slept*
> *Were toiling upward, through the night.*
>
> – Henry Wadsworth Longfellow

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NOMENCLATURE

BA	Basal area
CCF	Hundred cubic feet
dbh	Diameter at breast height
d.i.b.	Diameter inside bark
d.o.b.	Diameter outside bark
i.b.	Inside bark
IO	Input-output
IMPLAN	Impact analysis for planning
MBF	Thousand board feet
MTE	Mean temperature exposure
o.b.	Outside bark
PPI	Producer price index
RCW	Red-cockaded woodpecker
RPC	Regional purchase coefficient
SI	Site index

CHAPTER 1

INTRODUCTION

Problem Statement

Red Cockaded Woodpecker Decline

The red-cockaded woodpecker (*Picoides borealis* Vieillot) population in eastern Oklahoma and western Arkansas is in serious decline. The species was first listed as endangered in the autumn of 1970 (US Fish and Wildlife Service 2000). One reason for the decline is that RCWs are particularly selective about their habitat, requiring open stands of large-diameter pines, with few or no trees in the midstory (Masters 1989). Also, they nest only in live pines infected with red-heart disease caused by the fungus *Phellinus pini* (Brot.:Fr.) A. Ames.

Humans have also played a significant role in the RCW's near extinction. The logging boom during the early years of the 20th century decimated open stands of virgin pine that were prime woodpecker habitat. Successful wildfire-suppression programs later allowed the once-open stands to develop a substantial mid-story component, effectively eliminating much of the remaining habitat (Smith and Neal 1991).

Program for Recovery: Amendment 22

Concerned because earlier efforts to recover the endangered RCW were largely unsuccessful, the USDA Forest Service decided to undertake a more aggressive restoration program. Thus, the Forest Service began a process in 1989 that culminated in an amendment to the land and resources management plan for the Ouachita National Forest (USDA Forest Service 1996a). This amendment, called Amendment 22, proposed allocating 155,010 acres (9.4 percent of the entire Ouachita National Forest area) to a new management area. Amending the forest plan was justified on the basis of a need "to recover the endangered red-cockaded woodpecker, [and] renew the shortleaf pine-bluestem ecosystem ... on National Forests in the Southern Region" (USDA Forest Service 1996a). The amendment was approved in July 1996 (USDA Forest Service 1996b).

By creating this new management area, the Forest Service underscored the importance of sufficient, appropriate habitat in increasing the woodpecker population. In very general terms the desired future stand conditions in this new management area can be described as containing large, scattered shortleaf pine (*Pinus echinata* Mill.) and hardwood stems, with herbaceous vegetation – especially big- and little-bluestem grasses (*Andropogon* spp.) – in the understory (Wolters et al. 1977, Reed and Noble 1987). This plant community is called the shortleaf pine – bluestem grass, or pine-bluestem, ecosystem.

Key Elements. Management Area 22, as it has come to be called, is located in Scott and Polk Counties of western Arkansas, just across the border from Oklahoma (Figure 1.1). Its management plan includes the following actions:

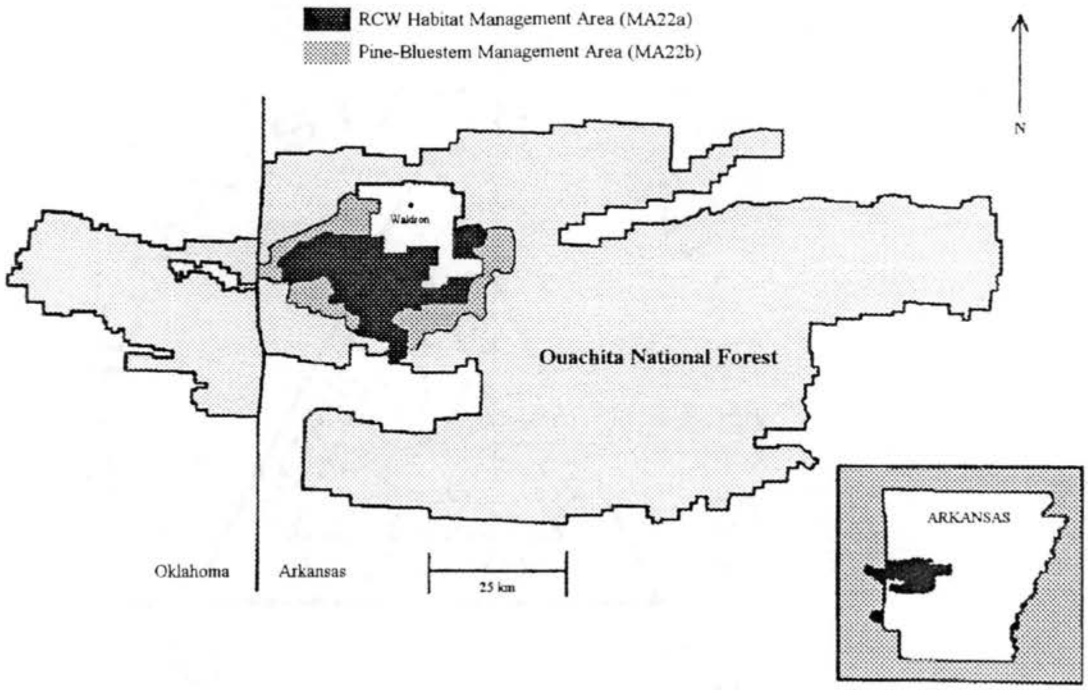

Figure 1.1. Location of the areas dedicated to red-cockaded woodpecker (RCW) and shortleaf pine – bluestem grass ecosystem recovery on the Ouachita National Forest (from USDA Forest Service 1996a).

- Dedicates roughly half of the management area to RCW recovery (MA22a in Figure 1.1), and emphasizes renewal of the pine-bluestem ecosystem on the remainder of the area (MA22b). Management in the two sub-areas is essentially the same, except that Area 22b allows for expanded timber harvesting and does not require the immediate designation of RCW recruitment stands.
- Removes from timber production 2,220 acres that will be used as RCW recruitment stands.

- Extends the planned rotation age for stands in the management area to 120 year (from the usual 70).
- Allows for the increased use of prescribed burning – including during the growing season – and midstory reduction treatments.
- Establishes a policy of allowing certain wildfires to burn to the nearest natural or man-made barrier unless human life or private property is endangered by doing so.

The documentation associated with Amendment 22 did not completely or clearly answer several questions. Among them are: 1) Will the new silvicultural prescriptions imposed upon Management Area 22 measurably alter the volume of timber available for removal? 2) To what degree will revenue and cost streams be affected? 3) What effects may this amendment to the Forest Plan have on the economic vitality of the region including and surrounding the Ouachita National Forest?

Study Goal

The goal of this study is to answer the questions listed at the end of the previous section and, in the process, provide the Forest Service with a framework for better communicating the biological and economic impacts of future forest plans and amendments. It also seeks to provide information on how shortleaf pine trees respond to two different management regimes, and the economic consequences of transitioning from one regime to the other.

This study is unique in the academic literature in that it explores the effects of restoring an ecosystem, ranging from changes in the growth patterns of individual trees to the level of the region's economy. It also attempts to provide the Forest Service with a method by which to more clearly document the procedures used when quantifying the biological and economic impacts of restoring an entire ecosystem.

Study Organization

Chapter 2 contains an overview of ecosystem management as viewed by the Forest Service. It also describes various methods proposed by researchers for assigning values to the services provided by natural ecosystems.

The questions are addressed in separate chapters. Chapter 3 relates to the question of changes in physical output. It describes the methods whereby stand-level information about Management Area 22 was generated. It also references the mathematical models used to simulate the growth and yield of stumpage. Finally, it compares the accumulation of growing stock and product yields under the traditional and pine-bluestem management scenarios.

Chapter 4 describes differentiated-input price theory and its application to the development of an equation for forecasting timber sale values. Also included is an explanation of the procedure used to aggregate the administrative compartments of Management Area 22 into hypothetical timber sales. The revenues generated by both the traditional and pine-bluestem scenarios are compared.

Chapter 5 presents the theory of input-output analysis, and describes the model used to trace the effects of changes in timber sale output and revenue through the regional economy. Changes in other sectors' output, value added and employment are described.

Chapter 6 presents comparisons of cost streams between the two scenarios, brings together the results of the previous chapters, and presents implications for the management of Area 22. Chapter 7 contains final comments, and presents areas for further research.

CHAPTER 2

EVALUATION OF ECOSYSTEM MANAGEMENT ALTERNATIVES

Introduction to Ecosystem Management

What is Ecosystem Management?

The waning years of the 20th century brought with them mounting concern over the increased pressures exerted on natural resources, and whether those resources were being, or could be, managed in a sustainable manner. Particularly at the federal level this concern led to a shift in resource management philosophy from production of food, fiber and forage to protection, restoration and management of ecosystems (Prato 1999). In the context of forestry, the philosophy has assumed several names (e.g., sustainable forestry, biodiversity retention, new perspectives, etc.); it is now most commonly referred to as "ecosystem management" (Thomas 1997).

The shift to ecosystem management has been rationalized in the following ways (Daily 1997): 1) For a biophysical system to sustain itself, all component parts must be present and healthy; even those components not providing market-valued ecological services have existence value[1] because they contribute in some, perhaps unknown, way to the overall system's health. 2) Since the ranges of most species transcend man-made

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[1] Following Krutilla (1967), existence value is here defined as "having intrinsic value independent of any direct benefit or harm to humans" (Stevens et al. 1991).

ownership or political boundaries, their management should also occur at broader scales (e.g., at watershed, rather than stand levels) than has been the case in the past; efforts should include slowing or reversing the process of habitat fragmentation.

While recognizing the importance of economics in sustainability (Backiel 1994, Allen and Hoekstra 1995), ecosystem management has sought to de-emphasize the production of market-valued resources (especially timber and species of game animals) and, instead, to sustain the entire constellation of characteristics and organisms that comprise an ecosystem – including humans (Thomas 1997). Commodity extraction is consistent with ecosystem management, but only as an ancillary or subordinate goal (Callicott 2000).

To summarize, ecosystem management is "a concept for dealing with larger spatial scales, longer time frames and many more ecological, economic and social variables than have commonly been considered in past management approaches" (Thomas 1997). Put another way, ecosystem management "attempts to maintain the complex processes, pathways, and interdependencies of forest ecosystems intact, and functioning well, over long periods of time" (Norris et al. 1993).

How does the restoration of red-cockaded woodpecker habitat and the shortleaf pine-bluestem grass forest type qualify as ecosystem management? It qualifies insofar as this undertaking probably would not have been attempted much beyond the recent past. The lack of economic incentive alone would have doomed the idea in its infancy. Available literature ascribes no direct or indirect economic value to the RCW. In addition, maintaining stands of shortleaf pine trees at low densities well beyond their financial maturity appears inefficient from a revenue-generation standpoint. The pine-bluestem restoration qualifies as ecosystem management because of the Forest Services' emphasis on non-market resources, the length of the planning horizon, and the scale of the effort.

Information Needs in Ecosystem Management

In many respects, ecosystem management is an expansion of traditional principles. In order to undertake such management, then, the Forest Service needs much the same information as it required in the past. Ideally this would include:

- A complete inventory of species in the United States, along with their past and present natural ranges; also, a complete inventory of land forms and other natural features (which, for some species, might include migratory areas outside the U.S.), and their correlation with these species.
- Biophysical models indicating how these different species interact with themselves and one another, and influence each others' populations; also models specifying how incremental changes in their habitats affect short- and long-term population survival.
- Methods for assigning values to the contribution that each species makes toward the health of the overall system.
- Models estimating the economic interrelationships within and between regions of the U.S.

In other words, ecosystem management requires all of the information used in the past, but on a larger (and simultaneously, smaller) scale.

In order to carry out its mandate to restore the red-cockaded woodpecker habitat and pine-bluestem forest type, the Ouachita National Forest needs a complete inventory of Management Area 22. Such an inventory should include land ownership types, natural and man-made land forms, plant and animal (including humans) species and their distribution. The Forest Service must also understand the association and interrelationships of the species with one another, and with the land around them. The effects of different management practices need to be quantified. Finally, the economic activities within the region, the region's relations to other geographic areas, and the potential impacts of management changes must be understood.

This dissertation deals with a small part of the overall picture described above. It seeks to provide information on how shortleaf pine trees respond to two different management regimes, and the economic consequences of transitioning from one regime to the other.

Evaluating Ecosystem Management Alternatives

Management alternatives have been evaluated in many different ways (Davis and Johnson 1987). Despite their abundance, the evaluation methods can be separated into two basic categories – one stressing the output(s) and the other emphasizing the decision-making process. Contingent valuation is one example of a method that stresses the outputs. It has been used to value endangered species and wilderness areas whose values come primarily from existence rather than active use (McFadden 1994). In these studies, a researcher creates a hypothetical market for a good or service, and then elicits individuals' willingness to pay for that good or service. Specific applications include valuing northern spotted owl (*Strix occidentalis caurina)* habitat (McKillop 1992), comparing the value of land for grazing elk (*Cervus elaphus*) versus beef cattle (Corey and Martin 1985), and estimating the value of recreational opportunities (Gibbs et al.

1979), including by individuals who either will not, or are uncertain whether they will make use of those opportunities (Corey et al. 1988, Silberman et al. 1992).

Contingent-valuation studies have been criticized on several fronts. Respondents are not actually required to pay, and thus there is no way to validate their valuations (McKillop 1992). This method is often employed to measure the value of passive use; but the concept of value may be unclear to survey respondents when the commodity or service under question is not directly linked to an observable consumption activity (Bjornstad and Kahn 1996). Typically, values are solicited for a single commodity, often with an abbreviated or stylized description that assumes the respondent can call upon prior knowledge (McFadden 1994). Some researchers feel this single-attribute valuation technique is poorly suited for evaluating the diverse impacts arising from resource management decisions (Prato 1999).

Closely related to contingent valuation is the technique of cost-benefit analysis. In this method, all costs and benefits occurring over a given planning horizon are discounted back to a common point in time (Klemperer 1996). Although useful when evaluating projects with clearly defined market-valued outputs (e.g., Busby et al. 1995) and short time frames, cost-benefit analysis has drawbacks that make it less attractive for ecosystem management applications. First is the bias caused by omitting impacts that are unforeseen or difficult to measure. Also, cost-benefit analysis suffers from the same problem as contingent valuation in that outputs not exchanged in markets are difficult to value. Third, ecosystem management projects often have high initial costs and uncertain long-term benefits (Prato 1999); in such cases, discounting disproportionately weights the costs. Finally, Goulder and Kennedy (1997) point out that because cost-benefit analysis is primarily an economic efficiency measure, it ignores fundamental issues of fairness and distribution – particularly between current and future generations.

The other class of evaluation methods emphasizes the process of obtaining a management plan as much or more than the outputs the plan creates. That all stakeholders have an opportunity to participate in a plan's formulation is at least as important as the outcome represented by the plan. One example of this class of methods is called multiple-attribute decision making. This technique has been used in diverse situations, from awarding research proposals (King et al. 1990), and screening water resources systems investments (Cohon and Marks 1973, Haimes and Hall 1974), to selecting land and water resource management systems (Prato 1999). The process used to develop national forest resource management plans incorporates many characteristics of multiple-attribute decision making. An ecosystem management application might involve the following steps (after Prato 1999): 1) identify technically feasible management alternatives, based on economic and biophysical considerations; 2) select the attributes to be used in the evaluation process; 3) derive the attributes' values from biophysical and economic models; 4) specify socially acceptable ranges of attributes based on the public's preferences; 5) derive efficient combinations of attributes, generally with the assistance of a decision-support system; 6) select the most preferred combination of attributes and, by extension, the management alternative.

Proponents of multiple-attribute decision making argue that this tool is superior to either contingent valuation or cost-benefit analysis because it facilitates public participation, and is well suited for collaborative decision making (Yaffee and Wondolleck 1997) and scientific assessments (Johnson 1997). They claim this technique maintains the diversity of criteria and objectives associated with complex decisions, and does not require assigning monetary values to ecological services. These characteristics allow a broader perspective than cost-benefit analysis' classical utilitarian view of optimality (Prato 1999). Proponents admit, however, that multiple-attribute decision making may be difficult to apply on public lands because managers have to assuage diverse groups who often hold conflicting interests.

This dissertation makes no attempt to select a preferred management alternative. That decision has already been made by the Ouachita National Forest. Instead, this study attempts to fulfill the requirement by the Forest and Rangeland Renewable Resources Planning Act of 1974 to provide an assessment "of present and potential renewable resources, ...together with estimates of investment costs and direct and indirect returns to the federal government." It also discusses "important...factors expected to influence and affect significantly the...management of forest...lands" in Management Area 22.[2] To that end the study evaluates the incremental changes in physical outputs, revenue and management costs, and the distribution of effects on the region's economic activity caused by the adoption of the pine-bluestem management scenario.

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[2] 16 U.S.C. 1600-1614 §3(a)(2,4).

CHAPTER 3

GROWTH AND YIELD PROJECTIONS IN MANAGEMENT AREA 22

Stands on the Ouachita National Forest designated as "pine" or "pine-hardwood" typically carry between 70 and 100 ft^2/ac of basal area (BA), with 80 percent of that BA in pine.[1] Rotations are set at 70 yr, although this upper limit is not firmly enforced. In Management Area 22, however, the Forest Service intends to replicate stand conditions similar to those pictured in Matoon (1915, p. 17) and described in accounts written by early European explorers and elsewhere (e.g., du Pratz 1774, Lewis 1924, Nuttall 1980, Foti and Glenn 1991). Specifically (USDA Forest Service 1996a, Appendix G), pine BA will generally exceed 60 ft^2/ac; stands left uncut for several entry periods might retain over 100 ft^2/ac. Hardwoods will comprise between 10 and 30 percent of the stand (in terms of either stems per acre if average diameter < 5 in., or stand BA if diameter ≥ 5 in.), with an average of about 15 percent. The goal is to produce as many older ($\geq$50 yr) stands as possible with 60 ft^2/ac of pine BA and 10 ft^2/ac of hardwood BA. Rotations will be lengthened to 120 yr. Regeneration cuts will reduce pine BA to 40 ft^2/ac.

To augment the differences between traditional and pine-bluestem management, this study employed slightly lower residual BA limits in the pine-bluestem scenario: for commercial thinnings, residual pine BA was set at 45 ft^2/ac; for regeneration cuts, 30

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[1] Personal communication, Jack Courtenay, USDA Forest Service silviculturalist, 9 August 1999.

ft^2/ac. In practice, then, the Forest Service will observe less dramatic results than those reported here.

The questions addressed in this chapter are: How do the physical outputs from traditional and pine-bluestem management compare? Will the lighter stocking and longer rotations of the pine-bluestem scenario reduce volume production? We begin by reviewing growth and yield modeling techniques. Next, the data and methods are described. Finally, results are compared.

Techniques of Growth and Yield Modeling

Forecasting the future states of forested stands has long been an important element of forest management. Most of the early modeling work in shortleaf pine was based on temporary plots assumed to be fully stocked (Lynch et al. 1999). Examples include USDA Miscellaneous Publication 50 (USDA Forest Service 1929), and Schumacher and Coile (1960). By the mid-1960s, however, stand-level growth equations were being developed from periodically remeasured stands. Brinkman (1967) published volume equations for stands that had been measured at 15-yr intervals. Forest Inventory and Analysis plots provided the basis for creating stand-level models that can be applied to a range of forest conditions (Murphy and Beltz 1981, Murphy 1982, Miner et al. 1989).

Thinning studies also provide useful information. Although individual studies (e.g., Brinkman et al. 1965, Sander and Rogers 1979, Rogers 1983, Rogers and Sander 1985, Lynch et al. 1991, Murphy et al. 1992, Wittwer et al. 1996) sometimes cover a limited range of stand attributes, thinning studies as a class are advantageous for the following reasons: 1) plots are usually located in managed stands; thus, plot histories are generally known; and 2) other outcome-influencing factors are controlled to the extent possible (Lynch et al 1999).

Description of the Simulator

This study employs a more recent development in growth and yield modeling: equations describing the behavior of individual trees or classes of trees. This technique is advantageous in that it can achieve levels of specificity unmatched by stand-level equations. Lynch et al. (1999) used this technique when developing a model for even-aged, natural shortleaf pine in the Ouachita Highlands. Their model consists of a system combining equations for estimating BA growth, probability of survival, heights of dominant and codominant trees (site index), total height, crown ratio, and volume. These equations have been compiled in a computer program called the Shortleaf Pine Stand Simulator, or SLPSS (Huebschmann et al. 1998). For this study the SLPSS software was modified to include hardwood growth equations and the probability of mortality from fire in order to more accurately reflect actual conditions in Management Area 22. Appendix A contains detailed descriptions of the shortleaf and hardwood growth and yield models. Appendix B gives a brief overview of fire-related literature, and the methods used to quantify the effects of prescribed fire (including mortality) in the pine-bluestem stands.

The basic input to the simulator consists of initial stand conditions in the form of either a stand table (number of trees by diameter class and species group) or inventory data from field plots. If stand table data are input, the simulator uniformly distributes the trees within a diameter class in 0.1-in. increments.

Each tree (or group of trees in a diameter-class increment) is grown on a year-by-year basis. The simulator begins by estimating each tree's annual BA growth increment and probability of survival. A tree survives the year if its probability of survival exceeds the value of a uniformly distributed random number, restricted to the interval [0,1], generated for that tree. If a prescribed burn is conducted, the probability of girdling is computed for each tree. Again, a tree survives the fire if its probability of survival (1 - probability of girdling) exceeds the value of a uniformly distributed random number, restricted to the interval [0,1], generated for that tree.

The simulator next estimates the average total height of the dominant and codominant shortleaf pine trees, based on user-supplied site index values. That value is used to compute the total height of every other shortleaf in the stand. Each tree's crown ratio is also predicted. Finally, each shortleaf pine's total, pulpwood and sawtimber volumes are computed. Hardwood heights and volumes are similarly estimated.

The simulator allows considerable flexibility in the way thinnings can be conducted. Excess trees can be removed via "low" thinnings (i.e., starting with the smallest tree and removing progressively larger stems until the desired BA is reached), or else by specifying the number of stems to remove in a particular diameter class. Low thinnings were used exclusively in this study to favor retention of the largest-diameter stems.

Management Area 22 Stand Information

The Ouachita National Forest silviculturalist provided a dataset containing basic information about the stands included in Management Area 22. Variables in the dataset included compartment and stand numbers, stand condition, the year in which the stand was regenerated, forest type (pine or pine-hardwood), site index (i.e., the height of dominants and codominants at age 50 yr), BA (ft^2/ac) of shortleaf and hardwood sawtimber- and pulpwood-size trees, ocularly estimated average diameter at breast height (in.) of shortleaf and hardwood sawtimber- and pulpwood-size trees, and the BA of hard-mast trees.

Although Management Area 22 covers 155,010 ac, not every acre will be managed for pine-bluestem. The actual land area upon which the pine-bluestem restoration is to occur encompasses approximately 99,400 ac in 1,826 stands across 109 compartments. The remaining area is composed of roads, riparian areas, or stands containing no shortleaf pine.

The Management Area 22 stand dataset is a management, rather than a research dataset; thus it contained a considerable number of anomalies and missing values. What follows are the steps used to correct those errors and fill in the missing values. The biophysical and economic outcomes reported in this study are strongly influenced by the initial conditions assigned to the stands in Management Area 22.

Changes Made to the Management Area 22 Dataset

Stands classified as "in regeneration" were reclassified as "mature sawtimber" if they contained shortleaf sawtimber BA. Many of the remaining "in regeneration" stands had not been assigned shortleaf or hardwood pulpwood BAs. These stands were arbitrarily assigned 55 ft^2/ac of shortleaf pulpwood BA and 15 ft^2/ac of hardwood pulpwood BA if the forest type was "mixed pine-hardwood," or 60 ft^2/ac of shortleaf pulpwood BA and the average hardwood pulpwood BA of similar stands if the forest type was "pure shortleaf." The hard-mast BA was assigned to hardwood pulpwood BA if the former exceeded the sum of hardwood pulpwood and sawtimber BAs.

Stands classified as "sparse sawtimber" were assigned 3 and 24 ft^2/ac of shortleaf pulpwood and sawtimber BA, respectively, and 3 ft^2/ac of hardwood sawtimber BA. These values are the averages of similarly classified stands.

If stands classified as "mature sawtimber" reported missing shortleaf sawtimber values, they were assigned shortleaf and hardwood pulpwood and sawtimber values in the following way: If a compartment contained two stands with the same forest type and similar birth years, and one stand reported a missing shortleaf sawtimber BA value, that stand was assigned the nonmissing-value stand's values. If a compartment contained several "mature sawtimber" stands, stands with missing shortleaf sawtimber BA values were assigned the averages of the nonmissing-value stands of the same forest type in that compartment. Finally, if all the "mature sawtimber" stands in a compartment reported missing values, they were assigned the averages of stands that had the same forest-type code and birth years within the same 20-year interval. For example, if a pure shortleaf stand had a birth year of 1908, it was assigned the average values of pure shortleaf stands with birth years greater than 1890 but less than or equal to 1910. If a stand's hard-mast BA exceeded the sum of hardwood pulpwood and sawtimber BA, and the sum of hardwood pulpwood and sawtimber BA was less than 2 ft^2/ac (there was a noticeable break between stands with sums less than 2 ft^2/ac and those with sums greater than 2 ft^2/ac), the pulpwood BA was set equal to the hard-mast BA value. Otherwise, the hard-mast value was considered in error, and set equal to the sum of the hardwood pulpwood and sawtimber BA.

