A DESCRIPTION OF OPTIMAL MANAGEMENT REGIMES FOR EVEN-AGED STANDS OF LOBLOLLY PINE IN SOUTHEASTERN OKLAHOMA

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PREFACE

This study was conducted to provide further knowledge and insight with regard to the economics of timber production in southeastern McCurtain County, Oklahoma. Funding for this project was provided through a USDA National Needs Fellowship. It is hoped that the information provided here will help non-industrial private forest owners make more profitable timber management decisions.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction

This paper covers a set of forest management problems faced by all timber producers in the southeastern United States, particularly those practicing even-aged pine plantation management in the Gulf Coastal Plain. Specifically, this paper aims to shed light on the forest management problems in southeastern Oklahoma by approaching the timber management problem from several different angles, but using the same growth and price data so that results can be compared. Each chapter used the same log rule measurements for sawtimber and volume measurements for pulpwood. Timber greater than ten inches in diameter at breast height (eight inch inside bark diameter top) was measured in International 1/4 log rule. Pulpwood was measured in cubic feet from a four-inch inside bark diameter top.

Chapter 2 deals with the problem of finding optimal, or best management practices for the non-industrial private forest owner in southeastern Oklahoma. The overall objective of Chapter 2 was to determine pine plantation management strategies (planting density-thinning combinations) that provide maximum or near maximum returns over a range of prices and discount rates. In Chapter 2 the problem of forest management is viewed as if the land is bare, and management decisions need to be made to decide whether or not to plant a stand of trees, and if so how many trees to plant, and what thinning strategy, if any, should be followed. The question answered in Chapter 3 was, "given the current price level and expected price level, and the probability of loss of the stand should the stand be harvested, or held another year?" The focus of Chapter 3 is backward looking in sivicultural management and forward looking in prices. That is, what should have been the best planting density and thinning strategy? Chapter 4 approached the problem of forest management from a multi-product perspective. Grazing and hunting income was incorporated into the model, as were several stands of loblolly pine on different site quality lands. Each Chapter required economic evaluation of forest management strategies. The following is a theoretical description of the optimal forest rotation problem.

Theory of Optimal Forest Rotations

The timber value of a stand of trees is determined by the volume of timber produced and the price of timber. To illustrate this, first assume a continuous, strictly convex timber growth function $f(t)$ exists over time. Further assume that $f'(t) > 0$ (the function $f(t)$ is non-decreasing in *t*) and that $f''(t) < 0$ (the growth rate is declining). The revenue from timber sales is $pf(t)$, where *p* is the price of timber, net of all costs at the time of harvest and assumed constant over time. The current value of a single rotation is $pf(t) - c$ where *c* is the regeneration cost, assumed constant and *T* is the age of timber harvest. If regeneration costs are incurred at the start of the rotation and timber revenues occur at the end of the rotation, and a discount rate of r is assumed then

(1.1) $$\pi = e^{-rT} pf(T) - c$$

is the present value of profit from a single harvest at age T. The first order condition for the partial derivative with respect to t is

(1.2) $$\frac{\partial \pi}{\partial t} = -re^{-rt} pf(t) + e^{-rt} pf'(t) = 0$$

which yields

(1.3) $$re^{-rt} pf(t) = e^{-rt} pf'(t)$$

dividing both sides by e^{-rt} and rearranging terms gives

(1.4) $$pf'(T)/pf(T) = r$$

which states that harvest should be delayed until the return on the forest stand is equal to the discount rate. This is the solution to the single rotation forest optimization problem.

When replanting is possible, the optimal rotation should take into account the value of the current rotation, and the discounted value of subsequent rotations. Assuming that all the parameters remain unchanged, and planting begins with bare land, the profit function becomes:

(1.5) $$SEV = -c + e^{-rt_1}\left[pf(t_1) - c\right] + e^{-rt_2}\left[pf(t_2) - c\right] + \ldots + e^{-rt_\infty}\left[pf(t_\infty) - c\right]$$

Recognizing that the producer faces the same problem each period, equation 1.5 is a geometric progression, which simplifies to:

(1.6) $$SEV = \frac{pf(T) - c}{e^{rt} - 1} - c$$

The first order partial derivative with respect to t for equation 1.6 is

(1.7) $$\frac{\partial SEV}{\partial t}=\frac{pf'(T)\left(e^{rt}-1\right)-re^{rt}\left(pf(T)-c\right)}{\left(e^{rt}-1\right)^{2}}$$

which yields

(1.8) $$\frac{pf'(T)}{\left(e^{rt}-1\right)}=\frac{re^{rt}\left(pf(T)-c\right)}{\left(e^{rt}-1\right)^{2}}$$

and by cross-multiplication:

(1.9) $$\frac{pf'(T)}{pf(T)-c}=\frac{r}{1-e^{rt}}$$

Equation 1.9 is the Faustmann formula (Hartman, 1976) and is more easily explained as:

(1.10) $$pf'(T)=rpf(T)+r\frac{pf(T)-c}{e^{rT}-1}$$

Equation 1.10 states that the rate of return on the forest stand $pf'(T)$ should equal the interest that the net value of the forest would generate if invested, plus the rate of return of investing the present value of all future rotations at the interest rate *r*. The expression $\left(pf(T)-c\right)/\left(e^{rT}-1\right)$ is the site value at the time of harvest, and the second term in equation 1.10 is the opportunity cost of the investment tied up in the trees and the land (Hanley, Shogren, and White, 1997; Pearse, 1967). The term $r/\left(1-e^{rt}\right)$ is strictly increasing as the discount rate *r* increases. Since $p'(T)/\left(pf(T)-c\right)$ is strictly decreasing in *T* (by assumption), the age of optimal rotation declines as the discount rate increases, *ceterus parabus*. Comparative statics also show that as regeneration costs increase, the length of the rotation increases, *ceterus parabus* (Bowes and Krutilla, 1985).

The problem of multiple use forestry, such as grazing and hunting has been treated by Hartman (1976). Using the previous assumptions, a non-timber component is added to the model:

(1.11) $$SEV = \underset{T}{MAX}\frac{1}{1-e^{-rt}}\left[\int_0^T h(t)e^{-rt}dt + pf(T)e^{-rT} - c\right]$$

In this example, $h(t)$ represents the flow of revenue from non-timber sources as a function of time. The first order conditions are:

(1.12) $$pf'(T) - rpf(T) + h(T) - rSEV = 0$$

Rearranging equation 1.12 results in equation 1.10 with *h(T)* as an additional term.

(1.13) $$h(T) + pf'(T) = rpf(T) + rSEV$$

Notice that if $h(t) = 0$, the flow of non-timber goods is constant over time and equation 1.13 is the Faustmann formula. In this case, the optimal age of rotation is the same as the Faustmann. Equation 1.13 states that the gain from postponing harvest one period, $(h(T) + pf'(T))$, includes the non-timber value during the period plus the value of timber growth over the period. The cost of holding the stand one more period, $(rpf(T) + rSEV)$, includes the interest foregone by postponing harvest one period. Hartman (1976) shows that if the flow of non-timber value is large at beginning of the rotation, and decreases with *t* that the optimal rotation age is decreased. Grazing in which the output occurs early in the rotation is such an example. If the flow of non-timber values is small at the beginning of the rotation, but increases as the stand ages, then the optimal rotation age is increased.

Thinnings are conducted to remove trees of poor quality, small trees, and/or rows of trees. The purpose of thinnings is to concentrate growth on the remaining trees. Thinnings never increase the total volume of wood produced but should produce larger timber that is more valuable. There are two types of thinnings that may be taken during the course of the rotation. They are precommercial thinnings and commercial thinnings. Precommercial thinnings produce only expenses at the time of thinnings, with no revenues (Klemperer, 1996, p. 243; Davis and Johnson, 1987, p. 507). Precommercial thinnings are feasible when

$$C_j < \frac{\left(pf(T)+pg(T)-c\right)-\left(pf(T)-c\right)}{(1+r)^{T-j}} \tag{1.14}$$

which simplifies to

$$C_j < \frac{pg(T)}{(1+r)^{T-j}} \tag{1.15}$$

where C_j is the cost of thinning at time period j, and $g(T)$ is a growth function representing the additional volume of sawtimber at rotation age T due to thinning. Equation 1.15 states that the precommercial thinnings are economically feasible when the cost of thinnings is less than the additional value produced by thinning discounted back to the time of thinning.