Stands classified as "immature poletimber" were treated in much the same manner as the "mature sawtimber" stands mentioned above. In addition, stands with birth years between 1969 and 1979 and shortleaf sawtimber BA greater than 10 ft^2/ac had their birth-year values decreased by 10 years. The rationale for doing so is that the Weibull parameters (see the following section) estimated for the 20-yr age class generate sawtimber BAs of less than 5 ft^2/ac. If a stand's hard-mast BA exceeded the sum of hardwood pulpwood and sawtimber BA, and the sum of hardwood pulpwood and sawtimber BA was less than 5 ft^2/ac, the sum was considered to be an error. The pulpwood BA was set equal to the hard-mast BA value. Otherwise, the hard-mast value was considered in error, and set equal to the sum of the hardwood pulpwood and sawtimber BA.

Stands classified as "immature sawtimber" were treated in much the same way as the "mature sawtimber" stands mentioned above. In addition, if a stand's hard-mast BA exceeded the sum of hardwood pulpwood and sawtimber BA, and the sum of hardwood pulpwood and sawtimber BA was less than 3 ft^2/ac, the sum was considered to be an error. The pulpwood BA was set equal to the hard-mast BA value. Otherwise, the hard-mast value was considered in error, and set equal to the sum of the hardwood pulpwood and sawtimber BA.

Stands classified as "seedling/sapling – adequately stocked" were reclassified as "mature sawtimber" if they contained shortleaf sawtimber BA; their birth years were also moved back 50 years. Alternatively, if a "seedling/sapling" stand contained only shortleaf pulpwood BA, it was reclassified as "immature poletimber." Finally, if a "seedling/sapling" stand's hard-mast BA exceeded the sum of hardwood pulpwood and sawtimber BA, and the sum of hardwood pulpwood BA was less than 3 ft^2/ac, the sum was considered to be an error. The pulpwood BA was set equal to the hard-mast BA value. For those stands with hardwood pulpwood and sawtimber BA greater than 3 ft^2/ac, the hard-mast value was considered in error, and set equal to the sum of the hardwood pulpwood BA.

Several stands had no reported birth year. A stand with a missing birth year was assigned the average birth year of its stand-condition and forest-type combination. E.g., a mixed pine-hardwood stand considered "in regeneration" was assigned the average birth year of stands with similar characteristics. A number of stands also had missing site index values. They were assigned the average site index value of their respective compartments. A preferable method would have been to calculate an average for each forest type within a compartment, but upon occasion, the only stand with a particular forest type within a compartment was also the stand with a missing site index value. Hardwood site index values were estimated to be 5 ft less than shortleaf values. Finally, each stand was then classified by stand age and shortleaf BA class combinations (Table 3.1) for this phase of the study. Management Area 22 is composed primarily of stands in the 20- or 80-yr age classes, with pine BA falling in the 60- and 90-ft^2/ac classes.

Estimating Weibull Parameters

Because the Management Area 22 dataset contained only BA estimates, but the simulation software requires stand tables as input, diameter distributions were generated for each stand. The best information available for accomplishing this task comes from the study described in Lynch et al. (1991, 1999) of 215 permanent research plots located in the Ouachita Highlands. These plots had been categorized into the same age and BA classes as shown in Table 3.1. This section describes how Weibull parameters were

Table 3.1. Number of stands in Management Area 22 and their associated acreage, by initial shortleaf pine basal area and stand age class combination. This classification scheme was used when assigning diameter distributions to the stands.

Age class (yr)	Class range (yr)	Basal area class[*] (ft^2/ac) 30 (<46)		60 (46-75)		90 (76-105)		120 (>105)		Total	
		Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres
20	<31	57	2,976	460	25,647	5	179	--[†]	--[†]	522	28,802
40	31-50	10	404	66	3,156	15	908	3	116	94	4,584
60	51-70	23	1,172	119	6,915	68	3,509	33	1,320	243	12,916
80	>70	27	1,141	408	22,860	442	24,227	90	4,878	967	53,106
Total		117	5,693	1,053	58,578	530	28,823	126	6,314	1,826	99,408

[*] Class ranges in parentheses.

[†] No stands or acreage in this combination.

recovered from diameter distributions representing the research plot data, and used to generate diameter distributions for the Management Area 22 stands.

The Weibull is a three-parameter distribution defined by the probability density function:

$$f(X) = \frac{c}{b}\left(\frac{X-a}{b}\right)^{c-1} \exp\left[-\left(\frac{X-a}{b}\right)^{c}\right] \quad (a \leq X < \infty) \tag{3.1}$$
$$= 0, \text{ otherwise}$$

where *a*, *b* and *c* are the location, scale and shape parameters, respectively. The *b* and *c* parameters must always be positive while, for diameter distributions, the *a* parameter need merely be nonnegative. This function defines the amount of probability density associated with each possible value of the random variable *X*. The closed form of the cumulative distribution function is:

$$F(X) = 1 - \exp\left[-\left(\frac{X-a}{b}\right)^{c}\right] \quad (a \leq X < \infty) \tag{3.2}$$
$$= 0, \text{ otherwise}$$

Thus, the probability that *X* is between some arbitrary lower (*L*) and upper (*U*) bounds – i.e., $P(L< X <U)$ – is $F(U)$ - $F(L)$, or:

$$P(L < X < U) = \exp\left[-\left(\frac{L-a}{b}\right)^{c}\right] - \exp\left[-\left(\frac{U-a}{b}\right)^{c}\right] \tag{3.3}$$

Percentile estimation is one method of recovering Weibull parameters (Clutter et al. 1983). This method is accomplished by sorting in ascending order the diameters of trees in a sample (in this case one or more plots), and accumulating the proportion of the total number of trees in the sample from smallest to largest tree. By equating two percentiles to their respective Weibull cumulative distribution functions, and using the minimum diameter at breast height (dbh) as the location parameter (a), one can solve for b and c. Let X_p represent the p-percentile in the sample (i.e., the diameter at which percentile p occurs). Applying Equation (3.3) yields:

$$p = 1 - \exp\left[-\left\{(X_p - a)/b\right\}^c\right]$$

which, when solved for X_p, gives:

$$X_p = a + b\left[-\ln(1-p)\right]^{1/c} \qquad (3.4)$$

The 24th and 93rd percentiles theoretically yield the most efficient estimates (Dubey 1967). A lack of trees in some older, sparsely populated plots resulted in coarse percentile increments. The 87th was the largest percentile present in every age- and BA-class combination, and thus was chosen for this procedure. The 24th and 87th percentiles yield:

$$X_{.24} = a + b\left[-\ln(1-.24)\right]^{1/c}$$

$$X_{.87} = a + b\left[-\ln(1-.87)\right]^{1/c}$$

which can be rearranged to give:

$$c = \frac{\ln\left[\ln(1-.24)/\ln(1-.87)\right]}{\ln\left[(X_{.24} - a)/(X_{.87} - a)\right]} \qquad (3.22)$$

$$b = \left[\frac{X_{.87} - a}{\left\{-\ln(1-.87)\right\}^{1/c}}\right] \qquad (3.23)$$

Weibull parameters (Table 3.2) were recovered for each combination of stand age and shortleaf pine BA class represented in Lynch et al.'s (1991, 1999) dataset. These parameters were, in turn, used to generate shortleaf pine diameter distributions in stands with corresponding age- and BA-class combinations in the Management Area 22 dataset.

Because the plots mentioned in Lynch et al. (1991, 1999) did not contain hardwoods, and no other hardwood dataset was available, the percentile method could not be used for recovering hardwood Weibull parameters. A variant of method-of-moments estimation (Johnson and Kotz 1970) also failed to yield usable parameters, primarily because the Management Area 22 dataset did not contain sufficient information. Consequently, coefficients (Table 3.2) were manually chosen so that the resulting hardwood diameter distribution in each combination of stand age and shortleaf BA classes matched the hardwood quadratic mean diameters in the pulpwood and sawtimber size classes, as well as the proportions of total hardwood BA in the two product classes.

Table 3.2. Weibull parameters used to generate shortleaf pine and hardwood diameter distributions for the Management Area 22 stands, by stand age and shortleaf BA class combinations.

Age class	Pine BA class	Weibull parameters					
		Shortleaf pine			Hardwoods		
		a	*b*	*c*	*a*	*b*	*c*
20	30	2.1	2.92	1.76	4	6.34	2.65
	60	1.1	3.73	2.45	4	6.24	3.40
	90	1.1	3.74	2.06	4	2.81	1.20
	120*	1.2	3.32	1.93	-	-.-	-.-
40	30	5.8	4.37	1.74	5	6.00	3.00
	60	3.2	6.22	2.61	5	5.70	3.01
	90	2.0	6.28	2.56	5	5.75	3.00
	120	1.8	6.40	2.75	6	8.01	5.30
60	30	7.8	5.69	2.44	6	5.15	3.00
	60	4.4	8.31	3.12	6	4.15	1.55
	90	2.8	9.23	3.25	6	3.95	1.68
	120	1.8	8.70	3.05	5	4.10	1.50
80	30	9.6	5.16	2.01	5	5.15	1.80
	60	5.0	9.07	3.54	5	5.15	1.80
	90	3.9	9.98	3.76	5	5.19	1.93
	120	3.8	9.18	2.70	5	5.19	2.02

*Stands with this combination of characteristics reported no hardwood.

It should be noted again that the methods used to estimate initial stand conditions in this study substantially affect the outcome of the simulations. In other words, the volumes produced by these stands and the revenues they generate might have been different if other methods, or other Weibull parameters, had been used to create the initial stand conditions.

After creating shortleaf and hardwood diameter distributions for each stand in Management Area 22, the stands were combined into "metastands" according to another, more detailed classification scheme (Table 3.3) for purposes of growth simulation. I.e., the characteristics of individual stands with similar class-variable combinations were averaged to create one representative, or "meta" stand. For example, the 150 individual stands with the age class = 70 yr, site index class = 60 ft, and pine BA class = 90 ft^2/ac were averaged into a single metastand. This second classification scheme allowed the variation in total tree height resulting from differences in site quality to be expressed when estimating metastand volumes. Also, the narrower age classes allowed better control over the length of individual simulations; the metastands were ideally to be grown to age 120 yr under the pine-bluestem scenario, or 70 yr under the traditional management scenario. The computational burden was thus reduced from 1,826 individual stands, comprising the Management Area 22 data, to fewer than 100 metastands in the initial round of simulations.

Growth Projections

Pine-bluestem scenario. Growth simulations were conducted for a 100-yr-long period, beginning in the year 2000, and continuing until 2100. The growth models referenced earlier in this chapter do not reliably project growth of stands younger than

Table 3.3. Number of stands in Management Area 22 and their acreage, by initial stand age and shortleaf pine basal area, and shortleaf site index classes.

Stand age class* (yr)	Site index class† (ft)	Basal area class* (ft^2/ac)								Total	
		30 (<46)		60 (46-75)		90 (76-105)		120 (>105)			
		Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres
20 (<26)	50	5	303	30	1,376	–††	–††	–	–	35	1,679
	60	36	1,910	369	21,511	1	45	–	–	406	23,466
	70	15	685	59	2,714	3	114	–	–	77	3,513
	80	–	–	–	–	–	–	–	–	0	0
	Total	56	2,898	458	25,601	4	159	0	0	518	28,658
30 (26-35)	50	2	107	4	164	5	200	1	66	12	537
	60	5	288	33	2,094	5	294	1	31	44	2,707
	70	–	–	6	235	2	170	1	19	9	424
	80	–	–	–	–	2	73	–	–	2	73
	Total	7	395	43	2,493	14	737	3	116	67	3,741
40 (36-45)	50	–	–	1	112	1	140	–	–	2	252
	60	1	24	13	391	1	51	–	–	15	466
	70	–	–	8	150	–	–	–	–	8	150
	80	–	–	1	19	–	–	–	–	1	19
	Total	1	24	23	672	2	191	0	0	26	887

Table 3.3. (Continued)

Stand age class* (yr)	Site index class† (ft)	Basal area class* (ft²/ac) 30 (<46) Stands	Acres	60 (46-75) Stands	Acres	90 (76-105) Stands	Acres	120 (>105) Stands	Acres	Total Stands	Acres
50 (46-55)	50	2	67	3	214	2	124	–	–	7	405
	60	8	316	14	717	4	259	2	108	28	1400
	70	1	11	3	109	4	251	2	49	10	420
	80	–	–	1	8	–	–	–	–	1	8
	Total	11	394	21	1,048	10	634	4	157	46	2,233
60 (56-65)	50	5	302	13	886	6	300	2	102	26	1,590
	60	6	352	46	2,148	22	831	16	650	90	3,981
	70	1	50	2	70	5	256	1	26	9	402
	80	–	–	1	17	1	15	–	–	2	32
	Total	12	704	62	3,121	34	1,402	19	778	127	6,005
70 (66-75)	50	2	56	18	1,562	28	2,256	5	264	53	4,138
	60	17	907	146	7,805	150	8,387	34	1,649	347	18,748
	70	2	74	21	1,291	9	417	4	91	36	1,873
	80	–	–	–	–	3	58	–	–	3	58
	Total	21	1,037	185	10,658	190	11,118	43	2,004	439	24,817

Table 3.3. (Continued)

Stand age class* (yr)	Site index class† (ft)	Basal area class* (ft^2/ac)								Total	
		30 (<46)		60 (46-75)		90 (76-105)		120 (>105)			
		Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres
80 (76-85)	50	–	–	8	560	19	861	2	265	29	1,686
	60	5	96	166	9,514	160	8,040	39	1,845	370	19,495
	70	1	40	28	2,403	23	1,534	2	151	54	4,128
	80	–	–	–	–	–	–	–	–	0	0
	Total	6	136	202	12,477	202	10,435	43	2,261	453	25,309
90 (86-95)	50	–	–	3	248	7	435	4	373	14	1,056
	60	2	81	24	867	45	2,351	6	439	77	3,738
	70	–	–	19	850	7	767	1	21	27	1,638
	80	–	–	–	–	–	–	–	–	0	0
	Total	2	81	46	1,965	59	3,553	11	833	118	6,432
100 (96-105)	50	–	–	–	–	–	–	1	10	1	10
	60	–	–	9	382	8	372	1	78	18	832
	70	–	–	1	10	–	–	–	–	1	10
	80	–	–	–	–	–	–	–	–	0	0
	Total	0	0	10	392	8	372	2	88	20	852

Table 3.3. (Continued)

Stand age class* (yr)	Site index class† (ft)	Basal area class* (ft^2/ac) 30 (<46)		60 (46-75)		90 (76-105)		120 (>105)		Total	
		Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres	Stands	Acres
110 (>105)	50	–	–	1	59	–	–	–	–	1	59
	60	1	24	2	92	6	151	1	77	10	344
	70	–	–	–	–	1	71	–	–	1	71
	80	–	–	–	–	–	–	–	–	0	0
	Total	1	24	3	151	7	222	1	77	12	474
Grand total		117	5,693	1,053	58,578	530	28,823	126	6,314	1,826	99,408

*Class ranges in parentheses.

†Site index class ranges are 50: <56; 60: 56-65; 70: 66-75; 80: >75 ft.

††No stands or acreage in this combination of classes.

about 15 years of age. Consequently, for stands younger than the 20-yr age class in 2000, the Management Area 22 dataset provided initial conditions for simulation in either 2010 or 2020 when the stands achieved the 20-yr age class. Growth simulation for a particular metastand continued until either age 120 yr or the year 2100 was reached, whichever occurred first.

Metastands with age classes between 20 and 110 yr were grown until they reached age 120 yr, at which time a new generation of trees was assumed to occupy the stands. Figure 3.1 illustrates the life cycle of a hypothetical stand that was 60 yr old in 2000. Beginning in 2000, and at 10-yr intervals thereafter, each metastand was evaluated to determine whether pine or hardwood BA levels exceeded the allowable limits (70 and 20 ft^2/ac, respectively). If the limits were exceeded, a low thinning cut BA levels back to the minimum allowable levels (45 and 15 ft^2/ac for pine and hardwoods, respectively) for intermediate thinnings. Otherwise, the stand was left to grow for another decade. This conforms with current Poteau Ranger District policy of entering each stand once per decade.[2] When the stand reached the 110-yr age class a regeneration cut reduced the BA to 30 and 10 ft^2/ac for pine and hardwood, respectively. The remaining overstory served as a seed source for the next generation of trees.

Prescribed burning was conducted in each metastand every 3 yr, beginning in 2001, except for during the regeneration phase. During the last 8 yr of a first-generation metastand (which also corresponds to years 2-10 of the second generation), fire was excluded to allow the regeneration to grow. After the second-generation stand reached an age of 10 yr, the burning cycle resumed.

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[2] Personal communication, John Strom, USDA Forest Service silviculturalist, 10 August 1999.

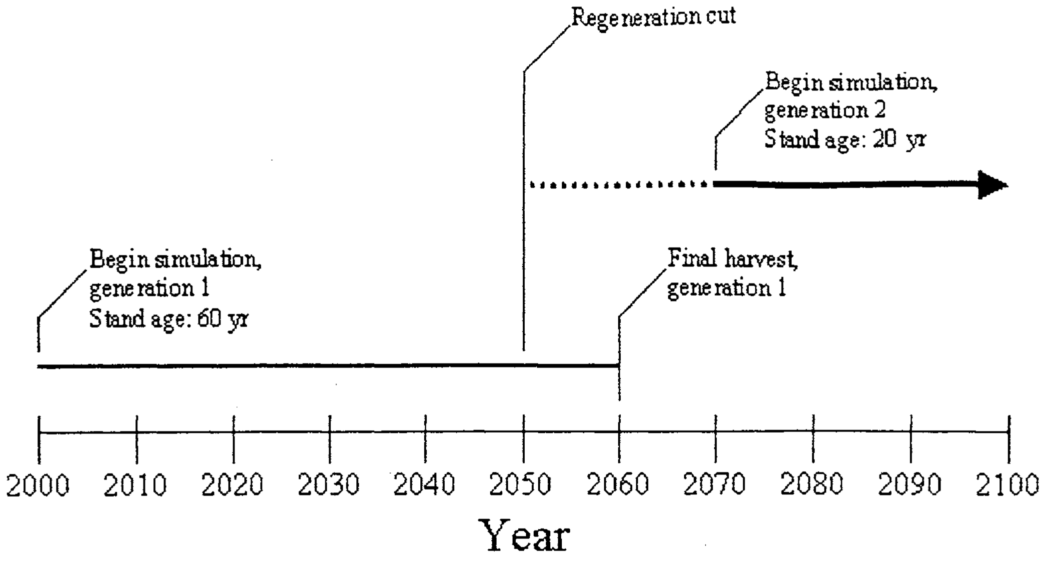

Figure 3.1. Life cycle of a hypothetical 60-yr-old metastand managed under the pine-bluestem scenario.

Metastands already in the 110-yr age class in 2000 were immediately thinned from below to simulate a regeneration cut, burned in 2001, and allowed to grow until 2010. In 2010, the remaining overstory stems were removed, and the regeneration was burned for the first time. Simulation of the second-generation growth commenced in 2020 when the saplings reached age 20 yr, and continued until 2100.

When beginning the second-generation growth simulation, metastands were assumed to contain 70 ft^2/ac BA in pine and hardwoods combined. That BA was distributed as indicated in Table 3.4. These values are within the range observed by Lynch et al. (1999) and Nkouka (1999) for stands in the Ouachita Highlands.

Traditional scenario. As in the pine-bluestem scenario, simulations projected stand growth between the years 2000 and 2100. The main difference with this scenario was that the target stand rotation age was 70 yr instead of 120. As a result, this scenario required three rounds of simulations – instead of two, as in the pine-bluestem scenario – for all stands to reach the year 2100.

Table 3.4. Initial conditions in 20-yr-old, subsequent-generation metastands, used for both pine-bluestem and traditional management scenarios, by shortleaf site index class.

Site index class (ft)	Basal area (ft^2/ac)		% of hardwood BA in hard mast species
	Shortleaf	Hardwood	
50	65	5	50
60	60	10	40
70	55	15	30
80	50	20	20

The BA levels of each metastand were checked once each decade, beginning in 2000, to determine whether they exceeded the limits (90 and 40 ft^2/ac for shortleaf and hardwoods, respectively) of this scenario. Stands with excessive BA were thinned from below to 70 and 20 ft^2/ac (pine and hardwoods, respectively), the minimum BA allowed in this scenario for intermediate thinnings. Once a metastand reached age 60 yr, a regeneration cut reduced the BA to 30 and 15 ft^2/ac (pine and hardwood, respectively), opening up the stand for natural regeneration.

Traditional management of natural, even-aged shortleaf pine stands in the Ouachita National Forest calls for prescribed burns to be conducted every four years. Consequently, a 4-yr burning cycle was used in this scenario, beginning in 2000. Only during the last 7 yr of a metastand's regeneration phase was the burning cycle stopped. Once regeneration reached 10 yr of age, the burning cycle was resumed.

Metastands already in or beyond the 60-yr age class when simulations began in 2000 were immediately thinned for regeneration, burned and allowed to grow until 2010.

At that time, the remaining stems were removed. The regeneration in these stands was burned in 2012. Growth simulations resumed in 2020, when the regenerated stands achieved age 20 yr. Initial conditions in the second- and third-generation metastands were assumed to be the same as those already mentioned in the pine-bluestem scenario (see Table 3.4 above).

Example stand-level comparison. Table 3.5 displays the merchantability specifications used in this study. Figure 3.2 compares the growth of a young stand under the traditional and pine-bluestem scenarios. Both scenarios begin in 2000 with the same stand conditions: stand age=20 yr; SI_{pine}=60 ft; approximately 500 pine and 30 hardwood stems per acre; and pine and hardwood BA of 60 and 15 ft^2/ac, respectively. First thinnings occur in 2010 when the stands are 30 yr old, reducing BA to target residual levels (70 and 45 ft^2/ac pine BA, respectively, for the traditional and pine-bluestem scenarios).

Virtually all of the pine volume removed in the traditional scenario thinnings is comprised of pulpwood, as evidenced by the smooth increase of the pine sawlog volume curve. The hardwoods in the stand exert enough competitive pressure to slow the development of a pine sawtimber component, and low thinnings remove the smaller stems. A small amount of hardwood sawtimber is removed in 2020, a result of the large remnants present at the beginning of the simulation. Only when the regeneration cut occurs in 2040, at stand age 60 yr, is the pine volume primarily sawlog size. The remaining overstory is removed in 2050, leaving the regeneration (age 10 yr in 2050) to occupy the site.

Table 3.5. Merchantability specifications used in this study.

Attribute	Value	Attribute	Value
Stump height (ft)		Minimum piece length (ft)	
Pulpwood	0.5	Pulpwood	5
Sawlog	1	Sawlog	8
Top diameter limit (in.)*		Minimum tree length (ft)	
Pulpwood (o.b.)	4	Pulpwood	15
Pine sawlog (i.b.)	7	Pine sawlog	16
Hardwood sawlog (i.b.)	10	Hardwood sawlog	12

*o.b. is outside bark; i.b. is inside bark.

The growth simulator used in this study does not yield accurate forecasts for young stands; hence, simulation of the second-generation stand does not begin until 2060, when the regeneration is 20 yr old (hence the 10-yr gap in the lines). The stand is estimated to have the conditions indicated in the second row of Table 3.4. Because no large residual hardwoods remain in the stand at the start of the second-generation simulation, they exert less competition and allow the pine sawtimber component to develop earlier. The pine sawlog volume growth curve begins its climb earlier, and rises more quickly than is the case in the first-generation stand.

The pine-bluestem scenario develops pine sawtimber-size trees more quickly than does the traditional scenario. Cutting the pine BA back an additional 25 ft^2/ac (when compared to the traditional management scenario) at age 30 reduces the competition so that a small amount of pine sawtimber can be removed in 2020. Per-acre BA growth recovers more slowly after each subsequent thinning, eventually becoming almost flat after the regeneration cut in 2090.

The two scenarios are quite comparable in their cumulative sawtimber volume growth until 2070, when the second-generation traditional stand reaches age 30 yr. The pine-bluestem stands lags increasingly far behind, thanks primarily to the less vigorous

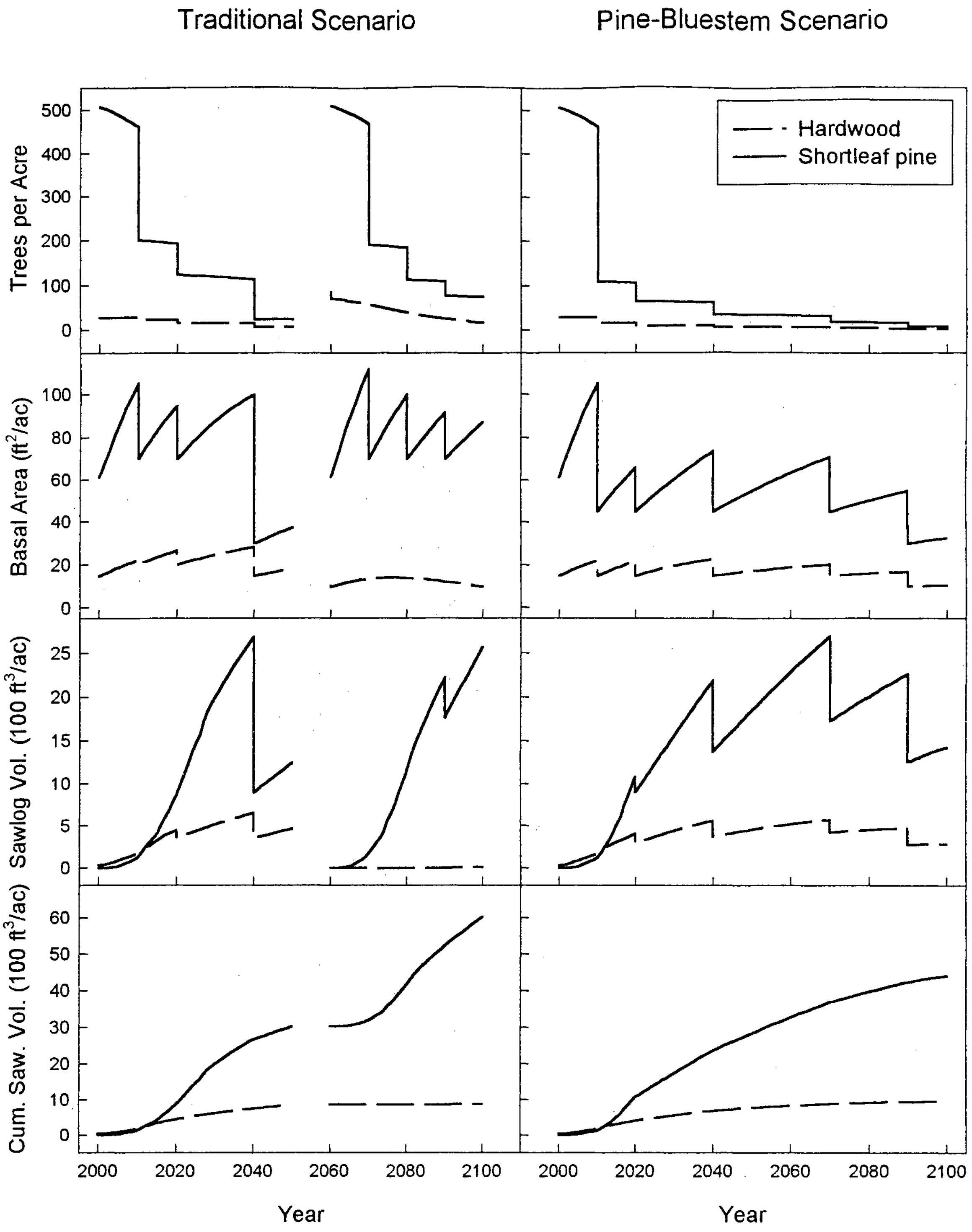

Figure 3.2. Comparison of stand dynamics under traditional and pine-bluestem management of a stand with initial conditions: age 20 yr, SI_{pine} 60 ft, and 60 and 15 ft^2/ac, respectively, of pine and hardwood BA.

growth potential of the older trees. By 2100, the pine-bluestem scenario has amassed only about two-thirds the volume produced by the traditional scenario. This disparity would be even greater if merchantable, rather than just sawlog volumes were compared.

Appendix C presents in tabular form the growth and yield of stands under traditional and pine-bluestem management scenarios, similar to the information shown graphically in Figure 3.2. Projections begin at age 20 yr, with initial shortleaf pine basal area levels of 30, 60 and 90 ft^2/ac. Shortleaf site index is either 50 or 70 ft at base age 50 yr.

Aggregation of Timber Sales

After completing growth simulations for both the pine-bluestem and traditional management scenarios, the volumes of intermediate and final harvests occurring in the metastands (as well as the final stand conditions in 2100) were assigned to the actual stands in Management Area 22. E.g., each actual stand in Management Area 22 exhibiting the 40-yr, 90-BA and 60-SI class combination in 2000 was assigned the volumes removed from – and final stand conditions of – the metastand with the same class characteristics. Two datasets resulted from this reassignment, one for the pine-bluestem scenario and another for the traditional management scenario, containing volumes and other information by compartment, stand number and year.

Timber sales on the Ouachita National Forest often encompass multiple compartments (see Chapter 4) containing a mixture of pulpwood and sawtimber. By selling a mixture of stumpage, the Forest Service is able to dispose of roundwood that most primary processors in the locale – who are predominantly dimension lumber producers – would prefer not to handle. In most cases, the compartments forming a single sale are numerically either contiguous or else quite close to one another (e.g., compartments 1231, 1232 and 1234 might comprise a sale).

To mimic the Forest Service's method of organizing sales, the list of stands to be harvested during any particular year was sorted by compartment in ascending numerical order. A single compartment constituted a sale if at least one of its stands contained sawlog volume. Obviously, the number of sales could be reduced by forcing sales to contain at least two compartments. A compartment containing young stands with only pulpwood was combined with the next compartment in the list. This aggregation process continued until the sale contained at least some sawlog volume. As Table 3.6 indicates, six or seven compartments might be aggregated into a single sale.

Statistically valid hardwood valuations could not be derived in Chapter 4 because so few actual sales contained hardwood volumes. Although the hardwood component is important from a competition standpoint when simulating stand growth, it generally contributes a negligible amount to sale revenue . Consequently, the hardwood volumes predicted by the simulator will hereafter be ignored.

Despite lower residual stocking, average per-acre sawtimber harvest volumes are higher in the pine-bluestem scenario. While the number of sawtimber trees removed per acre from the average sale is approximately the same in the two scenarios, the average sawtimber volume removed per acre is higher in the pine-bluestem scenario. This outcome can be at least partially explained by the fact that individual pine-bluestem trees contain, on average (and up to 2.5 times), more volume than their traditional counterparts. Although not documented in Table 3.6, sawtimber also makes up a larger proportion of total sale volume in the pine-bluestem scenario than is the case in traditional management.

These observations might seem to contradict the earlier assertion that traditional management produces more sawtimber volume than does pine-bluestem management. The key difference lies with the average acreage harvested in each scenario: the average traditional sale is 1.5 times larger than its pine-bluestem counterpart.

One explanation for the disparity in sale acreage between the scenarios is that the higher stocking and shorter rotations in the traditional stands – with their concomitantly younger, more vigorous trees – combine to make available more area for thinning or regeneration cuts in any compartment during any particular time. Comparing the total acreage involved in harvest activities during the entire simulation period supports this argument. During the 100-yr simulation period, volume is removed from approximately 738,000 acres in the traditional scenario; and 473,000 acres in the pine-bluestem scenario. In other words, each of the 99,408 acres in Management Area 22 will have some volume removed from it 7.5 times under the traditional scenario, but only 4.8 times under the pine-bluestem scenario.

Another explanation for the larger traditional sales is that during periods in which young stands predominate, more compartments must be aggregated to create timber sales with some sawtimber volume. This situation occurs in 2030 and 2040, as evidenced by the large proportion of total volume removed as pulpwood (Figure 3.3).

For the most part, hypothetical sales created in this phase of the study compare favorably with actual timber sales carried out on the Ouachita and Ozark National Forests (compare Tables 3.6 and 4.2). The most obvious disparity lies with the traditional sale

Table 3.6. Comparison of 953 traditional and 966 pine-bluestem timber sales occurring prior to 2100.

	Traditional timber sales				Pine-bluestem timber sales			
Variable	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum
Sale Acreage	774.2	497.0	38	5,505	489.6	318.4	16	2,080
Compartments in sale	1.1	0.5	1	7	1.1	0.4	1	6
Total volume cut (100 ft^3)								
Sawtimber	5,561	4,994	19	27,801	4,003	3,571	24	21,242
Roundwood	1,479	1,880	0	17,699	775	1,294	0	10,941
Topwood	535	514	3	3,340	352	364	3	2,394
Average pine volume cut (100 ft^3/ac)								
Sawtimber	7.18	5.51	0.05	28.16	8.18	3.85	0.07	16.26
Roundwood	1.91	1.69	0	6.29	1.58	1.91	0	6.89
Trees/ac								
Sawtimber	22.6	19.9	0.1	86.1	22.2	16.0	0.2	64.1
Roundwood	44.2	33.9	0	138.7	43.1	58.1	0	205.9
Volume (100 ft^3) per tree								
Sawtimber	0.34	0.17	0.06	0.86	0.44	0.21	0.06	2.10
Roundwood	0.05	0.04	0	0.13	0.04	0.04	0	0.15

acreage: the average hypothetical sale in the traditional scenario is 185 ac larger than the average actual sale. In addition, average volumes per tree and per acre are lower in the actual sales than the hypothetical sales of either scenario. The most likely explanation for this is overly optimistic growth projections from the simulator. For a variety of reasons, research plots often produce better-than-average yields. Models derived from research plots may thus overestimate the yields of more typical stands. Finally, rotation-end tree ages in the pine-bluestem scenario extend beyond the range observed in the data used for growth model development. Consequently, predicted volume accumulations may be greater than what actual stands will experience.

Figure 3.3 compares the sawtimber and pulpwood (roundwood and topwood) harvest volumes produced by the traditional management and pine-bluestem scenarios during the 100-yr simulation period. Harvest volumes vary considerably from year to year under both management scenarios.

Over the entire period, by converting to the pine-bluestem management regime, sawtimber harvest volume drops by 27 percent; pulpwood harvest volume drops by 47 percent; and total (sawtimber and pulpwood) harvest volume drops by 34 percent.

The hypothetical harvests created in this chapter and their associated volume estimates provide the basis for comparisons of value discussed in Chapter 4.

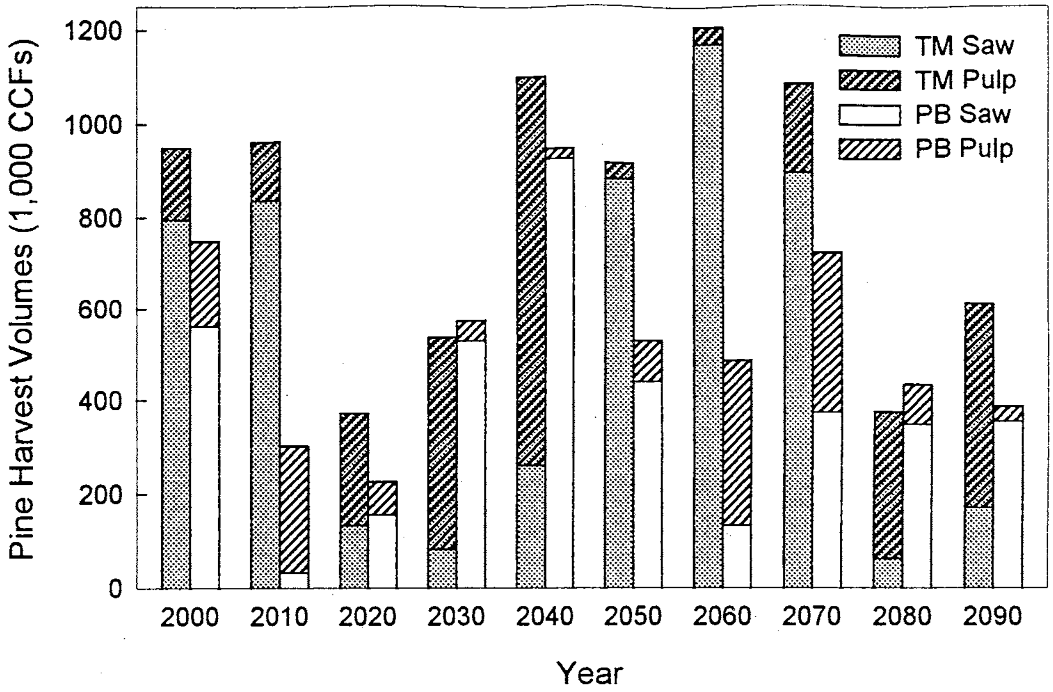

Figure 3.3. Comparison of traditional-management (TM) and pine-bluestem (PB) sawtimber (Saw) and pulpwood (Pulp) harvest volumes (1 CCF=100 ft^3), by decade.

CHAPTER 4

VALUATION OF STAND GROWTH UNDER TRADITIONAL AND PINE-BLUESTEM MANAGEMENT

Overview of Forest Service Timber Sale Administration

Interest in the valuation of publicly and privately owned forest products has a long history. When attempting to forecast price trends for commercial species in the important timber-producing regions of the U.S., for example, Steer (1938) cited studies of stumpage prices dating back to the beginning of the 20th century. Much of this interest stems from the fact that the methods used to appraise and sell federally owned assets affect the flow of revenue into the U.S. Treasury. The objective of this chapter is to describe the derivation of a timber sale valuation model, and its use in assigning values to the hypothetical timber sales created in Chapter 3.

Unlike manufactured goods or commodities, National Forest stumpage is not sold in uniform lots. Purchasers do not have the option of buying timber of a single species and/or quality; they must bid for an entire sale (Brannman et al. 1981). Timber sales differ with respect to geographic location, species composition, stand density and volume, and other characteristics that may affect potential bidders' valuations.

The Forest Service employs two methods when appraising stumpage on National Forest lands (Wiener 1981). The first method, known as the residual or "realized" valuation method, begins with the value in the output market of the products that a firm of average efficiency is likely to manufacture from the stumpage. The costs of production (including extraction, shipping and manufacturing), as well as an allowance for profit, are subtracted from the output value to determine the final appraisal or reserve price. The transactions evidence method, on the other hand, bases the appraised value on historical data of similar sales, adjusting for departures from comparability. Proponents of the transaction evidence approach suggest that it is more reliable; fewer assumptions are required, and it is a more direct approach to timber valuation (Bare and Smith 1999).

The Ouachita National Forest uses the transactions evidence method when appraising timber sales. A timber sale on a ranger district begins with an inventory of the stands to be included in the sale. In some sales all sawtimber trees may be measured, but more commonly only a portion are sampled. When sampling is employed, any of several methods – including fixed- and variable-radius plots, and strips – may be used to estimate stumpage volume. Sample intervals vary by tree size, with smaller trees being sampled less frequently than larger trees.

In addition to the estimated numbers of trees and volumes reported by diameter class, and the type of cut employed (e.g., single-tree selection, seed tree, or something intermediate), the district's timber management assistant forwards to the forest supervisor's office a preliminary appraisal of costs associated with the sale. These costs may include estimates for activities including road construction and/or maintenance, erosion control (e.g., seeding and fertilization) of landings and temporary roads, and special slash disposal.

Upon receipt of a preliminary appraisal package, the timber resource specialist in the forest supervisor's office calculates "base-period" prices for stumpage components and sale costs. The base-period stumpage prices are the average amounts bid for 100 ft^3 of pine and hardwood sawtimber and pulpwood during the previous four fiscal quarters. Base-period sale costs (which are also calculated on a 100-ft^3 basis) are derived in a similar manner. Stumpage components in the new sale are initially assigned the difference of the base-period stumpage prices and the deviation between the base-period and new sale costs (e.g., if the new sale's costs are lower than average, the stumpage components will initially be priced higher than average). The timber resource specialist then adjusts the initial value estimates according to three factors. The first factor adjusts for trends in the lumber market. For example, if lumber prices around the time of the sale have been trending significantly higher/lower than the base-period price, the regional Forest Service office may instruct its timber resource specialists to adjust sale appraisal values accordingly. This adjustment can range from 80 percent above to 50 percent below the base-period price.

The other two factors are determined by the local timber resource specialist alone. The first is a risk adjustment which accounts for any unusual sale features that might hinder a buyer's ability to recover the stumpage value. For example, if the Forest Service offered a salvage operation in June, and temperatures had been unseasonably high, the appraisal value could be lowered to account for the possibility that the stumpage might be lost to a wildfire. The risk adjustment is limited to ±20 percent of the adjusted base-period price. The last factor is a quality adjustment. If more than 75 percent of the sawlogs in a sale fall within the 10- to 14-in. diameter class, for example, the timber resource specialist might reduce the appraisal value by 10 percent because the lumber derived from that sale probably will grade out below average.

The sale is then advertised at the net appraised price in accordance with the Organic Administration Act of 1897 (30 Stat. 34), amended in 1976 (16 U.S.C. §476), which requires that Forest Service stumpage be sold for not less than the appraised value. On average, the advertised price must fall within 75 percent of the actual winning bid. Failure to meet that standard implies flaws in the estimation of either sale costs or stumpage values.

Each sale is advertised in one or more newspapers, describing the sale location, estimated stumpage volumes and cost of road construction, and the date upon which sealed bids are to be submitted. Public Law 94-588, §14(i)(1) mandates that the Forest Service use first-price sealed-bid auctions exclusively.[1] In their bids, potential purchasers submit a separate value for each component in the timber sale. Thus, if a sale contains both pine and hardwood sawtimber and pulpwood, each valid bid will contain four values. The party submitting the highest total bid purchases the sale.

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[1] Considerable controversy exists over the relative merits of sealed-bid and oral auctions. Johnson (1979) found sealed-bid sales more likely than oral auctions to result in the highest-value user not submitting the winning bid. He presented empirical evidence, from a region in which sealed bids and oral auctions were used concurrently, showing a higher frequency of resale to third parties after sealed bid auctions. Bierman and Fernandez (1998) concur, arguing that when risk-neutral bidders hold independent private values (IPV) about an offering, oral auctions generally yield greater expected revenue because bidders gradually reveal their valuations during the bidding process. This allows more aggressive bidding. In a common-values (CV) situation, an offering has the same value for all potential bidders, but they are uncertain of its true value. CV bid values depend upon the number of potential competitors. Since timber sales probably contain attributes of both IPV and CV assumptions, the optimal bid strategy is a function of sale tract characteristics and (perhaps) the number of bidders (Carter and Newman 1998).

Derivation of a Timber Sale Valuation Model

Producer Price Indices

Seasonally unadjusted producer price index (PPI) monthly data for softwood logs and bolts and softwood pulpwood, encompassing the time period between June 1992 and December 1998, were obtained from the Bureau of Labor Statistics website (U.S. Dept. of Labor 1999). These indices used the average of 1982 prices as their bases. However, to be consistent with IMPLAN (see Chapter 5), the index was modified so that the average of 1996 prices was set equal to one. Seasonally unadjusted PPI monthly data for southern yellow pine #2 dimension lumber were similarly obtained from the Bureau of Labor Statistics (U.S. Dept. of Labor 1999). December 1980 prices were the base in the original dimension lumber dataset, requiring modification so that the average of 1996 prices was set equal to unity. Prices for other years were adjusted accordingly. See Appendix D for PPI values observed during the study period.

As Figure 4.1 indicates, prices paid for softwood sawlog stumpage rose by approximately 30 percent during the 1992-93 period. This price rise was prompted in part by the dramatic logging reduction in the Pacific Northwest resulting from concerns over losses of northern spotted owl habitat. Sawlog stumpage prices have dropped gradually since peaking in mid-1993. Pulpwood stumpage prices have behaved somewhat differently, rising gradually throughout the period. Prices for southern pine dimension lumber have also been quite volatile during the study period, first rising in response to spotted owl-induced supply constraints, then falling about the time large

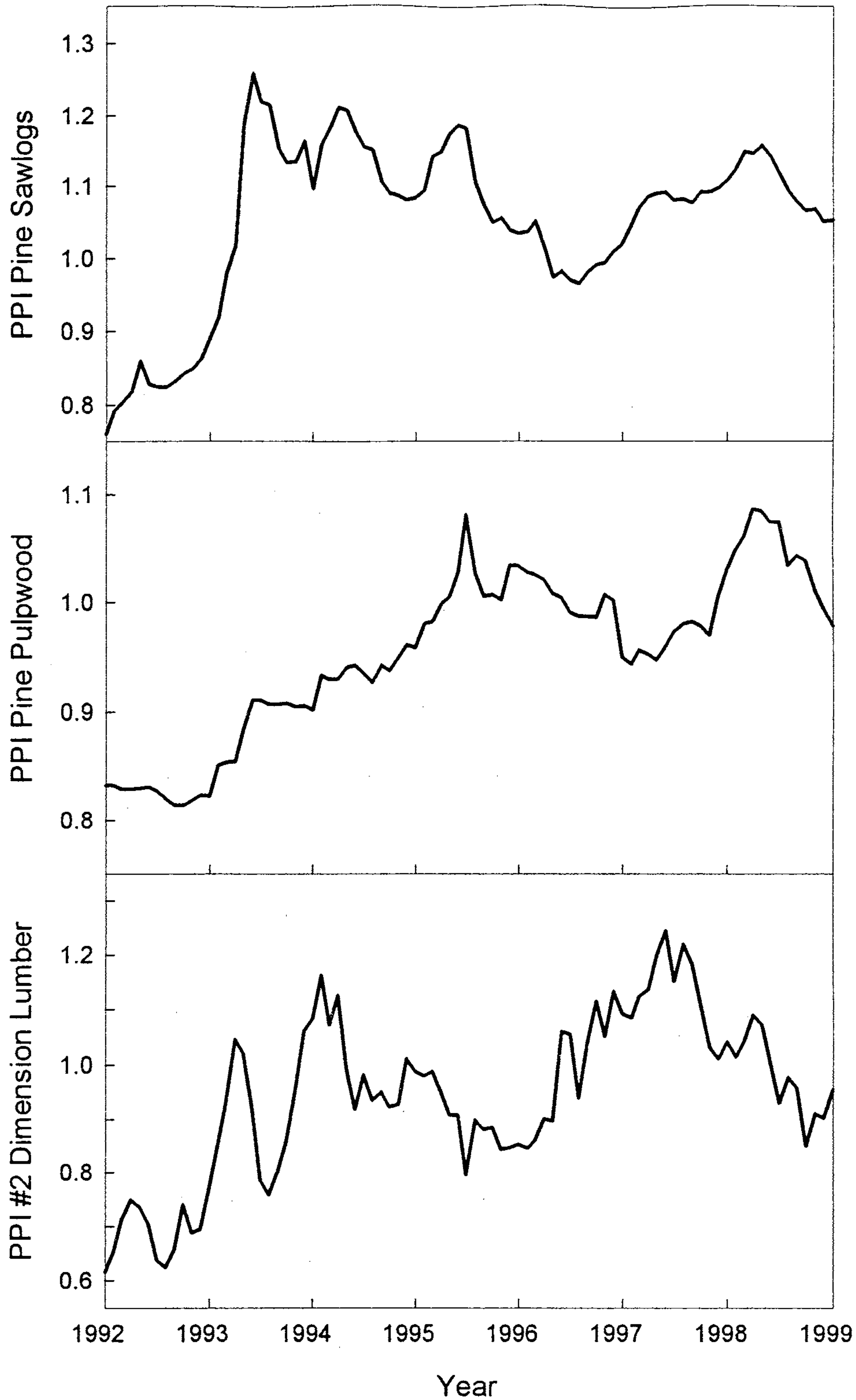

Figure 4.1. Trends of producer price indices for pine sawlogs, pine pulpwood, and southern yellow pine #2 dimension lumber over the period covered by the timber sale data. Average of 1996 prices equals 1.0 (from U.S. Dept. of Labor 1999).

quantities of lumber from Hurricane Andrew salvage operations began to reach the market in mid-1993.

Timber Sale Data

To serve as the basis for the derivation of a timber sale valuation model, characteristics of 150 active timber sales on the Ouachita and Ozark National Forests were obtained, spanning the time period between June 1992 and December 1998. Information for each timber sale originated from its corresponding Form FS-2400-6T, the appraisal summary, and timber sale prospectus. Variables collected on each sale included the location (forest, state, ranger district and county); dates of value estimation, awarding of contract, and contract termination; contract number; whether or not the bidder pool was restricted to "small" businesses under Small Business Administration regulations; miles of different types of roads to be (re)constructed, along with the associated total temporary development cost; number of administrative compartments included in the sale, the list of compartments in the sale boundary, operable acreage, and methods of cut employed; unit in which sawtimber volume was reported – either hundred cubic feet (CCF) or thousand board feet (MBF); estimated volumes of shortleaf sawtimber, roundwood (pulpwood), and topwood, and their corresponding advertised per-unit prices; number of bids received, and the company names and per-unit component bids of up to the four top bidders; the number and volumes of shortleaf trees in each one-inch diameter class; and the average shortleaf sawtimber and roundwood volumes cut per acre.