Commercial thinnings are feasible when

$$R_j > \frac{\left(pf(T)-c\right)-\left(pf(T)+pg(T)-c\right)}{(1+r)^{T-j}} \tag{1.16}$$

which simplifies to

(1.17) $$R_j > \frac{-pg(T)}{(1+r)^{T-j}}$$

where R_j is the net revenue due to thinning. Equation 1.17 indicates that commercial thinnings are feasible when the net revenue due to thinning at age *T* is greater than any loss at final harvest (Pearse, 1967).

Equation 1.11 can be modified to represent thinnings. The objective function is:

(1.18) $$SEV = \underset{T}{MAX} \frac{1}{1-e^{-rt}} \left[\int_j^T v(t) e^{-rt} dt + pg(T) e^{-rT} + pf(T) e^{-rT} - c \right]$$

where $v(t)$ is the revenue collected from thinning at time period *j*. The other variables are as previously described. First order conditions for equation 1.18 is

(1.19) $$v(T) + pg'(T) - rpg(T) + pf'(T) - rpf(T) - rSEV = 0$$

which simplifies to:

(1.20) $$v(T) + pg'(T) + pf'(T) = rpg(T) + rpf(T) + rSEV$$

Equation 1.20 states that the gain from postponing harvest one period, $(v(T) + pg'(T) + pf'(T))$ includes the revenue plus interest from thinning revenue from age of thinning *j* to age of final rotation *T* plus the value of timber growth over the period. The cost of holding the stand one more period, $(rpg(T) + rpf(T) + rSEV)$, includes the interest foregone by postponing harvest one period. The objective is to choose the thinning regiment, $g(T)$, that maximizes *SEV*. Because thinning is a discrete choice, finding the best thinning strategy frequently involves direct search methods, linear programming, or dynamic programming.

Review of Methods

The previous theoretical example assumes that the production function is strictly convex and continuous, and therefore an analytical solution exists. Roise (1986) indicates that production functions for timber, especially those involving thinning are non-convex and may contain many local optima. For this type of problem direct search techniques such as those described in Roise (1986) can be used.

Roise (1986) outlines four possible approaches to this type of forestry problem. While numerous methods have been developed to solve this type of problem, they can be classified into three groups. Those groups are gradient methods, derivative free methods, and dynamic programming. Gradient methods require both function and derivative evaluations. Derivative free (direct search) methods only require function evaluations. Because of the additional information produced by gradient methods (some type of first and or second order condition information), they are generally accepted as more efficient. When the production surface is rough, and numerical derivative approximation is used, there is little difference in the efficiency of derivative and derivative free methods (Kuester and Mize, 1973).

Because of the time and difficulty of deriving analytical or numerical derivatives of computer simulation models such as used in this research, one is lead to use derivative free models (Roise, 1986). Roise examines three direct search models, the Nelder Meade Simplex, Hooke and Jeeves, and Powell's method. These models performed equally well in finding an optimum, with the only difference being computation time and complexity of writing the program. He also used a discrete dynamic programming model, which worked equally well. Another approach for problems such as this, if there are not too many dimensions, is a grid search. A grid search can be performed in a spreadsheet where numerous possible management strategies (such as thinning and planting density) can be compared. With today's computing power, literally hundreds of possible strategies can be evaluated at the same time. Klemperer (1996) suggests using a spreadsheet as a method for finding the optimal planting density. Finding the optimal strategy is simply searching for the strategy yielding the highest net present value (Klemperer, 1996, p. 240). One advantage to the grid search approach is that near optimal solutions can be found. Sometimes these near optimal solutions may be the best across all possible criteria, but not optimal for any specific criteria such as a specific price-discount rate combination. Such strategies may be referred to as "robust".

When prices are allowed to be stochastic, stochastic dynamic programming (used in Chapter 3) is generally the best choice (Roise, 1986). Dynamic programming (DP) is a computational approach used to solve complex optimization problems. Unlike linear programming (LP), which is basically mathematical modeling, DP is more like simulation, except that DP searches for an optimal solution like LP. DP transforms multistage or sequential decision processes containing many interdependent variables into a series of single-stage problems, each with only a few variables. Then the problem is solved recursively, and the solution indicates an optimum where all decisions are found at the same time (Schreuder ,1968; Kennedy, 1986; Boungiorno and Gilless, 1987). Schreuder (1968) was one of the first to use this approach to solve multistage forestry problems. Roise (1986) indicates that DP does not necessarily select a global or local optimum, DP chooses a network optimum. He also indicates that DP is well suited to incorporate uncertainty.