Hardwood variables were also recorded, but the number of sales (six) containing hardwood volume was insufficient to develop useful statistical relationships. Consequently, those variables were excluded from the analysis.

Several researchers have included distance between the timber sale and nearest mill as an explanatory variable in their valuation models. Distance to the nearest mill was not recorded in this study because several other researchers have observed that log flows frequently exceed the distance to the nearest mill (Jackson and McQuillan 1979).

Prior to 1996, sawtimber volumes were reported in MBF or both MBF and CCF units. So that all sales employed a consistent unit of sawtimber volume, the early sales were converted from MBF to CCF units. See Appendix E for details. Total revenue from each timber sale was obtained with the following formula:

$$\text{Revenue} = \left(\frac{\$/CCF_S}{PPI_S}\right)CCF_S + \left(\frac{\$/CCF_R}{PPI_P}\right)CCF_{R+T}$$

For each sale, the nominal bid price for sawlogs ($\$/CCF_S$), in units of dollars per CCF, was deflated by the PPI for pine sawlogs (PPI_S) current at the time of the sale. Total revenue from sawlogs was obtained by multiplying the deflated price by the total volume of sawlogs (CCF_S) in the sale. Similarly, the bid price for roundwood ($\$/CCF_R$), in units of dollars per CCF, was deflated by the current PPI for pine pulpwood (PPI_P). Total pulpwood revenue was obtained by multiplying the deflated pulpwood price by the total volume of roundwood and topwood (CCF_{R+T}). Total sale revenue was the sum of sawtimber and pulpwood component revenues.

Table 4.1 contains basic statistics for the 150 timber sales. As mentioned above, these sales vary greatly with respect to acreage, number of trees and volumes cut per acre, the proportion of total volume in sawtimber, and the size of individual trees.

Table 4.1. Basic statistics of 150 Ouachita and Ozark National Forest timber sales used to relate real winning bids to sale characteristics.

Variable	Mean	Standard deviation	Minimum	Maximum
Winning total bid*	522.3	381.9	3.6	2,808.7
Sale Acreage	589.4	496.8	40	4,500
Compartments in sale	2.1	1.4	1	10
Total volume cut (100 ft^3)				
Sawtimber	3,531	2,320	63	14,634
Roundwood	792	769	0	3,770
Topwood	185	261	6	1,624
Average pine volume cut (100 ft^3/ac)				
Sawtimber	5.99	4.07	0.50	32.10
Roundwood	1.34	1.26	0	8.70
Trees/ac				
Sawtimber	24.4	11.2	1.2	61.6
Roundwood	21.7	30.0	0	285.8
Volume (100 ft^3) per tree				
Sawtimber	0.25	0.08	0.05	0.60
Roundwood	0.06	0.02	0	0.15
Producer Price Indices†				
Sawtimber	1.08	0.06	0.82	1.22
Roundwood	0.99	0.05	0.82	1.09
Lumber	1.05	0.12	0.64	1.25
Lumber/ Sawtimber	0.98	0.12	0.62	1.14

*Thousands of 1996 dollars.

†During the period represented by the timber sales.

Differentiated-Input Price Theory

In 1974, Rosen formalized a theory describing the influence of product characteristics on consumers' behavior in a perfectly competitive market. Ladd and

Martin (1976) modified that theory to explain firms' input purchases based upon the characteristics of those inputs. Today, differentiated-input/product price theory is used to model derived demand for everything from rice (Brorsen et al. 1984) to agricultural land (Palmquist 1989).

Differentiated-input price theory can be applied as well to purchases of stumpage from national forests (Prescott and Puttock 1990, Puttock et al. 1990). This study assumed perfect competition in the stumpage market. Although some researchers question the validity of this assumption (e.g., Carter and Newman 1998, Vargas and Schreiner 1999), many assume it even if there are few firms in the locale (e.g., Buongiorno and Young 1984, Munn and Rucker 1995). With some 20 primary processors in the area, a dominant-firm model might be justified. However, attempts to model noncompetitive behavior were unsuccessful.

Following Prescott and Puttock's (1990) theoretical presentation, consider a profit-maximizing firm that faces perfect competition in both the input and output markets, whose production function may be represented by:

$$q = F(v_1, v_2, \ldots, v_n) \tag{4.1}$$

where q is the quantity of output, and v_j is the quantity of input characteristic j ($j = 1,2,\ldots,n$). Equation (4.1) indicates that the output depends upon the amounts of various input characteristics used in the production process.

Assume that bundles of characteristics are purchased in units of X. In the present context, X might represent the number of acres in a timber sale. The input X, which represents an n-dimensional vector of characteristics, is used to manufacture the firm's output. The firm's profit function can then be represented as:

$$\pi = P \cdot F(v_1, v_2, \ldots, v_n) - P_X X \tag{4.2}$$

where P and P_X are output and input prices, respectively.

The first-order conditions for profit maximization are:

$$\frac{d\pi}{dX} = P\sum_{j=1}^{n} \frac{\partial F}{\partial v_j}\frac{dv_j}{dX} - P_X = 0 \tag{4.3}$$

Solving for P_X yields:

$$P_X = P\sum_{j=1}^{n} \frac{\partial F}{\partial v_j}\frac{dv_j}{dX} \tag{4.4}$$

where $\partial F/\partial v_j$ is the marginal physical product from an additional unit of characteristic j; and dv_j/dX is the marginal contribution of input X to the jth characteristic. It follows, then, that $P(\partial F/\partial v_j)$ is the marginal revenue product of characteristic j. If $(\partial F/\partial v_j)$ can be approximated by a constant (α_j) over the range of variation in the data, and the quantity of characteristic j is proportional to the number of units in X (i.e., $v_j = \theta_j X$), then $dv_j/dX = \theta_j = v_j/X$, which allows Equation (4.4) to be rewritten as:

$$P_X = P\sum_{j=1}^{n} \alpha_j \frac{v_j}{X} \tag{4.5}$$

Rearranging Equation (4.5) and multiplying through by X to give total sale revenue yields:

$$P_X X = \sum_{j=1}^{n} P\alpha_j v_j \tag{4.6}$$

Letting β_j be the marginal revenue product for characteristic j (i.e., $\beta_j = P\alpha_j$) allows Equation (4.6) to be presented as a standard regression equation:

$$P_X X = \sum_{j=1}^{n} \beta_j v_j \tag{4.7}$$

Thus, the total value associated with a particular timber sale is equal to the sum of the marginal revenue product (β_j) of each characteristic times the total quantity (v_j) of each characteristic in the sale. In this formulation, the marginal revenue products can be estimated by regressing total sale revenue against the total quantity of each sale characteristic.

Guttenberg (1956) is generally credited with publishing the first regression analysis of Forest Service timber sales in the South. His price determinants included total sale volume, volume per acre, proportion of hardwood, and tree volume per unit of pine BA. Anderson (1976) presented further application of multiple regression to stumpage valuation.

Several analytical methods, and many different equation forms have appeared in the literature. Nautiyal (1982) concluded that a discontinuous step function best explains how the value of an individual tree changes as it grows. Munn and Palmquist (1997) applied stochastic frontier analysis to timber sale price functions describing private sales in which there is price uncertainty on the part of both sellers and buyers. The error term of their price function had an asymmetric component whose distribution depended upon the presence or absence of a consultant. They determined that involving a consulting forester in the timber sale increased revenue. Schuster and Niccolucci (1994) used probit and linear regression models to explore the relative merits of oral-auction versus sealed-bid sales.

Huang and Buongiorno (1986) discussed the problem that arises when substantial numbers of Forest Service sales receive no bids. Ignoring those sales biases the estimated value of other sales; so too would assigning unsold offerings a value of zero. They used a Tobit model to derive appraised values that would result in a certain percentage of sales being sold, and – by extension – the expected high bid. Huang and Buongiorno's (1986) concern over the introduction of bias because of sales that received no bids is unwarranted in this case. The Ouachita National Forest generally has to readvertise less than three percent of its sales.[2]

Estimation of Historical Timber Sale Values

Price Equation Estimation

An equation was derived for assigning value to the stumpage volumes the stand simulator (see Chapter 3) predicted will be available for harvest under traditional and pine-bluestem management scenarios. Because the model is used for prediction rather than hypothesis testing, all but one of the explanatory variables were limited to those readily available in or calculable from the simulator's output.

Two procurement foresters[3] were interviewed as part of the model estimation phase. Of the variables available from the simulator, they indicated that the volumes of sawtimber and pulpwood, harvest intensity (represented by average sawtimber volume per acre), and tree size (represented by average sawtimber volume per tree) are the most important when deciding if and how much to bid on a Forest Service timber sale. Because their companies produce primarily dimension lumber, the bids they submit are

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[2] Personal communication, Debbie DeBruler, USDA Forest Service timber resource specialist, 9 Feb. 2000.
[3] The individuals and their employers requested anonymity.

positively correlated with increases in sawtimber volume, and volumes per acre and per tree. Their bid prices are negatively correlated with increases in pulpwood volume.

An additional important variable, although not available from the simulator, is the relationship between dimension lumber and sawlog prices. Fluctuations in lumber prices are positively and highly correlated with fluctuations in sawlog prices (a correlation coefficient of r=0.85 was estimated during the period 1982 to 1999). The ratio of lumber PPI to pine sawlog PPI captures this relationship. A ratio greater than 1 implies that lumber prices are rising relative to sawlog prices; a ratio less than 1 implies falling lumber prices relative to sawlog prices. The foresters confirmed that their bid prices rise with increases in any of these variables.

The procurement foresters also factor their competitors' behavior into their bidding strategies. By monitoring the log inventory in other firms' wood yards, and maintaining records on the amounts each firm bid for past sales (along with the characteristics of those sales), they attempt to anticipate the level of competition for available stumpage. Carter and Newman (1998) modeled the effect of competition on optimal bid strategies by estimating a simultaneous-equation system. One equation predicted the market value of a timber sale, while the other predicted the number of bidders. Attempts to incorporate competitive bidding behavior into this study by duplicating Carter and Newman's (1998) model were unsuccessful, however. The equation predicting the number of bidders yielded practically the same value no matter how the other variables in the system changed. As a result, a simpler single-equation model was estimated instead.

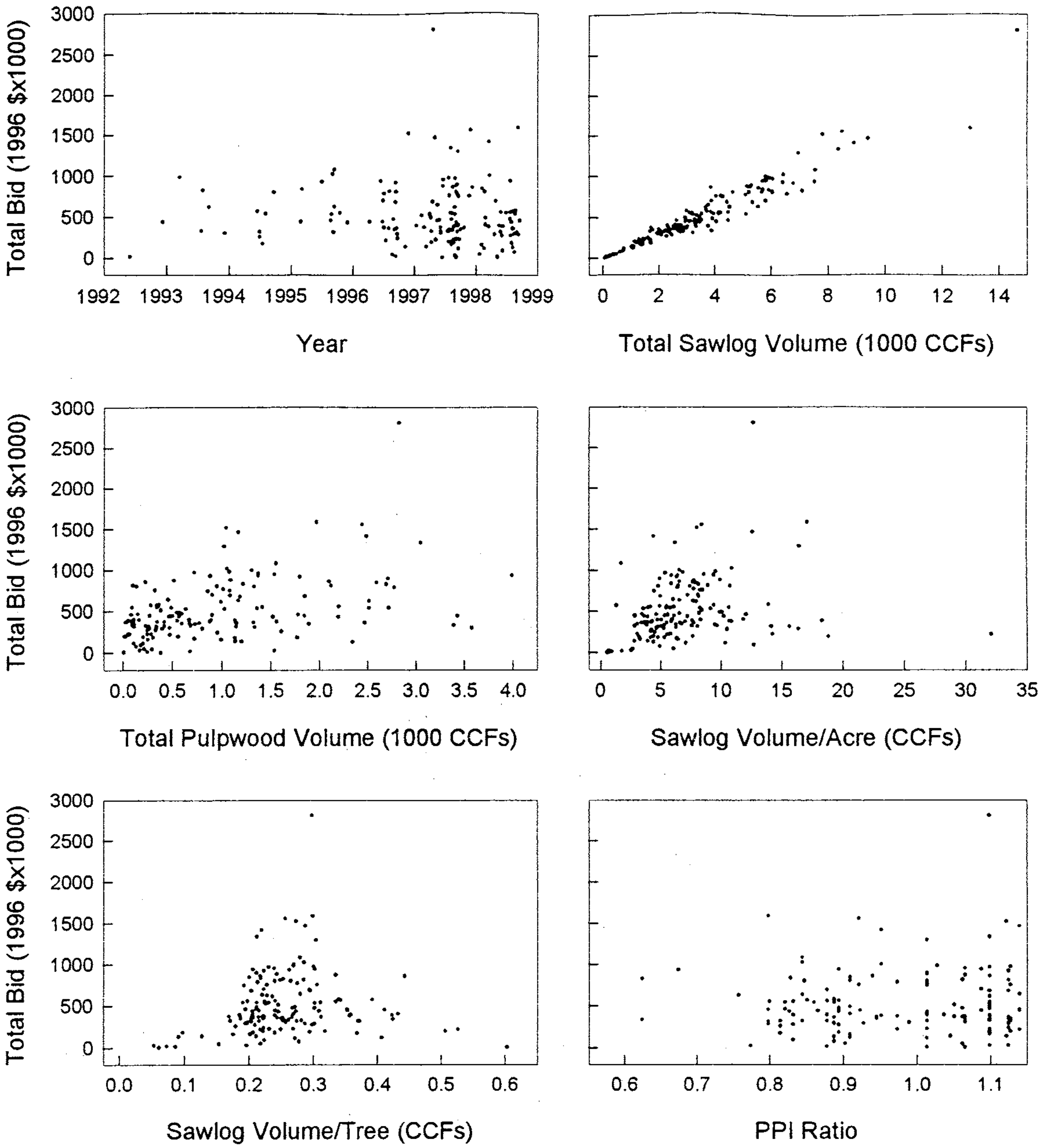

Figure 4.2. Behavior of real (1996) total bid prices over time, and the relationship of total bid price to each of the explanatory variables used in the timber sale valuation model. Note that 1 CCF = 100 ft^3.

Figure 4.2 shows the winning total bids plotted over time, and against the model's explanatory variables. Correlations among the variables in the final model are given in Table 4.2 The correlation table and Figure 4.2 show a strong relationship between bid prices and total sawlog volume.

Residual plots and McGuirk et al's (1993) misspecification tests revealed significant problems with heteroskedasticity in the original ordinary least squares equation. Correcting for multiplicative heteroskedasticity eliminated the misspecification problems.

Table 4.2 Correlations among the variables in the timber sale valuation model.

Variable	$TSV^{\dagger}$	$TPV^{\dagger\dagger}$	$SVPA^{\S}$	$SVPT^{\|}$	$PPIR^{\#}$
Bid^{*}	0.959	0.433	0.230	0.110	0.021
TSV		0.531	0.216	0.059	-0.097
TPV			-0.182	-0.399	-0.200
$SVPA$				0.548	-0.042
$SVPT$					-0.006

*Real winning total bid price (1996 dollars).
†Total sawtimber volume.
††Total pulpwood volume.
§Average sawtimber volume per acre.
$^{\|}$Average sawtimber volume per tree.
$^{\#}$Ratio of southern yellow pine #2 dimension lumber PPI (average of 1996 prices=1) to pine sawlog PPI (average of 1996 prices=1).

The final timber sale price model, in its logarithmic form, is:

$$\ln Bid_i = b_0 + b_1 \ln TSV_i + b_2 \ln TPV_i + b_3 \ln SVPA_i + b_4 \ln SVPT_i + b_5 \ln PPIR_i + \varepsilon_i \quad (4.8)$$

where Bid_i is the real, winning total bid price (thousands of 1996 dollars) of timber sale i; TSV_i is total pine sawtimber volume (thousands of CCFs); TPV_i is total pine pulpwood – roundwood and topwood – volume (thousands of CCFs); $SVPA_i$ is average sawtimber volume (CCF) per acre; $SVPT_i$ is average sawtimber volume (CCF) per tree; $PPIR_i$ is a ratio of producer price indices created by dividing the producer price index for southern yellow pine #2 dimension lumber (average of 1996 prices=1) by the sawlog PPI (average of 1996 prices=1) at the time sale *i* occurred; "ln" is the natural logarithm operator; ε_i is sale *i*'s unexplained error; and b_0, b_1, …, b_5 are parameter estimates given in Table 4.3

Table 4.3 Parameter estimates, with their standard errors and *P* values, for the variables in the timber sale valuation model.

Variable	Parameter estimate	Standard error	*P* value*
Intercept	5.0122	0.1311	0.0001
TSV	1.0512	0.0258	0.0001
TPV	-0.0151	0.0200	0.2255
SVPA	0.0504	0.0300	0.0477
SVPT	0.1333	0.0626	0.0175
PPIR	0.5242	0.0937	0.0001

*One-sided *P* values except for intercept.

The parameter estimates have the correct sign; they are also significant at α=0.05 or better, except for total pulpwood volume. Because other studies have shown it to be an important explanatory variable (e.g., Anderson 1976, Buongiorno and Young 1984, Carter and Newman 1998), the pulpwood volume term was left in the model despite its lack of statistical significance; also, the procurement foresters interviewed as part of this study indicated that their bids increase in value at a decreasing rate as pulpwood volume rises. The matrix of coefficient correlations and (co)variances is given in Table 4.4 The back-transformed model fit index (equivalent to an R^2) is 0.94.

A comparison of observed and predicted prices (Figure 4.3) indicates a good fit of the model to the data. The model appears unbiased over the range of observed data. The residual plots (Figure 4.4) show no appreciable trends or patterns.

Table 4.4 Matrix of correlations and (co)variances among the coefficients in the timber sale valuation model. Values above the diagonal are correlations; variances are on the diagonal, and covariances are below the diagonal.

Coefficient	b_0	b_1	b_2	b_3	b_4	b_5
b_0	1.72E-2	-0.4354	0.5372	-0.5416	0.9513	-0.0186
b_1	-1.47E-3	6.65E-4	-0.8015	-0.3972	-0.5274	-0.1055
b_2	1.41E-3	-4.14E-4	4.02E-4	0.2509	0.6352	0.1433
b_3	-2.13E-3	-3.08E-4	1.51E-4	9.03E-4	-0.3098	0.1406
b_4	7.81E-3	-8.51E-4	7.97E-4	-5.82E-4	3.92E-3	0.0208
b_5	-2.29E-4	-2.55E-4	2.69E-4	3.96E-4	1.22E-4	8.79E-3

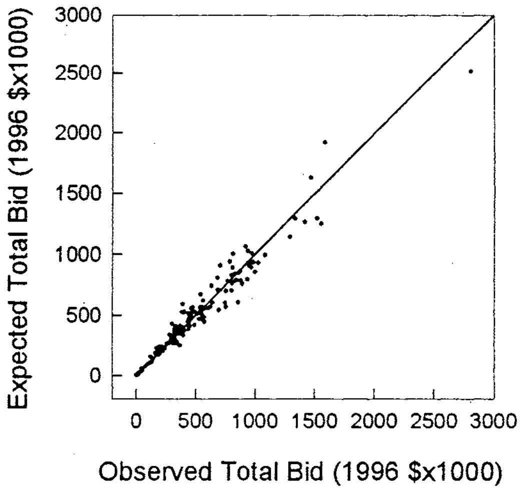

Figure 4.3. Comparison of observed and predicted timber sale bid prices from the Ouachita and Ozark National Forests.

Forecasting Revenue from Management Area 22

The revenue generated by each hypothetical traditional and pine-bluestem timber sale derived in Chapter 3 can be estimated by substituting the values of relevant sale characteristics, and an estimate of the ratio of lumber to sawlog PPI, for their corresponding variables in Equation (4.9):

$$\text{Revenue}_i = e^{\left(b_0 + b_1 \ln TSV_i + b_2 \ln TPV_i + b_3 \ln SVPA_i + b_4 \ln SVPT_i + b_5 \ln PPIR_i\right)} \cdot 1000 \qquad (4.9)$$

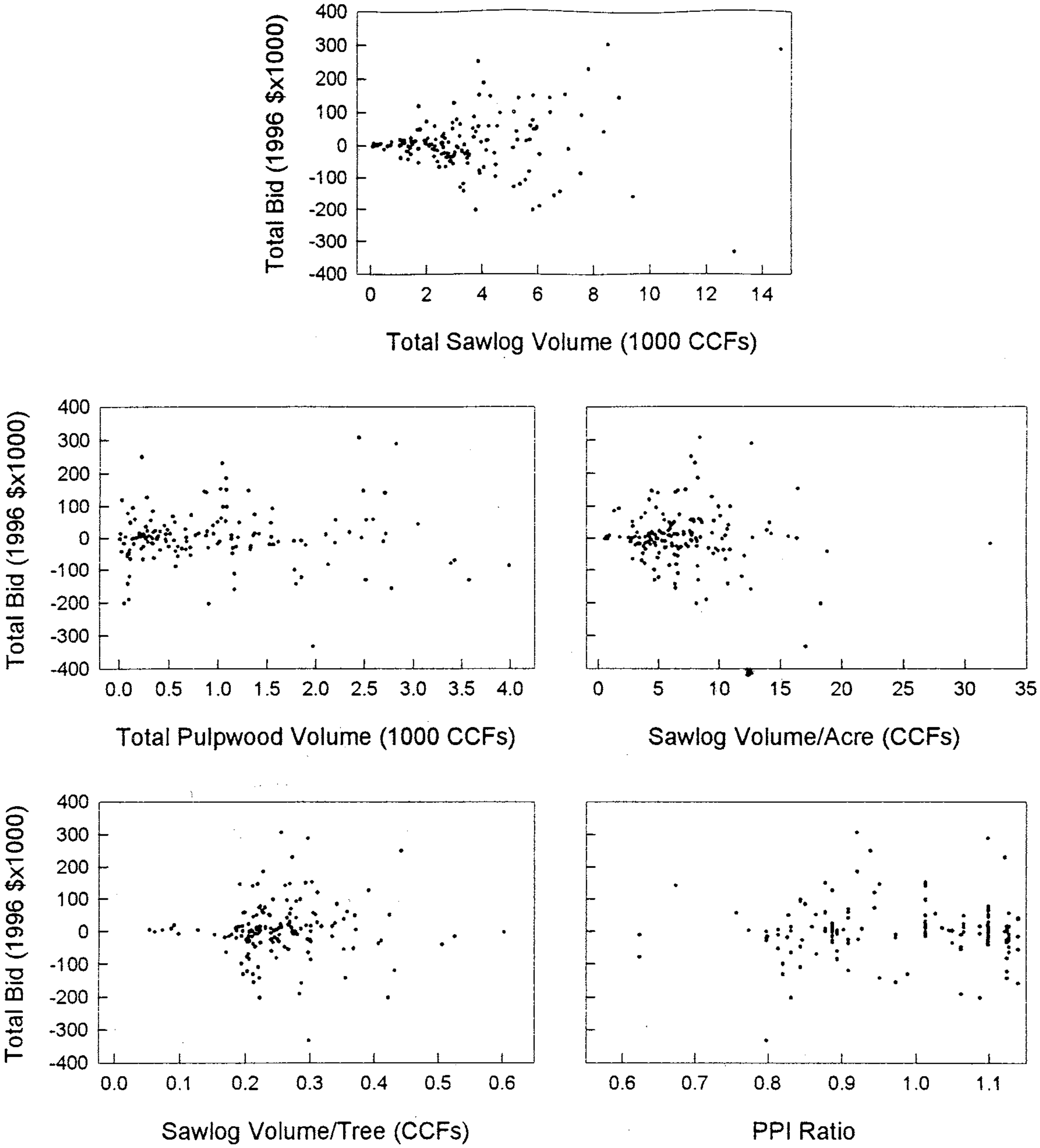

Figure 4.4. Residual (observed minus predicted) total bid prices plotted against each of the explanatory variables used in the timber sale valuation model.

where Revenue$_i$ is the total revenue from sale i (in undiscounted 1996 dollars). For forecasting purposes $PPIR_i$ is set equal to 1, signifying that lumber and sawlog prices move together in the long run. This assumption, supported by an observed average PPI ratio=1 during the period 1982 to 1999, causes the term to drop out of prediction of timber sale revenue. The other terms are as previously described.

The total revenue generated during each decade in Management Area 22 under traditional and pine-bluestem management can be obtained by summing the revenues from the hypothetical timber sales that occur in each scenario during that decade. Figure 4.5 illustrates the comparison between the scenarios. One can see that the pine-bluestem scenario returns 33 percent less revenue than traditional management does in 2000. In 2010, primarily as a result of the continued clearing of the harvest backlog, the traditional scenario continues to generate considerable income; pine-bluestem revenue in 2010, by contrast, is only about 3 percent of what traditional management returns.

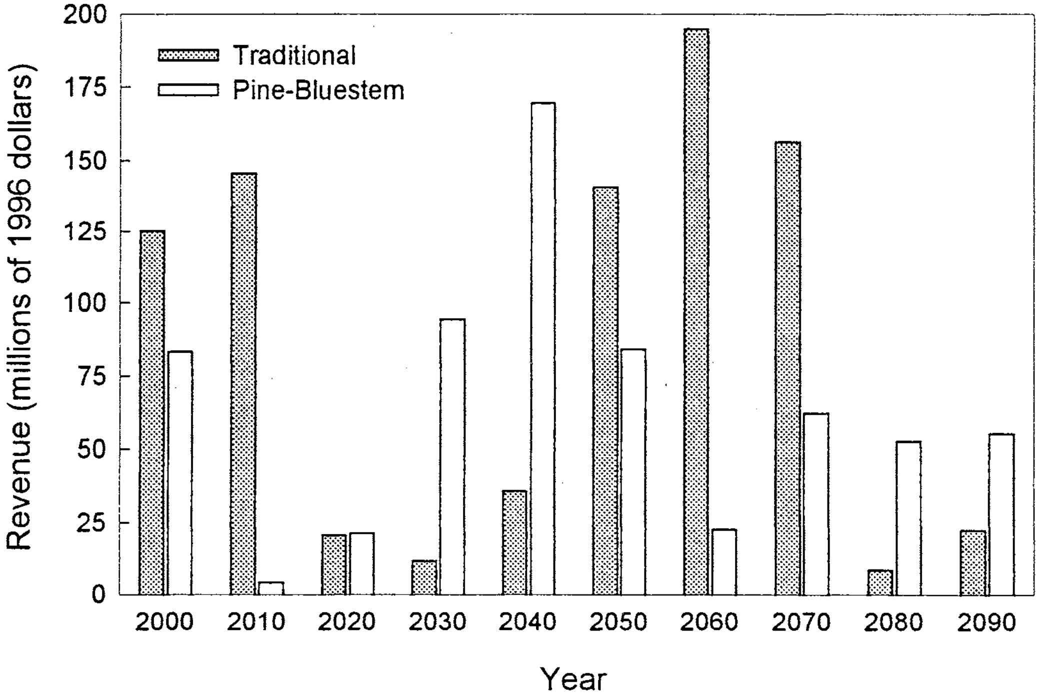

Figure 4.5. Revenue generated from hypothetical timber sales in Management Area 22, by decade, from the traditional and pine-bluestem management scenarios.

Obviously, traditional management does not return more revenue in every decade. However, over the entire simulation period, pine-bluestem management returns 75 percent of the revenue (in undiscounted dollars) generated by traditional management. In present-value terms, discounting the revenue streams back to 2000 at a real annual rate of 4 percent (USDA Forest Service 1990), the pine-bluestem scenario returns only 64 percent of revenue generated by traditional management. The harvests in 2000 and 2010 give traditional management a present-value "advantage."

This model accomplishes the objective of forecasting the present values of hypothetical timber sales as stated at the beginning of this chapter. Chapter 5 will explore the effect on the regional economy of these differences in timber sale revenue.

CHAPTER 5

REGIONAL ECONOMIC ANALYSIS

The objectives of this chapter are to present a brief overview of input-output analysis, and to demonstrate its use in estimating the impact on regional output, value added and employment resulting from changes in harvest volumes and timber sale revenue in Management Area 22.

Introduction to Input-Output Analysis

Input-output (IO) analysis is an outgrowth of Wassily Leontief's (1936) seminal work in which he sought to analyze the interdependence of industries in the U.S. economy. In its simplest form IO is a system of linear equations, each describing the distribution of an industry's output throughout the economy (Miller and Blair 1985).

Observed economic data for a specific region – which may range from a single county to multiple countries – are the underpinnings of IO models. These data indicate the channels through which industries distribute their goods (outputs) and obtain the goods needed (inputs) to produce their outputs (Hewings 1985). In other words, IO concerns itself with the flows of goods from producing to consuming industrial sectors. These flows are contained in an "interindustry transactions" table (the upper-left quadrant of Figure 1). A row in this part of the table describes, in monetary terms rather than physical units, the distribution of a producer's output among the various purchasing sectors, while a column describes the mix of inputs required for an industry's production. The other rows in the table account for the value added by nonindustrial inputs to production (e.g., labor). The remaining columns detail the sales by producing sectors to final demand sectors such as personal consumption expenditures and purchases made by various levels of government. The bottom row indicates the total amount each purchasing sector spends for its inputs, while the right-most column gives the value of total output for each sector. Because of the balanced nature of the transactions table, an industry's total output equals its total outlay.

		Purchasing Sector				Final Demand				
		Agriculture	Mining	...	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Net Exports	Government Purchases of Goods & Services	Total Output
Producing Sector	Agriculture									
	Mining									
	⋮									
	Other									
Value Added	Employees									
	Proprietors and Capital									
	Government									
	Total Outlay									

Figure 5.1. Simplified input-output transactions table (from Miller and Blair 1985).

If X_i and Y_i are, respectively, the total output of and final demand for sector i, the distribution of sector i's output can be represented by:

$$X_i = z_{i1} + z_{i2} + \cdots + z_{ii} + \cdots z_{in} + Y_i \tag{5.1}$$

where the z_{ij}'s are the interindustry sales by sector i to purchasing sectors j. The n sectors in the economy will be represented by an equal number of equations like Equation (5.1), one for each sector. Notice that industry *i* may purchase some of its own output as an input to production, hence the z_{ii} term. In matrix notation, Equation (5.1) is written as:

$$X = Z + Y \tag{5.2}$$

Dividing the flow of input from sector *i* to *j* by the total outlay of sector *j*, as follows:

$$a_{ij} = \frac{z_{ij}}{X_j} \tag{5.3}$$

yields the technical coefficient a_{ij}. This coefficient can be interpreted as indicating the amount of input *i* used to create one dollar of output *j*. One underlying implication of this ratio is that the relationship between a sector's outputs and inputs is fixed (Hewings 1985, MIG 1999). Since inputs are used in fixed proportions, each sector's production function is assumed linear – i.e., it operates under constant returns to scale.

Rearranging Equation (5.3) so that $z_{ij} = a_{ij}X_j$ allows Equation (5.2) to be rewritten in matrix notation as:

$$X = AX + Y \tag{5.4}$$

where the "*A*" term is the matrix of technical coefficients. This formulation explicitly demonstrates the dependence the interindustry flows have on each sector's total output. Moving the "*AX*" term to the left hand side and factoring out the "*X*" yields:

$$(I - A)X = Y \tag{5.5}$$

where "*I*" is the identity matrix. Rearranging Equation (5.5) as:

$$X = (I - A)^{-1}Y \tag{5.6}$$

shows that the value of gross output depends on the values of the final demands. Any change in final demand (dY) is translated into changes in output (dX/dY) by the $(I - A)^{-1}$ matrix, which is known as the Leontief Inverse or total requirements table.

Key Assumptions of Input-Output Analysis

Input-output analysis is based on several key assumptions. While simplifying model formulation, these assumptions sometimes introduce constraints that limit the method's applicability. The assumptions discussed below are adapted from Miller and Blair (1985), Johnson (1996) and MIG (1999).

The first assumption – constant returns to scale – was mentioned in the previous section. Again, because the production functions are considered linear, all inputs change proportionately to any change in final demand. Values in the input-output table are in fixed-price terms relative to a base year. This implies that prices are determined exogenously, rather than endogenously through a process of price discovery. It follows, then, that analyses are valid only as long as the price relationships remain stable.

IO also assumes unlimited and unfixed labor, natural resources and capital. With an unlimited supply of inputs, an industry's output is constrained only by the demand for its output.

Another assumption is a fixed commodity input structure. Because input prices are assumed fixed, an industry has no incentive to substitute inputs. Changes in the economy may affect the industry's output level, but not the mix of commodities and other inputs needed to make its product. Since the parameters making up the commodity input structure are tied to the year during which the data were collected, any policy recommendations resulting from an analysis may be adversely affected if the benchmark year is unusual in some respect (Jorgenson and Wilcoxen 1995).

Homogeneous sector output is the fourth assumption. In other words, if an industry produces more than one output, it produces them in fixed proportion irrespective of the level of total output. It cannot increase the output of one commodity without proportionately increasing the levels of its other outputs.

Finally input-output analysis assumes that an industry uses the same technology to produce all of its outputs. Each industry is assumed to produce one main commodity; all other outputs are byproducts. Also, the technology is fixed to the period during which the data used in creating the input-output table was collected. This and the fixed-price assumption may limit the length of time over which any analysis is valid.

In conclusion, input-output may best be limited to short-term analyses in which prices and technology are not expected to change significantly. Although applied in this study to a long-term (100-yr) problem with unknown future price and technology changes, IO is preferred because of its relative simplicity and the availability of data regarding regional economic relationships. Also, the effects on the regional economy of the Forest Service's transition from traditional management to pine-bluestem management are expected to be minor. A final reason for using IO in this study is the Forest Service's familiarity with the methodology.

Environmental and Natural Resource Studies Using IO

IMPLAN is a static input-output model originally developed by the Forest Service for use in its forest planning activities. For example, the 1990 Land and Resources Management Plan for the Ouachita National Forest used IMPLAN extensively when considering management alternatives. The software has become widely accepted among researchers as well as state and regional development planners (Maki et al. 1989).

IMPLAN is a highly disaggregated model with 528 sectors, although a user can specify any level of aggregation desired. The software is not survey based, but instead derives its technical coefficients from the 1992 U.S. benchmark input-output accounts (U.S. Dept. Commerce 1998). IMPLAN assumes a uniform national production technology and uses regional purchase coefficients (RPCs) to tailor the technical coefficients to the region. RPCs of the goods-producing sectors are estimated econometrically, while those of the service sectors are computed from uncorrected multi-regional input-output interstate trade flow matrices and estimated regional demand (Rickman and Schwer 1995). Calculated supply/demand pooling ratios serve as upper bounds for all RPCs.

IMPLAN also generates direct, indirect and induced multipliers. Direct multipliers quantify changes in employment and income levels within the industries that, in the case of the forestry products sector, process the resource. These direct multipliers also include changes in "forward-linked" industries (e.g., industries that use the forestry products sector's output as an input to their own production processes). The forward-linked industries require other inputs, some of which may be purchased locally. Local employment and income generated by these additional factor-input purchases – the "backward" linkages – comprise the indirect multipliers. Finally, induced multipliers capture fluctuations in consumer spending associated with changes in payments to households.

The number of published studies using IMPLAN is legion. The software has been used for purposes ranging from determining the feasibility of locating an oriented-strand-board manufacturing plant in north Alabama (Carino et al. 1991) to studying the economic impacts of recreational visits to state parks (Bergstrom et al. 1990). While a complete literature review is beyond the scope of this study, a review of several recent natural resource applications follows.

Flick and Teeter (1988) compared output, income and employment multipliers of forest industries with those of other industries in eight southern states. They determined that forest industries have larger-than-average multipliers because they generally locate close to their resource base and purchase most of their inputs from local firms.

Sullivan and Gilless (1989) determined econometrically that a nonlinear relationship exists between sawmill industry employment and volume of logs processed. They suggested a hybrid approach using both econometric equations and standard input-output analysis when determining the effects of forest policy on employment. Later, Sullivan and Gilles (1990) demonstrated with a hybrid econometric/input-output model that the collective impact of timber harvesting activities by a group of national forests is greater than the sum of the individual-forest effects.

Pedersen et al. (1989) assessed the effects of projected levels of forest-related economic activity in the Lake States. Lord and Strauss (1993) reviewed the IMPLAN model for Pennsylvania with respect to the industries processing the state's solid hardwood resource. They showed that, at least for states like Pennsylvania that do not have a large conifer resource, IMPLAN's lack of distinction between hardwood and softwood timber can lead to inaccurate estimates of regional trade.

Holland et al. (1997) explored strategies the Forest Service might employ when attempting to revitalize and diversify rural communities. They observed that data inaccuracies complicate the analysis when the region is small, but these problems can be fairly easily rectified with on-the-ground reviews and additional secondary information.

Marcouiller et al. (1995) developed a supply-constrained social accounting matrix to quantify the distributional impacts of dramatically increasing forest productivity in McCurtain County, Oklahoma. Olson (1990) estimated the impacts of the Interagency Scientific Committee's northern spotted owl conservation strategy on the economies of Washington, Oregon and California.

Description of Economic Study Area

The region under consideration for this part of the study covers 23 counties in western Arkansas and southeastern Oklahoma (Figure 5.2). When creating the study region, the intent was to incorporate all of the counties that: 1) comprise the Ouachita National Forest, 2) contain primary forest products processors that obtain a significant portion of their raw material from the National Forest, and 3) are within the natural range of shortleaf pine. Because their presence would reduce the influence of the forest products industry, counties containing large metropolitan areas (e.g., Pulaski County, which contains Little Rock) were excluded from the study region.

According to the IMPLAN database, the population of this region exceeds 664,000 in about 252,200 households. The 313 active sectors employ approximately 347,000 individuals, generating $12.0 billion (1996 dollars) in personal income. Total industry outlay/output reached just under $27 billion in 1996. The combined transportation, services and government sector (Table 5.1) accounted for 45.4 percent of the economic activity; timber production and services 0.4 percent.

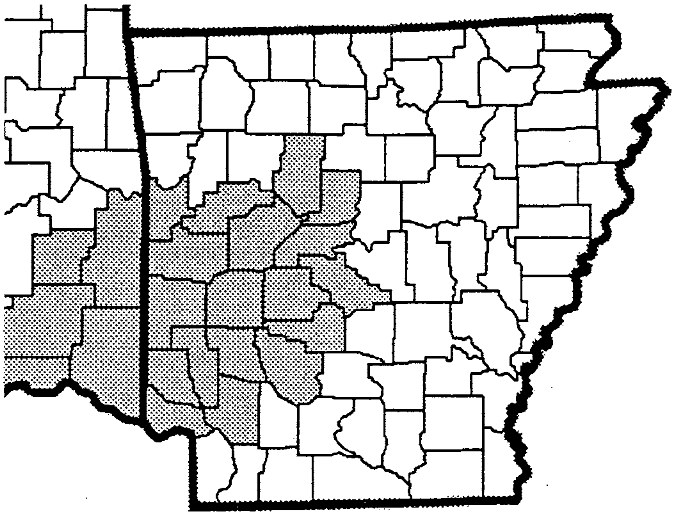

Figure 5.2. Map indicating the counties included in the regional economic analysis.

Forestry Products Sector Activity

In 1996, the region produced $98.7 million of forestry products (primarily stumpage). Just under 26 percent ($25.5 million) of that amount originated on the national forest (MIG 1999). The remainder came from private industrial (49 percent) and non-industrial (20 percent), and state forests (5 percent).

The default forestry products regional purchase coefficient is approximately 0.004, implying that 99.6 percent of the raw material used by primary processors is imported from outside the region. Also, by extension, the same percentage of locally produced stumpage is exported. Relatively low product values for stumpage preclude long haul distances (Flick and Teeter 1988), however, leading to a conclusion that IMPLAN's default coefficient is unreasonably small. The upper limit of the forestry products regional purchase coefficient is restricted by the software to about 0.52 (equal to the domestic supply/demand pooling ratio). Setting the regional purchase coefficient equal to the supply/demand ratio would imply no exports of stumpage from the region. Obviously, some stumpage finds its way out of the region; so a purchase coefficient less than 0.52 is appropriate. The coefficient was changed to 0.5, allowing approximately $6.5 million of regional production to be exported.[1] No other regional purchase coefficients were modified despite references to unrealistic values in the literature (e.g., Marcouiller 1992, Rickman and Schwer 1995).

Table 5.1. Sector-aggregation scheme, with each sector's associated industries and proportion of total regional output, used in the regional impact analysis.

Aggregated sector name	IMPLAN industry number	Proportion of total regional output (%)*
Agricultural production	1-7, 9, 11-13, 16-18, 21-23, 27	6.6
Food and fiber processing	58-60, 63-66, 69, 71, 77-80, 82, 85, 94-96, 100, 101, 108, 124, 126, 128-130, 132	13.5
General manufacturing	35-41, 45-54, 149-151, 153, 156, 160, 174-176, 178-180, 183, 184, 186, 189-191, 200-203, 205, 209, 211, 212, 215, 218-220, 224, 225, 229, 230, 232, 233, 240-248, 250, 251, 254, 257, 259, 263-265, 267, 268, 275, 276, 278, 279, 282-290, 294-297, 303, 304, 306-313, 315, 317-319, 321, 325, 327, 331, 332, 334-336, 339, 342, 345, 347, 349, 351, 353, 354, 356-358, 362, 369, 370, 376-379, 381, 383, 385-387, 389-391, 393, 394, 397, 399, 402, 403, 408, 412, 417-421, 424, 429, 432	24.5
Timber and wood processing	133-148, 154, 157, 162-164, 167, 169, 173	9.7
Timber production and services	24, 26	0.4
Transportation, services and government	55-57, 433-485, 487-509, 511-513, 515, 519-525	45.4

*From MIG (1999).

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[1] A commodity's supply/demand pooling (S/D) ratio estimates the proportion of regional demand satisfied by local production. IMPLAN assumes that local supply will be used to first satisfy local demand; only if supply exceeds demand will the remainder be exported. If a particular S/D ratio < 1, the region is a net importer of that commodity. Since IMPLAN ultimately uses regional purchase coefficients (RPCs) rather than S/D ratios to estimate trade flows, exports may still occur if the commodity's RPC < S/D ratio.

Demand for forestry products by other industries and households reached \$178.7 and \$5.8 million, respectively. To make up the shortfall, \$92.2 million of stumpage was imported into the region during 1996 (MIG 1999).

Methods

Comparison of Regional Output

As shown in Chapter 3, harvest volumes will decline as pine-bluestem management is adopted in Management Area 22. This decline will result in less stumpage available for distribution to other sectors, including raw materials to processing industries. Because this outcome violates IO's assumption of unlimited inputs, and because IMPLAN software is designed to analyze economic impacts originating with changes in final demand, it cannot be used to directly predict the effect of fluctuations in Forest Service timber sales. Nonetheless, much of the logic IMPLAN uses when conducting an impact analysis can be applied to this situation.

The first step of the analysis involves predicting the change in output of all other sectors resulting from a change in the forestry products industry (IMPLAN sector 24). This is accomplished by treating the change in forestry products output as if it originated entirely from a reduction in final demand (i.e., setting $\Delta Y_{24} = \Delta X_{24}$) much as IMPLAN would if forestry products were, in fact, a finished product – and then by multiplying the change in forestry products output by the coefficients (α_{ij}) of the Leontief inverse[2] as

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[2] This study used Type "SAM" multipliers – essentially Type II multipliers, but capturing the inter-institutional transfers by incorporating all social accounting matrix information. Type SAM multipliers typically have slightly smaller values than their Type II counterparts (MIG 1999).

shown in Equation (5.7). The resulting vector contains the change in each backward-linked industry's output resulting from a change in the forestry products sector.

$$\Delta X \qquad = \qquad (I-A)^{-1} \qquad \Delta Y$$

$$\begin{bmatrix} \Delta X_1 \\ \Delta X_2 \\ \vdots \\ \\ \Delta X_n \end{bmatrix} = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & \cdots & \alpha_{1,n} \\ \vdots & & & \vdots \\ \alpha_{24,1} & \alpha_{24,2} & \cdots & \alpha_{24,n} \\ \vdots & & & \vdots \\ \alpha_{n,1} & \alpha_{n,2} & \cdots & \alpha_{n,n} \end{bmatrix} \begin{bmatrix} 0 \\ \vdots \\ \Delta Y_{24} \\ \vdots \\ 0 \end{bmatrix} \tag{5.7}$$

Summing the vector of ΔX_i's yields the direct and indirect effects of the change in forestry products alone. For example, a \$1-million reduction in forestry products alone reduces regional output by \$1.33 million.

Step two estimates the changes in output of the industries that use forestry products as inputs. Here input-output's assumption of homogeneous sector output comes into play; i.e., a cubic foot of southern yellow pine harvested on the Ouachita National Forest is identical to that from a state or private forest. It follows, then, that the true source of a reduction or increase in stumpage output is irrelevant. Thus, we can treat the change in supply as if it came from the forestry products sector itself, rather than from a change in federal government institutional sales.

If a change in the supply of forestry products affects each purchasing industry in proportion to its flow, then multiplying the vector of purchasing industries' direct-output or distribution coefficients $\left(\vec{A}_{24,j}\right)$[3] by the change in forestry products output yields the

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[3] The direct-output coefficient $\vec{a}_{ij} = \dfrac{z_{ij}}{X_i}$, where X_i is sector i's gross output (row sum), indicates the proportion of sector i's output sold to industry j. Contrast with Equation (5.3).

change in flow ($\Delta Z_{24,j}$) of forestry products used by each purchasing industry j, as shown in Equation (5.8):

$$\begin{array}{ccccccc} \Delta Z_{24,j} & & & = & \Delta X_{24} & & \vec{A}_{24,j} \\ \left[\Delta z_{24,26}\right. & \Delta z_{24,27} & \cdots & \left.\Delta z_{24,432}\right] = & \Delta X_{24} & \left[\vec{a}_{24,26} \quad \vec{a}_{24,27}\right. & \left.\cdots \quad \vec{a}_{24,432}\right] \end{array} \tag{5.8}$$

The change in purchasing industries' outputs (ΔX_j) can be estimated by multiplying the vector of flow changes ($\Delta Z_{24,j}$) by a diagonalized vector of input-output coefficients ($A_{24,j}$) as in Equation (5.9).

$$\begin{array}{ccccc} \Delta X_j & = & A_{24,j} & & \Delta Z_{24,j} \\ \begin{bmatrix} \Delta X_{26} \\ \Delta X_{27} \\ \vdots \\ \Delta X_{432} \end{bmatrix} & = & \begin{bmatrix} a_{24,26} & & & \\ & a_{24,27} & & \\ & & \ddots & \\ & & & a_{24,432} \end{bmatrix} & & \begin{bmatrix} \Delta z_{24,26} \\ \Delta z_{24,27} \\ \vdots \\ \Delta z_{24,432} \end{bmatrix} \end{array} \tag{5.9}$$

For example, the sawmill and planing industry (sector 134) uses \$0.0266 of forestry products for every dollar of output. To manufacture its 1996 output of \$733.12 million (Table 5.2), that industry requires (733.12 · 0.0266) = 19.50 million dollars of forestry products (39.965 percent of the sector 24's output of \$48.8 million). Thus, a \$1-million reduction in forestry products industry output results in a (1 · 0.39965) = \$399.65-thousand reduction in output from sawmill and planing mill output, or almost \$893 thousand in all regional "downstream" industries combined.

Step three is quite similar to step one, except that instead of estimating the effects on the "backstream" industries resulting from a change in only the forestry products industry, the same procedure is carried out for all 26 industries mentioned in step two. The backstream changes from each of the 26 industries are aggregated into one vector.

Table 5.2. Example of the effect of a $1-million reduction in forestry products on industries using forestry products as an input.

Purchasing industry (PI)						
Sector number	Description	Industry-24 to PI direct coefficient	Total PI outlay ($$\cdot 10^6$)	Actual flow from Industry 24 to PI ($ thousands)	Proportion of actual flow to Industry 24 outlay (%)	Forward-linked change ($ thousands)
26	Agricultural, forestry and fishery services	6.42457E-04	48.14	30.93	0.0634	-0.634
27	Landscape and horticultural services	1.19813E-05	22.07	0.26	0.0005	-0.005
69	Pickles, sauces and salad dressings	8.51907E-05	22.62	1.93	0.0039	-0.039
82	Confectionery products	3.88020E-04	1.30	0.50	0.0010	-0.010
85	Salted and roasted nuts and seeds	2.08679E-04	117.77	24.58	0.0504	-0.504
95	Bottled and canned soft drinks and water	1.07305E-04	41.13	4.41	0.0090	-0.090
96	Flavoring extracts and syrups, N.E.C.	6.98470E-04	0.55	0.38	0.0008	-0.008
124	Apparel made from purchased materials	1.66847E-03	188.02	313.71	0.6428	-6.428
133	Logging camps and logging contractors	8.85262E-02	229.21	20,291.10	41.5801	-415.801
134	Sawmills and planing mills, general	2.66028E-02	733.12	19,503.05	39.9653	-399.653
135	Hardwood dimension and flooring mills	1.02989E-03	64.27	66.19	0.1356	-1.356
136	Special product sawmills, N.E.C.	7.36953E-03	0.17	1.25	0.0026	-0.026
139	Veneer and plywood	3.09201E-02	31.67	979.24	2.0066	-20.066
153	Household furniture, N.E.C.	4.88285E-03	8.84	43.16	0.0885	-0.885
186	Alkalies and chlorine	3.93353E-06	3.78	0.01	0.0003	-0.003
189	Inorganic chemicals, N.E.C.	3.35964E-06	162.53	0.55	0.0011	-0.011
190	Cyclic crudes, interm. and indus. organic chem.	4.94836E-06	4.95	0.02	0.0001	-0.001
200	Paints and allied products	2.40234E-04	9.83	2.36	0.0048	-0.048
201	Gum and wood chemicals	1.39987E-02	21.24	297.33	0.6093	-6.093
205	Adhesives and sealants	7.88346E-05	24.18	1.91	0.0039	-0.039
215	Tires and inner tubes	1.99435E-02	71.52	1,426.36	2.9229	-29.229
218	Gaskets, packing and sealing devices	1.67074E-03	33.59	56.12	0.1150	-1.150
219	Fabricated rubber products	1.14178E-02	42.70	487.54	0.9991	-9.991
267	Nonferrous wire drawing and insulating	3.36686E-04	32.55	10.96	0.0225	-0.225
421	Sporting and athletic goods, N.E.C.	3.32048E-04	49.71	16.51	0.0338	-0.338
432	Manufacturing industries, N.E.C.	2.22573E-04	3.31	0.74	0.0015	-0.015
Total					89.2646	-892.646

Summing the vector elements yields the regional "induced" effect of the forestry products change. A $1-million reduction in forestry products creates a $1.42-million induced reduction in regional output.