When many states and activities are incorporated into a forest planning model, such as numerous stands, timber and non-timber flows of revenues, and various stand management strategies, DP, direct search methods, or a grid search are not appropriate because of the "curse of dimensionality". For these problems, linear programming is a reasonable choice if things are linear, or can be made linear by use of step functions.

Forest management planning considers the entire forest, which is made of many stands of various ages of trees on various soils. The complexity of this problem when forest production is treated as a multi product enterprise where timber and non-timber flows are considered can make the problem difficult to simultaneously optimize. Linear programming (LP) can successfully handle this problem, and provides a mechanism for sensitivity analysis. Sensitivity analysis can be used as a way to consider risk and uncertainty (Davis and Johnson, p. 206). Non-linear equations, such as tree growth, are represented in an LP model through segmentation of the growth equations.

To achieve the objective in Chapter 4, a multiperiod linear programming system, Spectrum, was used. Spectrum evolved from FORPLAN, a linear programming based model used to develop the USDA Forest Service's first set of strategic forest plans for the national forests of the United States (USDA Forest Service, 1997). FORPLAN Version 1 was first released in 1980 in an effort to merge timber and land management planning (Iverson and Alston, 1986). FORPLAN became the "required primary analysis tool" for use in integrated planning for national forests. As computer power increased, FORPLAN was improved throughout the 1980's and early 1990's (Kent et al., 1993). Spectrum builds on the capabilities of FORPLAN, focusing on the needs of forest ecosystem planning and management (USDA Forest Service, 1997).

The Spectrum system includes modules for a data entry system, model management, matrix generation, linear programming, and report writing software. C-Whiz, a linear programming algorithm developed by Ketron, Inc., is used to solve the linear programming matrix generated by Spectrum. The linear programming component determines an optimal land allocation with activity and output scheduling for a forest over a specified planning horizon.

Description of Market Measured Non-Timber Values

Previous research has indicated that non-industrial private forest (NIPF) owners receive lower returns on their investment in timber lands than do industrial private forest (IPF) owners (Newman and Wear, 1993; Marcouiller, Lewis, and Schreiner, 1996). Part of this difference in returns may be due to more intensive sivicultural practices by IPF owners (Marcoullier, Lewis, and Schreiner). Returns may also be affected by the amount of timberland owned by NIPFs (Newman and Wear, 1993). de Steiguer (1982), in a study of sales from farmer owned forestland (a subset of NIPF), found per acre timber sale values to be inversely related to tract size. Compolli (1981) determined that smaller tracts could be expected to increase rotation length because harvesting costs are higher. Marcoullier, Lewis, and Schreiner found that returns to land and capital from timber in McCurtain County, Oklahoma were 6.4 percent for IPF lands and only 1.1 percent for NIPF lands. NIPF lands accounted for 66 percent of the timber area in southeastern Oklahoma, but only 45 percent of the timber removals in 1993 (Franco, Miller, and

Hartsell, 1993). Data from the southern United States indicate that 35 percent of timber removals are from IPF's although they only account for 23 percent of the forested acres. The NIPF share of forested acres is 67 percent, but they only account for 58 percent of the timber harvested (USDA Forest Service, 1988). Lewis and Goodier (1990) expected the acreage of pine plantations in Oklahoma to increase by 300 percent by 2030 (700,000 acres). Much of this projected growth should occur on NIPF holdings that currently contain a mixed hardwood softwood stands of timber. The inventory of softwood timber owned by farmers in eastern Oklahoma (about 60 percent of NIPF inventory) is expect to double by 2030 (Lewis and Goodier, 1990).