The final step eliminates the double counting that occurs as a result of the change in forestry products itself, as well as the direct, indirect and induced changes in forestry products output resulting in the changes in output of the 26 industries mentioned in step two. For example, when a $1-million reduction in forestry products output is run through the economy, the resulting reduction in all other sectors induces another $60,000 reduction in forestry products. That value is double counting, however (i.e., it was already accounted for in the original $1-million reduction). Running the $60,000 through the procedure outlined in step one yields the amount of double counting in each sector. The total double counting amounts to $80,000. Subtracting the double counted value from the direct and induced changes results in the final, net change in the regional economy. So, a $1-million reduction in forestry products output results in a net decrease of $2.67 million in the region's output.

$$\begin{array}{ccccc} \text{Direct \& Indirect} + & \text{Induced} - & \text{Double Counting} & = & \text{Net Change} \\ (-1.33) & +(-1.42)- & (-0.08) & = & -2.67 \end{array} \tag{5.10}$$

<u>Comparison of Value Added and Employment</u>

The comparison of value added between the traditional and pine-bluestem management scenarios was accomplished in much the same way as the change in regional output. IMPLAN reports each industry's total value added and employment. As shown in Equation (5.11), dividing each industry's total value added (VA_i) by its output yields the value-added direct coefficient. The difference in regional value added (ΔVA)

between the management strategies was obtained by multiplying the value-added direct coefficient by the difference in output between the two scenarios.

$$\Delta VA = \begin{bmatrix} \frac{VA_1}{X_1} & \frac{VA_2}{X_2} & \cdots & \frac{VA_n}{X_n} \end{bmatrix} \begin{bmatrix} \Delta X_1 \\ \Delta X_2 \\ \vdots \\ \Delta X_n \end{bmatrix} \tag{5.11}$$

As shown in Equation (5.12), the same procedure was used for estimating changes in regional employment (ΔE). Thus, a \$1-million reduction in forestry products output translates to a \$1.22-million reduction in regional value added, and 23.5 man years of employment lost region wide.

$$\Delta E = \begin{bmatrix} \frac{E_1}{X_1} & \frac{E_2}{X_2} & \cdots & \frac{E_n}{X_n} \end{bmatrix} \begin{bmatrix} \Delta X_1 \\ \Delta X_2 \\ \vdots \\ \Delta X_n \end{bmatrix} \tag{5.12}$$

Results

Changes in regional output and value added were estimated for each decade of the simulation period. Subtracting the undiscounted revenue generated by the pine-bluestem scenario from that of the traditional scenario yields the amount by which revenue increases or decreases as a result of the transition to the pine-bluestem scenario. The procedure outlined in the previous section (Equations 5.7-5.10) extends the changes in revenue (or forestry products output) to total regional output, value added and employment at the regional level. Table 5.3 presents the undiscounted differences in timber sale revenue over the projection period, and the resulting changes in total regional output, value added, and employment. Note that the values reported in Table 5.3

represent the cumulative impact during an entire decade. The lower revenue generated by the pine-bluestem scenario is reflected in reduced regional economic activity. In present value terms, forestry products output declines by $111.0 million during the entire 100-yr simulation period; regional output: $296.3 million; and total value added: $135.6 million. Regional employment declines by just under 5,000 man years.

Table 5.3. Undiscounted differences in forestry products sector output, and corresponding changes in total regional output and value added (millions of 1996 dollars) and employment, by decade, resulting from the transition from traditional even-aged management to pine-bluestem management.

Decade	Forestry products output	Regional output	Value added	Man years of employment
2000	-41.8	-111.6	-51.0	-983
2010	-141.3	-377.2	-172.6	-3,324
2020	0.7	1.8	0.8	16
2030	82.8	221.0	101.1	1,948
2040	133.7	356.8	163.2	3,145
2050	-56.3	-150.4	-68.8	-1,325
2060	-172.0	-458.9	-210.0	-4,045
2070	-94.3	-251.7	-115.1	-2,218
2080	44.1	117.6	53.8	1,036
2090	32.9	87.9	40.2	774

Although these numbers appear large, they are quite small as a percentage of total regional economic activity. For example, the largest cumulative decline in total regional output (during the decade of 2060-2069) is less than 1.7 percent of total 1996 industry output; similarly, man years of employment decline by just over one percent during the same decade.

Considerable disparity exists with respect to the distribution of impacts across economic sectors. Not surprisingly, the forestry-related sectors absorb the brunt of the impact from changes in the volume of stumpage offered for sale (Table 5.4). The transportation, services and government sector is also affected. Ag production, food and fiber processing, and general manufacturing are essentially stable. Employment in the transportation, services and government sector experiences an impact seemingly out of proportion to the impact on output. This can perhaps be explained by a comparatively large direct coefficient for employment.

Table 5.4 Distribution of total regional changes in output, value added and employment across aggregated sectors.

Aggregated sector name	Percentage of total regional change in		
	Output	Value added	Employment
Agricultural production	2.6	2.8	4.0
Food and fiber processing	1.4	0.7	1.4
General manufacturing	3.1	2.3	2.5
Timber and wood processing	37.2	28.0	28.5
Timber production and services	40.4	45.6	30.7
Transportation, services and government	15.2	20.6	33.0

Despite the apparent insignificance of the regional economic changes, one might question whether adopting the new regime may exacerbate the business cycle. Let us imagine that, during the decade of 2010 to 2019, the regional economy experiences a substantial upturn in activity accompanied by rising prices for stumpage and lumber. In such a situation strict adherence to the pine-bluestem management scheme, by making less stumpage available for sale, could cause stumpage prices to rise higher than they would otherwise. Alternatively, if during the decade of 2030 to 2039, the economy is experiencing a recession with falling prices, the extra infusion of stumpage the pine-bluestem scenario would inject into the market could further depress prices.

The Ouachita National Forest might consider scheduling the transition from traditional to pine-bluestem management in an attempt to minimize the impact on the regional economy in general, and stumpage and lumber prices in particular. The success of such an attempt, however, would hinge primarily upon whether the Forest Service is capable of accurately predicting the fluctuations in market prices and properly responding to them.

Judging from the changes in total regional output resulting from the transition to pine-bluestem management, adopting the new scenario will not cause significant adverse economic consequences. In most years, the revenue foregone from Management Area 22 could be recouped by offering a few additional sales elsewhere on the National Forest.

CHAPTER 6

ANALYSIS OF COST DIFFERENCES AND DISCUSSION OF RESULTS

This chapter quantifies differences in cost streams resulting from the transition from traditional to pine-bluestem management in Management Area 22. Also, results from previous chapters are summarized, and implications for management are discussed.

Cost Comparisons

For this analysis, cost comparisons were limited to timber marking and prescribed burning. Other costs are not expected to vary enough between management scenarios to warrant study.

Timber Sale Marking

As mentioned in Chapter 3, the Poteau District follows a policy of entering each stand once per decade. If stand conditions warrant, and there is sufficient volume in surrounding compartments to justify doing so, the staff foresters create a timber sale to remove excess stocking. A substantial share of the cost associated with a timber sale derives from the labor and materials expended to cruise and mark the stands.

Cost differentials when marking timber for harvest are well understood: stands comprised of younger, smaller stems are more expensive to treat than older stands with fewer, larger stems. Busby and Kluender (1994) found that commercial thinnings of young stands were approximately three times more costly to mark than shelterwood cuts in the Ouachita National Forest. As documented in Chapter 3, Management Area 22 will carry fewer stems for longer periods if converted to pine-bluestem stands than if they continued under traditional even-aged management. Thus, on average, marking costs under the pine-bluestem scenario will be lower than in the traditional scenario.

Methods. During each decade of the simulation period, some of the stands in Management Area 22 required commercial thinning or a harvest/regeneration cut. The simulation software tallied the trees removed from a stand during a timber sale by 1-in. diameter classes, allowing for differentiation between pulpwood and sawtimber. Stands whose harvest volumes contained only pulpwood were assigned Busby and Kluender's (1994) value of $4.20 per CCF for commercial thinning. Stands containing at least some sawtimber were assigned $1.45 per CCF, the value for shelterwood cuttings. Dubois et al. (1999) indicate that marking costs were unchanged between 1994 and 1996.

Results. Figure 6.1 compares the costs, by decade, incurred for marking thinning/harvest cuts under both the traditional and pine-bluestem management scenarios. Marking costs are consistently higher in the traditional scenario, because of the greater prevalence of pulpwood volume, even in 2030 and 2080 when the total volume marked under the pine-bluestem scenario is greater (compare Figure 3.3). Over the entire simulation period, total expenditures for marking pine-bluestem sales are only 63 percent of the traditional scenario's costs. The difference in total expenditures has a present value (in 1996 dollars) of $1.4 million.

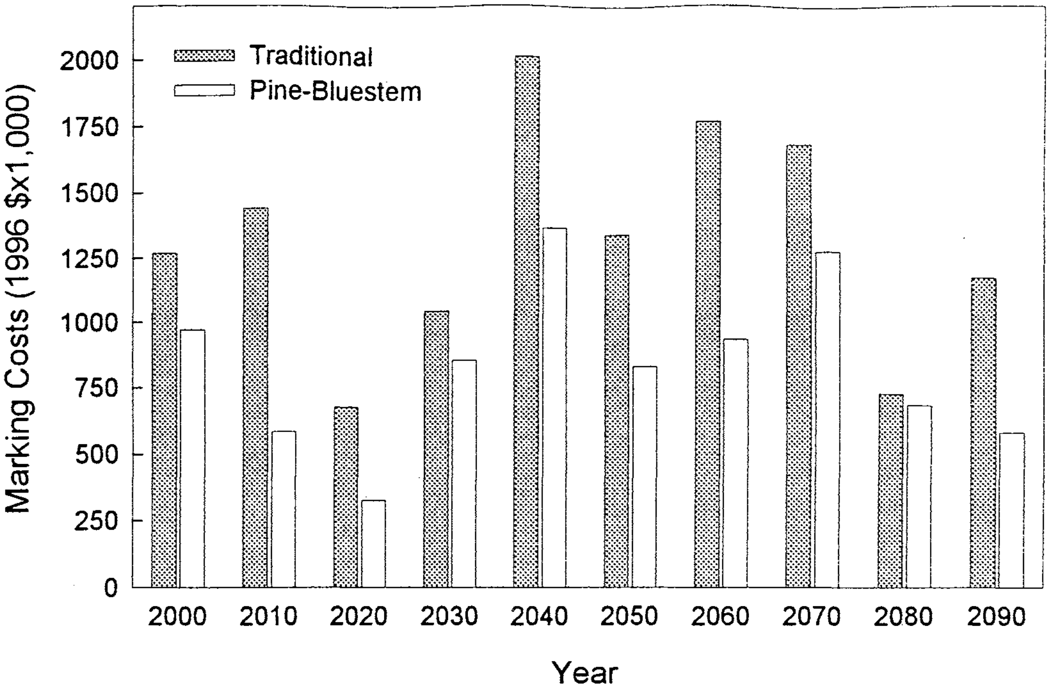

Figure 6.1. Comparison of undiscounted timber sale marking costs (thousands of 1996 dollars) for harvests under the traditional and pine-bluestem management scenarios, by decade.

Prescribed Burning

One of the features of pine-bluestem management is a more aggressive burning schedule. The Poteau Ranger District has traditionally attempted to maintain a 4-yr burning cycle, successfully burning 12,000 ac/yr during the past four years. During years of cooperative weather, the district staff estimate they could burn 20,000 ac/yr given current available personnel.[1] Appendix B contains additional details about the pine-bluestem fire regime, but the most important feature is a 3-yr burning cycle. Although a 1-yr reduction in the length of the burning cycle may not seem significant, the combination of longer rotations and shorter burning cycles should combine to substantially increase the annual burning quota. At present, no data have been published

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[1] Personal communication, Warren Montague, USDA Forest Service wildlife biologist, 17 April 2000.

indicating that pine-bluestem stands are less expensive to burn than traditional stands, so the same per-unit cost values are used in both scenarios.

Methods. During each 3- or 4-yr cycle (depending on the management scenario), all acres in Management Area 22 not in the early regeneration phase of stand development were treated with a prescribed burn. Cost estimates for prescribed burning in the Poteau Ranger District vary greatly, depending upon the season during which a burn is conducted, and ignition method used. For example, ignition from helicopters during the dormant-season is estimated to cost about $4/ac, whereas growing-season drip torch ignition costs $15/ac (year 2000 prices). Dubois et al. (1999) estimate that burning costs have increased by 6.3 percent annually since 1996, so the burning costs were discounted by that rate to translate them into 1996 prices (yielding $3.14 and $11.76 per acre, respectively, for the low and high estimates). Present values of the costs associated with each burning cycle were obtained by multiplying the acreage burned by the low and high cost estimates, and then discounting those products at the real rate of 4 percent back to the year 2000.

Results. Table 6.1 displays the acreage burned on an annual basis under the two management scenarios, and the present values (in 1996 dollars) of the burning expenditures incurred during the entire simulation period. As expected, the pine-bluestem scenario requires a substantially greater commitment with respect to the acreage burned and the associated expenditures. During the simulation period, the pine-bluestem scenario burns 41 percent more acreage and expends 48 percent more funds than the traditional scenario.

Table 6.1. Comparison of acres prescribed burned per year, and present values (low and high estimates) of burning expenditures over the entire simulation period, by management scenario.

	Acres burned per year				Present values of total expenditures*	
Management scenario	Mean	Standard deviation	Minimum	Maximum	Low estimate	High estimate
Traditional	21,387	6,204	7,582	24,852	1.67	6.26
Pine-bluestem	30,539	3,032	24,700	33,136	2.47	9.24

*Millions of 1996 dollars.

Current staffing and funding levels are nearly sufficient to cover the traditional burning regime in Management Area 22. During an average year, the Poteau District would burn a little over 21,000 ac. Some additional funding would be needed during peak burning years, however. Under the pine-bluestem scenario, on the other hand, current funding and staffing are insufficient to accomplish even the minimum burning goals. During an average year, district staff will need to burn 50 percent more acreage than their current capacity.

Implications for Management

The simulation results presented in Chapter 3 and Appendix C highlight some interesting points about the management of the Ouachita National Forest. Figure 6.2 shows that the traditional even-aged management scenario's 70-yr rotation length exceeds what foresters consider the biological rotation (indicated by the convergence of mean and periodic annual total volume increment). Additional revenue could be generated by reducing traditional rotations by between 5 and 15 years, depending upon site quality.

The accumulated volume production figures presented in Appendix C demonstrate that traditional management yields the greatest overall volume. In stands with site index=50 ft and initial pine BA of 30 ft^2/ac, traditional management produces 2,370 ft^3/ac of sawtimber volume by age 70 compared to 2,265 ft^3/ac under pine-bluestem management. At the other end of the spectrum, in stands with site index=70 ft and initial pine BA of 90 ft^2/ac, traditional management yields 4,484 ft^3/ac by age 70 compared to 3,835 ft^3/ac under pine-bluestem management. Although traditional stands produce more volume, pine-bluestem stands turn out trees with larger diameters. For example, after the regeneration cut occurs in the traditional scenario at age 60, quadratic mean diameter in the traditional stand with site index=70 ft and initial BA of 60 ft^2/ac is 1 in. smaller than in the comparable pine-bluestem stand. A lower-stocked stand may produce less volume overall, but the volume it produces is packaged on fewer and larger stems. As mentioned in Chapter 4, larger trees are more valuable to procurement foresters on a per-unit basis than smaller trees. While not advocating the imposition of pine-bluestem stocking levels everywhere on the Ouachita, the Forest Service might consider small stocking reductions in traditionally managed stands to stimulate the growth of larger stems.

One caveat to the previous statement, however, is that current sawmill technology is trending toward the processing of smaller logs. Thus, if the logs produced under pine-bluestem management exceed the size limits of all but one or two processors (the simulator predicts maximum average diameters of nearly 28 in.), prices offered for that material may in fact decline for lack of demand.

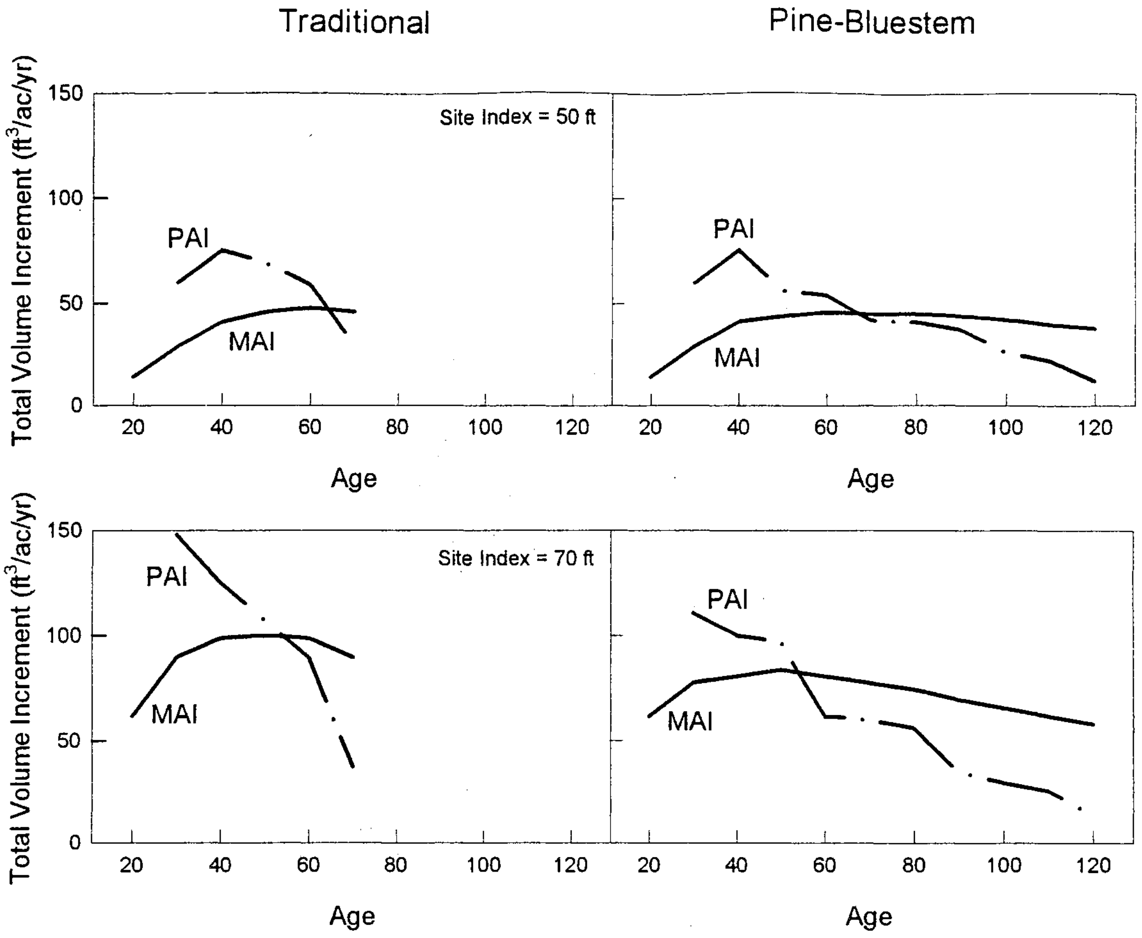

Figure 6.2. Comparison of biological rotation lengths, indicated by the convergence of mean and periodic annual total volume increment (MAI and PAI, respectively), for different quality stands.

By converting to the pine-bluestem scheme, the Forest Service will be retaining stands in Management Area 22 for approximately double the biological rotation length, until they are producing total volume at a rate of only 10 to 15 ft^3/ac/yr. The lowest site quality stand with sparse initial stocking (site index=50 ft; initial pine BA of 30 ft^2/ac) produces 3,610 ft^3/ac of sawtimber volume by age 120. If the stand had continued under traditional management, there would be a second generation of 60-yr-old trees on the site, and the area would have yielded almost 25 percent more sawtimber volume. Similarly, the high site quality, densely stocked stand (site index=70 ft; initial pine BA of 90 ft^2/ac) would produce almost 60 percent more sawtimber volume under traditional management than the 5,370 ft^3/ac produced under pine-bluestem management.

Duerr (1960), and Duerr and Christiansen (1964) present an approach for quantifying the incremental costs of changing management regimes.. This method estimates the cost of maintaining the inventory of stems required to sustain each scenario. The traditional regime, for example, requires the presence of stands in every age class between 0 and 70 years. Using Table C.2 to represent the traditional scenario, the age classes between 10 and 20 yr contain roughly 3,040 ft^3 $[608/2 \cdot 10]$. Age classes between 20 and 30 yr contain 11,105 ft^3 $[(608+1613)/2 \cdot 10]$. The inventory in the 40- and 50-yr age classes is estimated in a similar fashion. Finally, the age classes between 60 and 70 yr contain 10,450 ft^3 $[(880+1210)/2 \cdot 10]$. Altogether, the scenario requires 84,110 ft^3, or 1,202 ft^3/ac $[84110/70]$ of inventory. By contrast, the pine-bluestem scenario (Table C.6) requires stands aged 0 to 120 yr in order to sustain itself. These stands contain 168,875 ft^3 overall, or 1,406 ft^3/ac. In other words, the pine-bluestem regime contains an additional 204 ft^3/ac. If an average cubic foot of sawtimber is worth $1.48 (from Table 4.1), the difference in inventory between the two scenarios is worth approximately $300/ac. The return on this capital stock (i.e., rent) amounts to about $24/ac/yr at a real discount rate of 8 percent, or about $12/ac/yr at 4 percent.[2] In other words, once the Forest Service has converted Management Area 22 to the pine-bluestem forest type, it will incur an implicit cost of $12/ac/yr (applying the Forest Service's preferred discount

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[2] The return on capital stock can be estimated by rearranging the formula for calculating the initial value of a terminable annual series, as follows: $r = V_0 \left[i(1+i)^n\right] / \left[(1+i)^n - 1\right]$ where r is the rent, V_0 is the difference in value of the inventory, i is the discount rate, and n is the 120 yr in the pine-bluestem rotation.

rate) to maintain the red cockaded woodpecker habitat. For all 99,408 acres of Management Area 22 managed for pine-bluestem, this cost amounts to $1.2 million per year. When combined with the $111 million decline in the present value of projected timber sale revenue from the area (or $1.1 million per year), the total cost rises to $2.3 million per year. This translates into an implicit value for each pair of woodpeckers of either $5,750 or $9,200 per year (for the desired 400 total, or 250 reproducing pairs, respectively).

Is Pine-Bluestem Management Feasible?

The success of the pine-bluestem restoration hinges upon the Forest Service's ability to maintain a burning regime that prevents competing vegetation from occupying the middle canopy layer. Throughout the Ouachita Highlands, hardwoods have demonstrated a tremendous capacity to occupy sites and thrive in the absence of fire. Any significant deviation from the burning schedule will thus increase the probability that stems which would otherwise be limited to the understory layer can move into the midstory. A substantial midstory stand component, especially one dominated by hardwoods, shades out the bluestem grasses and related vegetation.

Other forms of competition control could possibly be substituted for prescribed burning, although implementing them might prove nearly impossible. Herbicides, for example, are strongly opposed by several groups who have attempted to redress past grievances through judicial appeal. Hand felling of stems is quite labor-intensive and would likely be prohibitively expensive. Moreover, none of the alternative methods of competition control duplicates the effect achieved by burning. Areas treated with these other forms of competition control could hardly qualify as pine-bluestem stands if the understory plant association contained little or no bluestem grass.[3]

Despite the Forest Service's strict adherence to smoke management policies, the capricious behavior of weather patterns can turn an otherwise successful burn into a public relations nightmare. On 24 March 1998, for example, a pall of smoke from fires burning on the Poteau, Cold Spring and Fourche Ranger Districts closed the airport in Fort Smith, Arkansas. Mansfield, Arkansas was similarly blanketed on 10 April 2000. By adhering to a more aggressive burning schedule, similar accidents have a greater probability of occurring. Such incidents may turn the tide of public opinion against prescribed burning.