Newman and Wear (1993) argue that NIPF owners are interested in other outputs besides timber. In these cases, production decisions by NIPF owners involving non-timber goods and services affect the level of timber output from the land (Newman and Wear, 1993; Marcoullier, Lewis, and Schreiner, 1996). Hartman (1976), Binkley (1981), and Boyd (1984) argue that non-timber benefits may be greater than timber benefits for NIPF owners. Industrial forestlands, held by firms that also own wood processing facilities, are managed almost exclusively for timber production (Newman and Wear, 1993).

Lewis and Goodier (1990) estimated that in Oklahoma, 4.6 million acres of forestland were grazed and 586,200 acres were leased primarily for hunting and fishing in 1984. Green (1997) indicated that pine timber production, cattle, and wildlife habitat can be complementary and profitable to forestland owners in eastern Oklahoma. Livestock grazing has also been suggested as a tool to aid in plantation establishment. It is important that adequate forage be available when grazing a young plantation, so that browsing animals do not disturb trees (Doescher,1987). Pearson (1987) found no significant difference in tree survival between grazed and ungrazed loblolly pine plantations. Lewis et al. (1983) reported a Georgia study where slash pine was planted at 12 x 12 foot spacings (300 trees per acre) and 20 x 20 foot spacings and introduced pasture was planted and fertilized in the plantation. They found that trees benefited from weed control and fertilization. Wider (12 x 12 foot and 20 x 20 foot) than conventional spacings were found to increase tree diameter and forage production, with most forage production occurring in the first ten years after regeneration. In another study, Clason (1986) found average returns to grazing bermuda grass in a loblolly pine plantation to be $37.50 per acre over 33 years. Clason (1986) suggested that combined timber and cattle production might produce more stable returns, cash flow, and marketing flexibility. Harwell and Dangerfield (1991), in a study of grazing loblolly pine plantations in Georgia, found that grazing would add from $13 to $20 per acre to net present values.

Hunting leases have been shown to provide significant income to forest owners. In a Louisiana study, hunting leases were estimated to be worth $5 to $10 per acre, annually (Conrad, 1985). Marsinko (1992) found that additional soil expectation value from hunting leases to be from $29 to $126 per acre over a 25 year rotation at six percent interest. Patterson and Patterson (1989) found that hunting leases were important supplemental income to forest owners. Porter suggests that non-monetary benefits such as reduced trespassing, poaching, theft, and vandalism are also gained from hunting leases.

CHAPTER 2

OPTIMAL MANAGEMENT STRATEGIES FOR EVEN AGED STANDS OF LOBLOLLY PINE WITH DETERMINISTIC PRICES

Introduction

In this chapter the sivicultural practices of initial tree spacing (planting density) and stand thinning were economically evaluated for various sites in southeastern Oklahoma. Early research was not consistent on the appropriate planting density for plantation forests. Frombling (1905) indicated that wide spacing violated the natural process of struggle for survival. In the 1930's Hiley suggested that spacing as wide as siviculturally possible would result in cost savings. In recent studies, Bailey (1986) found that planting density had more effect on final tree size than rotation age in loblolly pine. Broderick (1982) suggested wider spacings than the currently accepted 6 by 6 (1,500 trees per acre) or 6 by 8 (about 1,000 trees per acre) foot spacings would maximize net present value. Conrad (1990) also found that wider initial spacings (500 trees per acre or 10 by 9 foot spacings) increased net present values. Neither Broderick (1982) or Conrad (1990) considered planting densities less than 484 trees per acre, although the most sparse planting densities that they used yielded the highest net present values. Here wider spacings of 12 by 12 foot spacings (300 trees per acre) and 14.75 by 14.75 foot spacings (200 trees per acre) were economically analyzed. In addition, for each planting density, several thinning age-thinning level combinations were compared using net present value criteria. The sivicultural practice of choosing the age to thin and the amount of growing stock to remove at the time of thinning is referred to here as a "thinning regime". Optimal planting density-thinning regime combinations, those that yield maximum net present value, were found for loblolly pine plantations.

Theory of Optimal Rotation Age

Asset replacement principles are commonly used to find the harvest age that maximizes the present value of an infinite series of rotations. Asset replacement theory describes the proper time to replace an existing asset with a new asset. In plantation forests, the optimal economic rotation is commonly considered to be the one that yields the maximum net present value when identical replacement is repeated an infinite number of times (Buongiorno and Gilless, 1987; Davis and Johnson, 1987; Hanley, Shogren, and White, 1997; Klemperer, 1996, Perrin 1972).