Part of the smoke management problem lies with the fact that many of the stands in Management Area 22 still have a considerable hardwood fuel load in them. Fires set in those stands smolder for several days, thereby increasing the opportunity for problems. Once the hardwood fuel is consumed and herbaceous vegetation comprises the bulk of the fuel load, experience in other parts of the South indicates that smoke management problems are commensurately lessened.[4]

Statutory changes are currently being considered whereby the Arkansas Forestry Commission would be granted the authority to regulate prescribed burns undertaken anywhere in the state, including the Ouachita National Forest. If passed, permission would depend upon the number and locations of other parties who had already been permitted to burn at any given time. Any additional restrictions placed on the Forest Service's burning program – in the form of either stricter enforcement of existing air-

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[3] Personal communication, John Strom, USDA Forest Service silviculturalist, 2 May 2000.
[4] Personal communication, John Strom, USDA Forest Service silviculturalist, 2 May 2000.

quality regulations, or the drafting of additional regulations – may hamper its efforts to create and maintain the red-cockaded woodpecker habitat and pine-bluestem ecosystem.

Finally, the Poteau District staff are beginning to question whether, given current staffing and budgetary constraints, they may have set unattainable goals for the pine-bluestem restoration effort. They are currently evaluating the possibility of concentrating for the present on just the core area (Management Area 22a shown in Figure 1.1), and expanding outward as additional support becomes available.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Brief Overview of the Dissertation

The Problem

In 1996 the USDA Forest Service approved an amendment to the forest plan for the Ouachita National Forest whereby a little less than 10 percent of the Forest would be managed under long-rotation silviculture. The purpose of the new management area (Management Area 22) is to restore pre-European settlement forest conditions, and thereby recreate habitat for the endangered red-cockaded woodpecker. The core question addressed in this dissertation deals with whether any adverse economic effects will occur because of this shift in forest management, and if so, in what economic sectors would the effects be most noticed. The primary objective of this study was to develop procedures for estimating the magnitude of impacts resulting from changes in timber production in the pine-bluestem management area.

The Methods

This objective was accomplished in three ways: 1) by creating a system of equations that predicts how the growth and yield of shortleaf pine trees change under different conditions and management styles, and comparing the stumpage volume produced under pine-bluestem with that from traditional even-aged management; 2) by estimating the revenue from timber harvests occurring under each management scheme; and 3) by conducting an impact analysis, tracking the effects of the reduction in revenue through the greater regional economy. The methodology in this study is similar to that used by the Forest Service when developing forest management plans.

The Results

Under pine-bluestem management, with its longer rotation length and lower stand density, timber harvests in Management Area 22 decline by 31 percent during the 100-yr simulation period. This translates into a loss of timber sale revenue in present-value (1996 dollars) terms of about $111 million, or 38 percent less than the area might have generated under traditional management. On a regional level, total output declines by $296 million, in present-value terms, over the entire 100-yr period. Over 78 percent of the reduction of total output and 59 percent of employment is borne by the wood producing and processing industries. To maintain perspective, however, one must recall that these reductions occur in an economy whose total output exceeded $27 billion in 1996 alone.

Some management costs increase while others decrease under the new management scenario. Because of greater amount of time between harvests and a more open stand structure, timber sale marking costs decline in the pine-bluestem scenario. However, expenditures related to prescribed burning will rise substantially as a result of the shorter burning cycle. In fact, the acreage that should be burned each year in Management Area 22 is one-third the total area currently burned Forest-wide. A greater budgetary commitment will be required to maintain this fire-dependent ecosystem.

Implications and Conclusions

A resource not exchanged in traditional markets can be difficult to value in monetary terms. One can obtain an estimate, however, by observing the monetary value of another activity or resource that could have been produced or consumed instead of preserving the non-market resource (Goulder and Kennedy 1997). Thus, by restoring the pine-bluestem ecosystem in Management Area 22, the Forest Service is implicitly assigning monetary values to the red-cockaded woodpecker population of $111 million in timber sale revenue and $296 million in total regional output foregone during the 100-yr simulation period.

Maintaining the pine-bluestem ecosystem may become increasingly difficult what with public sentiment beginning to turn against widespread prescribed burning, and more stringent air quality regulations on the horizon. Alternative methods of controlling competing vegetation might be used, but they generally are either less effective or more expensive than prescribed burning.

Limitations of this Study

When this project was initiated, staff from the USDA Southern Research Station were only just beginning detailed inventories of Management Area 22. As a result, the stand tables required by the simulation software had to be generated with statistical techniques rather than inventory data. Therefore, the projections of growing stock accumulation and product yields are valid to the extent that the initial stand conditions and the growth models accurately reflect reality. These data have now been collected, however, and could be used to validate the stand tables and growth models.

The timber sale data used to estimate timber sale revenue cover a fairly limited time span. If those years do not represent the actual long-term trend in stumpage prices, the valuations will be inaccurate.

Regional impacts related to only the changes in the volume and value of stumpage are analyzed; thus, the study is biased to the extent that the exclusion of tourism and nonmarket values is important. Also, input-output studies generally are applied to short time periods. The time frame covered in this study violates that assumption. Other limitations associated with the assumptions of input-output, and the software used in this part of the analysis are mentioned in Chapter 5.

Suggestions for Future Research

As mentioned above, this study took into account only one market-valued commodity when studying the impact of the Forest Service imposing a new style of management in part of the Ouachita National Forest. A more complete picture could be developed if the effects on additional resources were quantified. For example, changes in water and air quality, aesthetics, recreation and tourism, hunting, and wildlife habitat in addition to the red-cockaded woodpecker should be incorporated into the analysis.

The stand growth and yield simulator is an amalgamation of models from forest types somewhat different from the pine-bluestem. Better models could be obtained from long-term observations of research plots established in the pine-bluestem area. Long-term studies researching the effects of prescribed burning on tree growth in the Ouachita Highlands would be particularly helpful.

This study did not look into the impacts of the restoration effort on income distribution, or which income groups are most affected by the change in management.

Another study might focus on these issues, and suggest ways to mitigate any adverse consequences. A related study might also look into ways in which the transition between management regimes could be accomplished with the minimum of impacts.

Understanding the interrelationships between public policy changes and private sector economic activity is an interesting research pursuit. Modifying and repeating over time the process presented here will enable decision makers to form better land-management policies.

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APPENDIX A

GROWTH AND YIELD MODELS USED IN THIS STUDY

This appendix describes the growth and yield models contained in the pine-bluestem stand simulator (with the exception of the fire-related models, which are covered in Appendix B).

Shortleaf Pine Models

Basal area growth

This individual-tree basal area (BA) growth equation represents potential tree growth with a Chapman-Richards function (Richards 1959) constrained by maximum tree size (Shifley and Brand 1984). A logistic modifier (Murphy and Shelton 1996), constrained to the interval [0,1], reduces the potential growth on the basis of variables representing stand and tree attributes. The equation (Lynch et al. 1999) has the following form:

$$G_{P,i} = \frac{0.0714 B_{P,i}^{0.4804} - \left(0.0714 B_{P,i} / B_{P,\max}^{1-0.4804}\right)}{1 + \exp(-3.2363 + 0.0158 B_S + 0.0279 A + 1.2945 R_{P,i} - 1.2127 B_{P,i})} \qquad \text{(A.1)}$$

where $G_{P,i}$ is annual growth (ft^2) of shortleaf pine tree i; $B_{P,i}$ is basal area (ft^2) of tree i; A is stand age; $R_{P,i}$ is the ratio of pine quadratic mean stand diameter to the dbh of tree i; $B_S = 1.33 B_H + B_P$ where B_S, B_H and B_P are total BA (ft^2/ac) in the stand, and BA of hardwoods and shortleaf, respectively; and $B_{P,max} = 7.07$ ft^2, the maximum BA expected for a shortleaf pine in the Ouachita Highlands. Multiplying B_H by 1.33 when aggregating B_S is justified by the fact that hardwoods exert greater competitive pressure, in terms of tree area requirement, per unit of BA than do pines (Gingrich 1967, Roach and Gringrich 1968, Cain 1989, Rogers 1983). Some researchers feel B_H=2.0B_P is also justified in terms of light requirement.[1] Use of a larger value would reduce shortleaf BA growth rates and increase hardwood BA growth rates.

Survival

Annual estimates of individual-tree survival are necessary in distance-independent models. The logistic model (Lynch et al. 1999) chosen for this application is:

$$S_{P,i} = \left[1 + \exp\left\{-\left(2.9124 + \frac{4.7893}{R_{P,i}} - 0.0151B_S - 0.0067H_{P,D}\right)\right\}\right]^{-1} \qquad \text{(A.2)}$$

where $S_{P,i}$ is the probability ($0 \leq S_{P,i} \leq 1$) of annual survival for shortleaf pine tree i; $H_{P,D}$ is the average total height (ft) of shortleaf pine dominants and codominants; and the other variables are as previously defined.

Height of dominants and codominants

The heights of dominant and codominant trees were estimated with Graney and Burkhart's (1973) polymorphic site index equation for natural shortleaf pine in the Ouachita Highlands:

$$H_{P,D} = \left[20.975 + 1.2113SI_P\right]\left[1 - \exp\left\{-\left(0.0124 + 1.3639\cdot 10^{-4}SI_P\right)A\right\}\right]^{1.0018} \qquad \text{(A.3)}$$

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[1] Michael Shelton, USDA Forest Service research forester. Personal communication, 7 October 1998.

where SI_P is total height (ft) at age 50 (i.e., site index, base age 50 yr); A is age in years; and the other variables are as previously defined. Equation (A.3) yields a value used in the following total-height equation.

Total height and total height growth

Tree heights are needed in order to estimate total and merchantable tree volumes. Initial total heights can be predicted from Lynch and Murphy's (1995) equation:

$$H_{P,i} = 4.5 + 3.0729(H_{P,D} - 4.5)^{0.7904} \exp(-2.4912 D_{P,i}^{-0.9408}) \qquad (A.4)$$

where $H_{P,i}$ is total height (ft) of shortleaf pine tree i; $D_{P,i}$ is dbh (in.) of tree i; and $H_{P,D}$ is as defined above. The following projection equation predicts future heights from previously measured heights:

$$H_{P,i,2} = 4.5 + (H_{P,i,1} - 4.5)\left(\frac{H_{P,D,2} - 4.5}{H_{P,D,1} - 4.5}\right)^{0.7904} \exp\left[-2.4912\left(D_{P,i,2}^{-0.9408} - D_{P,i,1}^{-0.9408}\right)\right] \qquad (A.5)$$

where $H_{P,i,t}$ and $D_{P,i,t}$ are, respectively, total height (ft) and dbh (in.) of shortleaf pine tree i at time t; and $H_{P,D,t}$ is average total height (ft) of shortleaf pine dominants and codominants at time t.

Crown ratio

Crown ratio is the ratio of the length of a tree's live crown to its total height. It is estimated by:

$$CR_{P,i} = 1 - \exp\left[-\left(2.0347 + 25.2792 A^{-1}\right)\left(\frac{D_{P,i}}{H_{P,i}}\right)^{0.9597}\right] \qquad (A.6)$$

where $CR_{P,i}$ is crown ratio of shortleaf pine tree i; and the other variables are as previously defined (Lynch et al. 1999). Equation (A.6) is used in the simulation software to select the appropriate set of volume equation parameters for each shortleaf pine tree.

Volumes

Total volumes and merchantable volumes to any desired upper-stem diameter limit can be estimated by integrating one of Farrar and Murphy's (1987) taper functions:

$$d_{P,i} = \begin{cases} D_{P,i}\left(h_{P,i}/4.5\right)^{n} & \text{if } h_s \le h_{P,i} \le 4.5 \\ \text{or} & \\ D_{P,i}X/\left(H_{P,i}-4.5\right)+b_1 XZ/H_{P,i}^2+b_2\,D_{P,i}XZ/H_{P,i}^2 & \\ +b_3\,D_{P,i}^2 XZ/H_{P,i}^2+b_4\,XZ\left(2H_{P,i}-h_{P,i}-4.5\right)/H_{P,i}^3 & \text{if } 4.5 \le h_{P,i} \le H_{P,i} \end{cases} \tag{A.7}$$

where $d_{P,i}$ is predicted stem diameter (in.), either outside or inside bark (o.b. or i.b.), at height $h_{P,i}$ (ft) above ground line of shortleaf pine tree i; n and b_1, b_2, …, b_4 are coefficients given in Table A.1; $D_{P,i}$ is diameter (in.) at breast height: $D_{\text{o.b.}}$ if $d_{P,i}$ is diameter o.b., or $D_{\text{i.b.}}$ if $d_{P,i}$ is diameter i.b. ($D_{\text{i.b.}} = g_1 + g_2 D_{\text{o.b.}}$ where g_1 and g_2 are coefficients given in Table A.1); h_s is stump height (ft) above ground line; $H_{P,i}$ is total tree height (ft); $X = (H_{P,i} - h_{P,i})$; and $Z = (h_{P,i} - 4.5)$.

Hardwood Models

Unless otherwise indicated, the equations in this section come from Murphy and Graney (1998). Although Murphy and Graney published separate sets of coefficients for several species groups, the species composition data obtained from the USDA Forest Service for Management Area 22 differentiated between only "hard mast" and "miscellaneous" species. Numerous species can be included in the hard-mast

Table A.1. Coefficients for shortleaf pine lower and upper stem taper functions by outside bark, inside bark, and three crown ratio (*CR*) classes (from Farrar and Murphy 1987).

Coefficient	Outside bark			Inside bark		
	$CR<0.36$	$0.36\leq CR<0.50$	$CR\geq 0.50$	$CR<0.36$	$0.36\leq CR<0.50$	$CR\geq 0.50$
n	-0.1325	-0.1199	-0.1180	-0.1220	-0.1091	-0.1116
g_1	-.-	-.-	-.-	-0.3728	-0.4060	-0.5348
g_2	-.-	-.-	-.-	0.9368	0.9302	0.9353
b_1	25.3854	19.5133	4.9957	19.4735	13.9338	-1.8788
b_2	2.2790	1.7729	2.0915	2.0669	1.5932	1.9548
b_3	-0.0445	-0.0263	-0.0276	-0.0389	-0.0200	-0.0238
b_4	-23.6371	-18.1204	-10.4848	-17.7381	-12.5759	-3.7806

classification, making the selection of one particular set of coefficients to represent the entire classification quite difficult. The coefficients of the "red oak" group were ultimately selected because the species group is composed of several members (*Quercus velutina* Lam., *Q. rubra* L. and *Q. falcata* Michx.) common to the Ouachita Highlands. Murphy and Graney's "miscellaneous species" coefficients were selected when simulating the development of the non-"hard mast" species in the dataset.

Basal area growth

The equation used to estimate individual-tree BA growth is similar in form to the one described in the corresponding shortleaf pine section above. It has the form:

$$G_{H,i} = \frac{b_{1j}\left[1-\exp\left(-b_{2j}B_{H,i}\right)\right]}{1+\exp\left(b_{3j}BL_i + b_{4j}B_S + b_{5j}D_Q + b_{6j}A + b_{7j}SI_{H,j}\right)} \qquad (A.8)$$

where $G_{H,i}$ is annual BA growth (ft^2) of hardwood tree *i*; $B_{H,i}$ is BA (ft^2) of tree *i*; BL_i is BA (ft^2/ac) in pine and hardwood trees whose dbh's are equal to or larger than tree *i* (including the subject tree *i*); $B_S = B_H + 0.75B_P$ where B_S, B_H and B_P are total BA (ft^2/ac) in the stand, and BA of hardwoods and shortleaf pine, respectively; D_Q is quadratic mean diameter (in.) of the stand; A is stand age (yr); $SI_{H,j}$ is site index (ft) of hardwood species group j; and b_{1j}, b_{2j}, ..., b_{7j} are coefficients given in Table A.2, by species group j. As mentioned in the analogous section of the shortleaf pine models, shortleaf pine exerts only about three-fourths the competitive pressure per unit of BA that hardwoods do, justifying the multiplication of B_P by 0.75.

Table A.2. Coefficients for the hardwood individual-tree basal area growth equation, by species group (from Murphy and Graney 1998).

Species group	Coefficient						
	b_1	b_2	b_3	b_4	b_5	b_6	b_7
Hard mast	0.0941	0.7474	0.0172	0.0029	-0.0914	0.0132	-0.0080
Misc.	0.5353	1.0435	-.-	0.0165	-0.0176	0.0331	-.-

Survival

The following logistic function describes individual-tree survival:

$$S_{H,i} = \left[1 + \exp\left\{-\left(b_{0j} + b_{1j}\frac{D_{H,i}}{D_Q} + b_{2j}BL_i + \frac{b_{3j}}{D_{H,i}} + b_{4j}B_S\right)\right\}\right]^{(-1/5)} \tag{A.9}$$

where $S_{H,i}$ is the probability ($0 \leq S_{H,i} \leq 1$) of annual survival for hardwood tree i; $D_{H,i}$ is dbh (in.) of tree i; b_{0j}, b_{1j}, ..., b_{4j} are coefficients given in Table A.3, by species group j; and the other variables are as defined above.

Table A.3. Coefficients for the hardwood survival equation, by species group (from Murphy and Graney 1998).

Species Group	Coefficient				
	b_0	b_1	b_2	b_3	b_4
Hard mast	4.3254	2.2467	-0.0418	-3.7859	-.-
Misc.	7.0624	-4.9706	-0.1366	-2.7815	0.1175

Height of dominants and codominants

The heights of dominants and codominants were estimated with Farrar's (1985) site index equation:

$$H_{H,D} = \hat{H}_A + \hat{s}_A (SI_H - 62.7)/8.37 \qquad \text{(A.10)}$$

where $H_{H,D}$ is total height (ft) of the hardwood dominants and codominants; SI_H is hardwood site index (ft), base age = 50 years; $\hat{H}_A = 81.63249 - 0.00786(100 - A)^2$, the average total height (ft) of hardwood dominants and codominants in a stand of age A years, predicted from Schnur's (1937) data; $\hat{s}_A = 4.09382A^{0.29} - 4.40767$, the standard deviation of total heights of hardwood dominants and codominants in a stand of age A years, also predicted from Schnur's data. Values resulting from Equation (A.10) is used to estimate the total heights of hardwood trees in the stands.

Total height

Again, tree heights are needed in order to estimate their corresponding total and merchantable volumes. The equation is as follows:

$$H_{H,i} = 4.5 + H_{H,D}\left[1 + b_{1j} \exp\left(b_{2j} H_{H,D}\right)\right]\left[1 - \exp\left(-b_{3j}\, D_{H,i} / H_{H,D}\right)\right] \qquad \text{(A.11)}$$

where $H_{H,i}$ is total height (ft) of hardwood tree i; $H_{H,D}$ is average total height (ft) of hardwood dominants and codominants, estimated from Equation (A.10); and b_{1j}, b_{2j} and b_{3j} are coefficients given in Table A.4, by species group j.

Table A.4. Coefficients for the hardwood total tree height equation, by species group (from Murphy and Graney 1998).

Species Group	Coefficient		
	b_1	b_2	b_3
Hard mast	0.7491	-0.0329	12.244
Misc.	1.6204	-0.0408	9.6837

Volumes

No volume equations are available for hardwoods in the Ouachita Highlands. Thus, volume equations for the southeast U.S. (Clark et al. 1986) were added to overcome this deficiency. If $D_{H,i}$<11 in. o.b., then

$$V_{H,i} = b_{1j}\left(D_{H,i}^{2} H_{H,i}\right)^{b_{2j}} \tag{A.12}$$

On the other hand, if $D_{H,i}$≥11 in. o.b., then

$$V_{H,i} = b_{1j}\left(D_{H,i}^{2}\right)^{b_{2j}} H_{H,i}^{b_{3j}} \tag{A.13}$$

where $V_{H,i}$ is volume (ft^3) of hardwood tree i; b_{1j}, b_{2j} and b_{3j} are coefficients for total-tree or total-stem (Table A.5) green volume, by hardwood species group j; and the other variable are as previously defined.

The proportion of total-stem volume contained in the portion of the stem below a prescribed top limit (d.o.b.) can be obtained from:

$$r_{H,i} = \exp\left(-b_{1j} d_{H,i}^{b_{2j}} D_{H,i}^{-b_{3j}}\right) \tag{A.14}$$

where $r_{H,i}$ is the proportion (ratio) of total-stem volume of hardwood tree i in the portion of the stem below the top diameter limit $d_{H,i}$; b_{1j}, b_{2j} and b_{3j} are coefficients (Table A.5) for hardwood species group j; and $D_{H,i}$ is as previously defined.

Table A.5. Coefficients for total-tree (ft^3, wood only) and total-stem (ft^3) green volume equations, by hardwood species group and dbh class (from Clark et al. 1986).

Species group and dbh class	Total-tree volume			Total-stem volume		
	b_1	b_2	b_3	b_1	b_2	b_3
Hard mast						
<11 in.	0.0023	1.0071	-.-	0.0024	0.9807	-.-
≥11 in.	0.0014	1.1114	1.0071	0.0025	0.9695	0.9807
Ratio*	-.-	-.-	-.-	3.4465	3.8843	4.4082
Miscellaneous						
<11 in.	0.0043	0.9262	-.-	0.0036	0.9339	-.-
≥11 in.	0.0018	1.1063	0.9262	0.0023	1.0232	0.9339
Ratio*	-.-	-.-	-.-	1.5080	4.2493	4.3258

*Ratio of volume of the stem below a specified top limit (d.o.b.) to total-stem volume.

APPENDIX B

MIMICKING THE EFFECTS OF FIRE

The purpose of this appendix is to explain the way in which the effects of prescribed burning are quantified in the pine-bluestem stand simulator. The appendix briefly reviews the history of fire in the Ouachita Highlands, summarizes research related to the effects of fire on southern pine, and describes the models used in the simulator.

Fire History of the Ouachita Highlands

Fire, both natural and anthropogenic, has played a crucial role in determining the structure and composition of forests in the Ouachita Highlands and the habitat they provide (Masters et al. 1995). Fire frequency during aboriginal and early settlement times was far higher that it is today. Guyette and Dey (1997) used dendrochronological and fire scar data to establish that between 1701 and 1802 for example, one area in the Ozark Mountains had an average fire-free interval of 6.3 yr. By contrast, the period 1821-1900 had an average fire-free interval of only 3.1 yr. In fact, Guyette and Dey (1997) noted that fires burned so frequently during the latter period, they effectively prevented pine regeneration in the area.

Fire prevention and suppression efforts found greater success in the 20th century, particularly after the 1930s. For example, Masters et al. (1995) indicated that between 1939 and 1956, the average fire-free interval in the McCurtain County Wilderness Area of southeast Oklahoma had reached almost 30 yr (in contrast to the 6-yr interval during the period 1834-1889). Hardwood species took advantage of the fire eradication efforts and invaded the once-open stands. Because shortleaf cannot survive indefinitely beneath a dense hardwood mid- or overstory (Lawson 1990, Baker 1992), many stands have converted to hardwood with a few scattered remnant pines.

By burning too frequently, logging and grazing too heavily, and then suppressing fire altogether, the shortleaf pine – bluestem grass ecosystem has been effectively eliminated from much of the range it covered just prior to European settlement. Along with the habitat have gone many associated wildlife species.

Prescribed Burning and Southern Pines

Prescribed burning in southern forests has been an important management tool for reducing fuel hazards, improving wildlife habitat, and enhancing timber production (Crow and Shilling 1980, Wade and Lunsford 1989, Masters 1991, Wade and Johansen 1986). The USDA Forest Service intends to shorten the burning cycle in Management Area 22 from the current 4-yr interval to 3 yr. One of the most controversial aspects of the pine-bluestem restoration effort is the degree to which this more-frequent application of prescribed burning will affect stand growth.

Fire is difficult both to analyze and predict. Factors such as wind direction and speed; slope; aspect; litter dynamics; soil, fuel and air temperature and moisture content; vegetation regime (both over- and understory species composition); and burning frequency all influence a fire's behavior – and in turn, the fire's effect on the subsequent stand (Masters et al. 1995). The variability of these factors has led to considerable confusion in the literature regarding whether fire is beneficial or detrimental to growth. In an effort to sort through the confusion, it may be helpful to split the discussion into individual-tree and stand-level effects. Although the various southern pine species differ substantially in their tolerance to fire, they all follow the same general trends.

Individual-tree Effects

There seems to be less disagreement about the effects of fire on individual organisms. As one might expect, all trees are quite susceptible to fire-induced mortality when young, but become more tolerant with increasing size (Cain 1985, Johansen and Wade 1987a). Walker and Wiant (1966) reported that while a prescribed burn killed all shortleaf pines smaller than 0.5-in. dbh, it did virtually no harm to those with dbh's exceeding 4 in. The rule of thumb for shortleaf pine seems to be that by the time a tree's diameter at the ground line reaches 2 in., the tree should survive all but a catastrophic fire.[1] Also, as fire intensity increases, so does the probability of mortality (Greene and Shilling 1987).

Shortleaf is one of the few southern pines capable of resprouting (Mattoon 1908, Walker and Wiant 1966), especially trees with diameters ≤ 3 in. at the ground line. Consequently, if a stand is accidentally or intentionally burned before all the pines have become fire resistant, the affected trees may resprout. There is a risk, however, that they may develop multiple stems. As an extreme example, Mattoon (1915) described an 18-yr-old coppice stand near Glenville, Arkansas in which nearly 33 percent of the trees had two or more stems. Multiple-stemmed trees are not only mechanically weaker, but their

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[1] Michael Shelton, USDA Forest Service research forester. Personal communication, 21 April 1999.

stems are smaller – and commensurately less valuable – than single-stemmed trees of the same age.

Reports regarding individual-tree radial and height growth are inconsistent. Some researchers have indicated a decrease in growth rate (MacKinney 1934, Boyer 1987, Cain 1996), no change in growth rate (Jemison 1943; Gruschow 1952, 1954), and even an increased growth rate (Somes and Moorhead 1954, Johansen 1975) in burned stands relative to unburned stands. The degree to which a tree's growth is affected by fire seems to be determined mainly by how severely its crown is damaged (Waldrop and Van Lear 1984, Cain 1985, Johansen and Wade 1987b). Even if its crown is completely browned, a shortleaf pine tree will not die unless some needles are charred (Storey and Merkel 1960). As long as the terminal buds survive, a pine tree is able to replenish its stock of needles within two years, at which time it should be able to resume normal growth rates. The adverse effect of fire on growth seems to be fairly short-lived – generally only one or two years. Lilieholm and Hu (1987) reported results from 19-yr-old loblolly pines subjected to a single winter burn. By the end of the third growing season after the burn, only trees that had been completely scorched had significantly less diameter growth.

Stand-level Effects

Because the presence of even small hardwoods can reduce the growth of overstory pine trees (Rogers and Brinkman 1965, Grano 1970a), primarily by competing for soil moisture, some steps need to be taken to favor the shortleaf pines. Prescribed fire can be an effective tool for reducing the size and number of hardwoods in the stand and increasing the amount of herbaceous vegetation. Sparks et al. (1999) conducted both growing- and dormant-season prescribed burns in Management Area 22, and concluded that fires during March and April were most effective in killing hardwood stems ≥ 1 m in height. This agrees with Grano (1970b), who found a winter burn can destroy the aboveground portion of almost all hardwoods with basal diameters up to 3.5 in. when sufficient fuel is available. Although hardwoods sprout prolifically after burning, the increased number of hardwood stems per unit area is offset by the dramatic reduction in their stem diameters. Smaller hardwoods are much more susceptible to fire's effects (Boyer 1983). If favorable burning conditions present themselves, early- to mid-summer burning may also effectively decrease hardwood sprout competition (Geisinger et al. 1989, Waldrop et al. 1989). This technique is effective primarily because fire kills the hardwood tops after they have almost fully leafed out, but before the roots' carbohydrate reserves have begun to be replenished. Finally, annual prescribed burns may eventually reduce the number of stems as well as their size (Grano 1970b).

Frequency and season of burn also influence species diversity and abundance in the understory. Masters et al. (1993b) and Sparks et al. (1998) showed that frequent burns favor fire-tolerant herbaceous vegetation over woody plants. Also, late growing-season burns reduce the distribution and abundance of panicums (*Panicum* spp.), while late dormant-season fires have the opposite effect.

Prescribed fire can affect the success of stand regeneration. Haywood and Toliver (1989) demonstrated the importance of obtaining successful pine regeneration in a timely manner. They monitored the total inside-bark volume of loblolly pines in pure stands and a pine-hardwood mixture between 5 and 15 yr after site preparation. By the ninth year, the pine-hardwood stand contained less than a quarter of the pine volume in the pure pine stands on a per-acre basis. Some managers are concerned that prescribed burns may actually reduce the number of shortleaf pine seedlings in stands they are attempting to naturally regenerate. These concerns can be partially alleviated by either carrying out a burn prior to the harvest/regeneration cut (Crow and Shilling 1980), or postponing burning until it coincides with a better-than-average seed crop (Cain 1986). Vose et al. (1997) compared pine seedling and sapling densities in burned and unburned stands. Hardwood competition was greatly reduced in the burned stands, resulting in improved growing conditions for, and greater numbers of pine trees.

Soil fertility seems not to be adversely affected as long as the decomposed litter layer remains relatively intact. In fact, some nutrients are made more available after burning (Waldrop et al. 1987). Masters et al. (1993a) observed increased available NO_3-nitrogen, calcium and phosphorous on harvested and burned sites in southeastern Oklahoma. Repeated burning may have a fertilizer effect, at least for very young trees (McKevlin and McKee 1986). The fertilizer effect for older trees, however, is unclear.

In order to account for the effect of prescribed burning in the Management Area 22 stands, Greene and Shilling's (1987) logistic equation predicting the probability of girdling were incorporated into the simulation software. Their equation had the following form:

$$P_{G,i} = \left[1 + \exp\left\{-\left(b_{0j} + b_{1j}dgl_i + b_{2j}MTE\right)\right\}\right]^{-1} \tag{B.1}$$

where $P_{G,i}$ is probability ($0 \leq P_{G,i} \leq 1$) of girdling, and dgl_i is diameter (mm) at the ground line of tree i; MTE is mean temperature exposure (°C·sec); and b_{0j}, b_{1j} and b_{2j} are coefficients given in Table B.1 by species group j. Although the pine coefficients are actually for loblolly rather than shortleaf, and the sweetgum (*Liquidambar styraciflua* L.) coefficients had to suffice for all hardwoods in the Management Area 22 stands, there is no better information available. Because loblolly is considered less fire tolerant, this model should yield conservative estimates of survival for shortleaf (i.e., fewer shortleaf should succumb to fire than this model predicts).

Table B.1. Coefficients for probability of girdling from prescribed fire, by species group (from Greene and Shilling 1987).

Species group	------ Coefficient ------		
	b_0	b_1	b_2
Shortleaf pine	5.1302	-0.4361	0.0002
Hardwoods	-2.3597	-0.0901	0.0003

Because all other equations in the pine-bluestem simulator use dbh (in.), those dbh's needed to be converted to diameter (mm) at ground line for use in Greene and Shilling's (1987) equations. Only Kluender and Yeiser (1986) have published an equation relating dbh and dgl for hardwoods in Arkansas. It is:

$$dgl_i = 25.43\left(\frac{dbh_i + 0.65}{0.83}\right) \tag{B.2}$$

where dgl_i is as defined above, and dbh_i is diameter at breast height (in.) of hardwood tree i. No corresponding equation exists for shortleaf pine in this area. Consequently, diameters at breast height and ground line were obtained from 442 small (dbh≤3.5 in.) shortleaf pine trees from seven sites in eastern Oklahoma, representing a range of stocking and site quality levels to develop the following relationship:

$$dgl_i = 25.43(0.8040 + 1.1031 dbh_i) \tag{B.3}$$

where dgl_i and dbh_i are as previously defined, except now they refer to shortleaf pine. The R^2=0.95, and both coefficients were significant at the α=0.0001 level.

For this study, medium fire intensity ($25{,}000 \leq MTE \leq 50{,}000$ °C·sec) was assumed for all prescribed burns. Also, because of the variability of published results, the following BA growth effects were chosen for all species: For stands age<30 yr, a 10 percent BA-growth reduction was assumed for the first season after a burn, and a 5 percent reduction during the second; stands 30≤age<40 yr, a 5 percent reduction during the first growing season, and a 2.5 percent reduction during the second; stands 40≤age<50 yr, a 5 percent reduction for one growing season; and stands age≥50 yr, no reduction.

APPENDIX C

GROWTH AND YIELD COMPARISONS IN MANAGEMENT AREA 22

This appendix contains tables indicating the growth and yield of stands under traditional even-aged, and pine-bluestem management scenarios. Tabulation begins at initial age of 20 yr, and initial shortleaf pine basal area levels of 30, 60 and 90 ft^2/ac. Shortleaf site index is either 50 or 70 ft at base age 50 yr.

Table C.1. Growth and yield of a traditional stand with initial pine basal area of 30 ft^2/ac and site index of 50 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	5.0	205	28	276				205	28	276
30	7.3	198	57	875				198	57	875
40	9.0	186	83	1,627				186	83	1,627
50	10.4	170	101	2,319	85	31	633	84	70	1,686
60	13.8	81	84	2,275	60	54	1,418	21	30	858
70	18.2	21	37	1,160				21	37	1,160

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
		Volume (ft^3)				Periodic annual	
Age	Basal area (ft^2)	Total	Pulpwood	Sawtimber	Total mean annual	Pulpwood	Sawtimber
20	28	276	90	1	14		
30	57	875	723	123	29	63	12
40	83	1,627	1,484	748	41	76	62
50	101	2,319	2,180	1,481	46	70	73
60	115	2,908	2,758	2,076	48	58	59
70	121	3,210	3,054	2,370	46	30	29

Table C.2. Growth and yield of a traditional stand with initial pine basal area of 60 ft^2/ac and site index of 50 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	4.7	507	61	608				507	61	608
30	6.5	463	105	1,613	261	35	470	202	70	1,142
40	9.5	194	95	1,988	68	25	484	126	70	1,504
50	11.6	121	88	2,228				121	88	2,228
60	12.7	115	100	2,813	90	70	1,933	25	30	880
70	16.8	24	38	1,210				24	38	1,210

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
	Basal area	Volume (ft^3)			Total mean annual	Periodic annual	
Age	(ft^2)	Total	Pulpwood	Sawtimber		Pulpwood	Sawtimber
20	61	608	164	0	30		
30	105	1,613	1,230	88	54	107	9
40	130	2,458	2,060	764	61	83	68
50	148	3,182	2,769	1,764	64	71	100
60	160	3,768	3,345	2,380	63	58	62
70	168	4,097	3,668	2,703	59	32	32

Table C.3. Growth and yield of a traditional stand with initial pine basal area of 60 ft^2/ac and site index of 70 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	4.7	498	60	801				498	60	801
30	6.5	453	105	2,077	254	35	591	199	70	1,487
40	9.5	191	95	2,548	67	25	632	124	70	1,916
50	11.6	119	88	2,834				119	88	2,834
60	12.8	112	99	3,556	87	69	2,449	25	30	1,107
70	16.9	24	37	1,506				24	37	1,506

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
	Basal area (ft^2)	Volume (ft^3)			Total mean annual	Periodic annual	
Age		Total	Pulpwood	Sawtimber		Pulpwood	Sawtimber
20	60	801	324	0	40		
30	105	2,077	1,598	166	69	127	17
40	130	3,139	2,647	983	78	105	82
50	148	4,056	3,551	2,278	81	90	129
60	159	4,778	4,264	3,060	80	71	78
70	167	5,177	4,657	3,454	74	39	39

Table C.4. Growth and yield of a traditional stand with initial pine basal area of 90 ft^2/ac and site index of 70 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	4.8	720	90	1,233	363	20	201	358	70	1,031
30	7.9	343	118	2,509	192	48	926	151	70	1,583
40	11.2	146	100	2,828	55	30	801	91	70	2,027
50	13.8	89	92	3,094	26	22	711	63	70	2,383
60	16.1	61	87	3,286	44	57	2,129	18	30	1,158
70	19.7	17	37	1,528				17	37	1,528

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
		Volume (ft^3)			Total mean annual	Periodic annual	
Age	Basal area (ft^2)	Total	Pulpwood	Sawtimber		Pulpwood	Sawtimber
20	90	1,233	599	24	62		
30	138	2,710	2,276	474	90	168	45
40	168	3,955	3,499	2,141	99	122	167
50	189	5,022	4,548	3,226	100	105	108
60	206	5,926	5,437	4,121	99	89	90
70	213	6,296	5,802	4,484	90	36	36

Table C.5. Growth and yield of a pine-bluestem stand with initial pine basal area of 30 ft^2/ac and site index of 50 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	5.0	205	28	276				205	28	276
30	7.3	198	57	874				198	57	874
40	9.0	186	83	1,626	122	38	686	64	45	941
50	13.3	63	60	1,502				63	60	1,502
60	14.9	61	73	2,046	29	29	761	32	45	1,285
70	17.8	32	55	1,707				32	55	1,707
80	19.4	31	63	2,114				31	63	2,114
90	20.8	30	71	2,488	13	26	894	17	45	1,593
100	23.3	17	50	1,849				17	50	1,849
110	24.6	16	55	2,071	8	25	930	8	30	1,141
120	26.7	8	32	1,263				8	32	1,263

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
		Volume (ft^3)			Total mean annual	Periodic annual	
Age	Basal area (ft^2)	Total	Pulpwood	Sawtimber		Pulpwood	Sawtimber
20	28	276	90	1	14		
30	57	874	723	123	29	63	12
40	83	1,626	1,484	748	41	76	62
50	98	2,188	2,033	1,314	44	55	57
60	111	2,732	2,566	1,852	46	53	54
70	121	3,154	2,980	2,265	45	41	41
80	129	3,561	3,379	2,662	45	40	40
90	137	3,935	3,746	3,027	44	37	37
100	142	4,190	3,997	3,275	42	25	25
110	147	4,412	4,215	3,492	40	22	22
120	149	4,534	4,335	3,610	38	12	12

Table C.6. Growth and yield of a pine-bluestem stand with initial pine basal area of 60 ft^2/ac and site index of 50 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	4.7	507	61	608				507	61	608
30	6.5	463	105	1,613	354	60	863	109	45	749
40	10.7	106	66	1,446	41	21	446	65	45	1,001
50	13.2	64	61	1,595				64	61	1,595
60	14.8	62	74	2,165	28	29	825	34	45	1,340
70	17.4	33	55	1,785				33	55	1,785
80	19.0	32	64	2,213				32	64	2,213
90	20.4	32	71	2,621	13	27	936	19	45	1,685
100	22.6	18	50	1,967				18	50	1,967
110	24.0	18	55	2,220	9	25	1,012	9	30	1,208
120	26.0	9	33	1,351				9	33	1,351

*Quadratic mean diameter (breast height)

	Total production (per acre)				Volume increment (ft^3)		
		Volume (ft^3)			Total mean annual	Periodic annual	
Age	Basal area (ft^2)	Total	Pulpwood	Sawtimber		Pulpwood	Sawtimber
20	61	608	164	0	30		
30	105	1,613	1,230	88	54	107	9
40	126	2,310	1,911	951	58	68	86
50	142	2,904	2,492	1,553	58	58	60
60	155	3,474	3,051	2,118	58	56	57
70	165	3,918	3,487	2,553	56	44	43
80	174	4,346	3,908	2,972	54	42	42
90	182	4,754	4,309	3,371	53	40	40
100	187	5,036	4,586	3,646	50	28	28
110	192	5,290	4,835	3,894	48	25	25
120	195	5,432	4,975	4,033	45	14	14

Table C.7. Growth and yield of a pine-bluestem stand with initial pine basal area of 60 ft^2/ac and site index of 70 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	4.7	498	60	801				498	60	801
30	6.5	454	105	2,078	346	60	1,084	107	45	994
40	10.7	105	66	1,840	40	21	560	65	45	1,280
50	13.2	63	60	2,008				63	60	2,008
60	14.8	61	73	2,700	27	28	1,021	34	45	1,678
70	17.4	33	55	2,207				33	55	2,207
80	19.0	32	63	2,696				32	63	2,696
90	20.4	31	70	3,132	12	25	1,124	19	45	2,008
100	22.6	18	50	2,322				18	50	2,322
110	24.0	18	55	2,598	9	25	1,180	9	30	1,418
120	26.0	9	33	1,572				9	33	1,572

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
	Basal area	Volume (ft^3)			Total mean	Periodic annual	
Age	(ft^2)	Total	Pulpwood	Sawtimber	annual	Pulpwood	Sawtimber
20	60	801	324	0	40		
30	105	2,078	1,598	166	69	127	17
40	126	2,924	2,429	1,269	73	83	110
50	141	3,652	3,145	2,019	73	72	75
60	154	4,344	3,826	2,714	72	68	69
70	164	4,873	4,347	3,236	70	52	52
80	172	5,362	4,829	3,718	67	48	48
90	180	5,798	5,258	4,148	64	43	43
100	185	6,111	5,568	4,455	61	31	31
110	190	6,387	5,839	4,726	58	27	27
120	192	6,541	5,991	4,876	55	15	15

Table C.8. Growth and yield of a pine-bluestem stand with initial pine basal area of 90 ft^2/ac and site index of 70 ft.

		Stand (per acre) before removals			Removals (per acre)			Stand (per acre) after removals		
Age	QMD (in.)*	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)	Trees	Basal area (ft^2)	Total volume (ft^3)
20	4.8	720	90	1,233	550	45	531	170	45	702
30	9.4	167	80	1,814	89	35	752	78	45	1,062
40	12.6	76	66	1,960				76	66	1,960
50	14.6	74	86	2,928	40	41	1,381	34	45	1,547
60	17.7	33	57	2,167				33	57	2,167
70	19.5	33	68	2,771				33	68	2,771
80	21.2	32	78	3,335	14	33	1,399	17	45	1,936
90	23.4	17	51	2,275				17	51	2,275
100	24.9	17	56	2,560				17	56	2,560
110	26.1	16	60	2,808	8	30	1,393	8	30	1,415
120	27.8	8	32	1,546				8	32	1,546

*Quadratic mean diameter (breast height)

	Total production (per acre)						
					Volume increment (ft^3)		
	Basal area (ft^2)	Volume (ft^3)			Total mean annual	Periodic annual	
Age		Total	Pulpwood	Sawtimber		Pulpwood	Sawtimber
20	90	1,233	599	24	62		
30	125	2,345	1,703	591	78	110	57
40	146	3,243	2,584	1,666	81	88	107
50	166	4,211	3,535	2,634	84	95	97
60	178	4,831	4,145	3,243	81	61	61
70	189	5,435	4,739	3,835	78	59	59
80	199	5,999	5,295	4,389	75	56	55
90	205	6,337	5,628	4,720	70	33	33
100	210	6,623	5,910	5,000	66	28	28
110	214	6,870	6,154	5,243	62	24	24
120	216	7,001	6,282	5,370	58	13	13

APPENDIX D

PRODUCER PRICE INDEX DATA

This appendix contains producer price index data for pine pulpwood, sawtimber, and southern yellow pine #2 dimension lumber during the time period covered in this study. The base of each commodity is the average of 1996 prices. The PPI ratio is the ratio of lumber to sawlog PPIs (from U.S. Dept. of Labor 1999).

Table D.1. Producer price indices of pulpwood, lumber and sawlogs.

		Producer price index			
Year	Month	Pulpwood	Lumber	Sawlogs	PPI Ratio
1992	June	0.83	0.64	0.82	0.77
	July	0.82	0.63	0.83	0.76
	August	0.81	0.66	0.83	0.79
	September	0.81	0.74	0.84	0.88
	October	0.82	0.69	0.85	0.81
	November	0.82	0.70	0.86	0.81
	December	0.82	0.77	0.89	0.87
1993	January	0.85	0.85	0.92	0.93
	February	0.85	0.93	0.98	0.95
	March	0.86	1.05	1.02	1.03
	April	0.88	1.02	1.19	0.86
	May	0.91	0.92	1.26	0.73
	June	0.91	0.79	1.22	0.64
	July	0.91	0.76	1.22	0.62
	August	0.91	0.80	1.15	0.70
	September	0.91	0.86	1.13	0.76
	October	0.90	0.96	1.14	0.84
	November	0.91	1.06	1.16	0.91
	December	0.90	1.08	1.10	0.99

Table D.1. (continued)

		Producer price index			PPI
Year	Month	Pulpwood	Lumber	Sawlogs	Ratio
1994	January	0.93	1.16	1.16	1.00
	February	0.93	1.07	1.18	0.91
	March	0.93	1.13	1.21	0.93
	April	0.94	0.99	1.21	0.82
	May	0.94	0.92	1.18	0.78
	June	0.93	0.98	1.15	0.85
	July	0.93	0.94	1.15	0.81
	August	0.94	0.95	1.11	0.86
	September	0.94	0.92	1.09	0.85
	October	0.95	0.93	1.09	0.85
	November	0.96	1.01	1.08	0.93
	December	0.96	0.99	1.09	0.91
1995	January	0.98	0.98	1.10	0.89
	February	0.98	0.99	1.14	0.86
	March	1.00	0.95	1.15	0.83
	April	1.01	0.91	1.18	0.77
	May	1.03	0.91	1.19	0.76
	June	1.08	0.80	1.18	0.67
	July	1.03	0.90	1.11	0.81
	August	1.01	0.88	1.07	0.82
	September	1.01	0.89	1.05	0.84
	October	1.00	0.84	1.06	0.80
	November	1.03	0.85	1.04	0.82
	December	1.03	0.85	1.03	0.83
1996	January	1.03	0.85	1.04	0.82
	February	1.03	0.86	1.05	0.82
	March	1.02	0.90	1.02	0.89
	April	1.01	0.90	0.97	0.92
	May	1.00	1.06	0.98	1.08
	June	0.99	1.06	0.97	1.09
	July	0.99	0.94	0.97	0.97
	August	0.99	1.04	0.98	1.06
	September	0.99	1.12	0.99	1.12
	October	1.01	1.05	1.00	1.06
	November	1.00	1.13	1.01	1.12
	December	0.95	1.09	1.02	1.07

Table D.1. (continued)

Year	Month	Producer price index			PPI Ratio
		Pulpwood	Lumber	Sawlogs	
1997	January	0.94	1.09	1.05	1.04
	February	0.96	1.12	1.07	1.05
	March	0.95	1.14	1.09	1.05
	April	0.95	1.20	1.09	1.10
	May	0.96	1.25	1.09	1.14
	June	0.97	1.15	1.08	1.07
	July	0.98	1.22	1.08	1.13
	August	0.98	1.18	1.08	1.10
	September	0.98	1.11	1.09	1.01
	October	0.97	1.03	1.09	0.94
	November	1.01	1.01	1.10	0.92
	December	1.03	1.04	1.11	0.94
1998	January	1.05	1.02	1.12	0.90
	February	1.06	1.04	1.15	0.91
	March	1.09	1.09	1.15	0.95
	April	1.09	1.07	1.16	0.93
	May	1.07	1.00	1.14	0.88
	June	1.07	0.93	1.12	0.83
	July	1.03	0.98	1.10	0.89
	August	1.04	0.96	1.08	0.89
	September	1.04	0.85	1.07	0.80
	October	1.01	0.91	1.07	0.85
	November	0.99	0.90	1.05	0.86
	December	0.98	0.96	1.05	0.91

APPENDIX E

TIMBER SALE VOLUME UNIT CONVERSIONS

This appendix explains the rationale and methodology for converting timber sale volumes measured in thousands of board feet to hundred of cubic feet.

As mentioned in Chapter 4, sawtimber volumes of sales advertised prior to 1996 were reported in thousand-board-foot (MBF) or both MBF and hundred-cubic-foot (CCF) units. So that all sales employed a consistent unit of sawtimber volume, the early sales were converted from MBF to CCF units. Consequently, sales for which volumes had been reported in both units were used to generate regression equations of the form:

$$CCF_d = b_{d,1}T_d + b_{d,2}MBF_d \tag{E.1}$$

where CCF_d is shortleaf CCF volume, T_d is number of trees, and MBF_d is MBF volume in diameter class d (in.), and $b_{d,1}$ and $b_{d,2}$ are parameters to be estimated for each diameter class d. Using a separate equation for each diameter class is supported by Reynolds (1937). The subset of data reporting both MBF and CCF volumes contained 42 observations. Because Equation (E.1) is a no-intercept model, the fit index (equivalent to the R^2) for each diameter class had to be calculated manually. Each fit index was at least 0.99, indicating excellent fits. Parameter estimates by diameter class are given in Table E.1.

Table E.1. Parameter estimates and associated *P*-values, and model fit indices (R^2s) for converting thousand-board-foot (MBF) volumes to hundred-cubic-foot volumes, by diameter class.

	Number of shortleaf pine trees (b_1)			
Diameter class (in.)	Parameter estimate	*P*-value	MBF (b_2) parameter estimate*	Model fit index
10	0.0085	0.2511	1.9015	0.995
11	0.0132	0.1396	1.7927	0.997
12	0.0341	0.0012	1.5592	0.997
13	0.0425	0.0010	1.4834	0.996
14	0.0561	0.0001	1.3993	0.998
15	0.0902	0.0001	1.2572	0.996
16	0.0936	0.0003	1.2533	0.997
17	0.0937	0.0001	1.2747	0.998
18	0.1556	0.0001	1.1059	0.997
19	0.2098	0.0001	0.9738	0.990
20	0.1588	0.0001	1.1417	0.997
21	0.1222	0.0001	1.2145	0.999
22	0.1613	0.0001	1.1802	0.999

*All *P*-values = 0.0001

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