The net present value of a single rotation of timber sales for age t can be expressed as

$$H_t = \sum_{j=1}^{t} (\sum_{i=1}^{3} P_i Q_{ijk} / \beta^j) - C_k, j = 1, \ldots, t \quad (2.1)$$

where H_t is the net present value of a single rotation, j is a time index representing the age at which either thinning, or final clear cut, or other management operations are conducted within the rotation. P_i is the price of product i and Q_{ijk} represents the quantity of product i (saw timber, pulp wood, or chip and saw) harvested at time period j for planting density k. C_k represents the initial costs of forest regeneration for planting density k following a clear cut. The annual discount rate is represented by r, and $\beta^j = (1+r)^j$. If prices and costs are assumed to increase at a constant rate over time, the trend can be estimated by using a trend adjusted discount rate if the discount rate also remains constant over time. As shown in equation 2.2, if all prices and costs each

(2.2) $$r = \frac{(1+r_d)}{(1+g)} - 1$$

increased at a constant rate of $(1+g)$ while the real discount rate was r_d then r would be the trend adjusted discount rate (Klemperer, 1996, p. 131).

The net present value of a forest plantation that is repeatedly cut and replaced with an identical stand of trees can be written as (Klemperer, 1996)

(2.3) $$WPL_\infty = H_t\left(\beta^t / \left(\beta^t - 1\right)\right)$$

which is the present value of all costs and returns that occur within the t year period for a single rotation multiplied by the factor

(2.4) $$\left(\beta^t / \left(\beta^t - 1\right)\right).$$

Equation 2.3 is also known as the soil expectation value or the Faustmann solution. Klemperer (1996) refers to this as willingness to pay for bare land given infinite replication of the existing stand of trees or WPL_∞. Here WPL_∞.across possible harvest ages was compared for different planting densities. The optimum rotation (maximum WPL_∞.) occurs where the marginal stumpage value equals the interest on the value of standing timber plus interest on the capitalized value of an infinite sequence of deferred receipts minus immediate planting costs (Howe, 1979).

The producer must also simultaneously determine the amount to thin and number of thinnings. Thinnings are considered economically feasible when the cost of thinning is less than the discounted value of additional timber harvested over the life of the stand (Pearse, 1967). Davis and Johnson indicate that thinnings that increase net present value at harvest are desirable. Klemperer (1996) states that the optimal thinning regime is the one that produces the maximum net present value ($WPL_{\infty,}$).

Objectives

The overall objective of this paper was to determine pine plantation management strategies (planting density-thinning combinations) that provide maximum or near maximum returns over a range of prices and discount rates. The specific objective was to determine the management strategy that maximizes net present value using infinite replication (Faustmann, 1849). A further objective was to determine the sensitivity of these strategies to changes in timber prices by using a price trend. Sensitivity of strategies was also tested by varying the discount rate. Strategies were located that were the most profitable (robust) across a range of discount rates and timber prices.

Data and Assumptions

Stumpage prices for pulpwood, chip and saw (CNS) and sawtimber were used. CNS includes saw timber from ten to thirteen inches diameter breast height (DBH) measured inside bark and sawtimber includes all timber above 14 inches DBH inside bark. Pulpwood includes stems with at least a four inch top, inside bark and less than ten inches DBH inside bark. Prices of sawtimber, CNS, and pulpwood were obtained from Timber Mart South (Norris, 1995). The prices were adjusted to 1990 price levels using the implicit GDP deflator. The mean of prices from 1984 to 1994 were used. Prices used were \$0.163 per ft^3 of pulpwood, \$0.094 per BF of CNS, and \$0.196 per BF of sawtimber. Sawtimber and CNS were measured using International ¼ inch logrule. Two price analyses were performed, one with prices constant over the rotation period and one with prices increasing at a two percent annual real rate. The USDA Forest Service projected real stumpage prices in the southern United States to increase by 1.5 percent per year through the year 2040 (Klemperer, 1996, p. 386). Davis and Johnson (1987, p. 484) indicate that the real stumpage price has increased at a rate over one percent for many decades. Baldwin and Feduccia (1987) show that from 1947 to 1979 real stumpage prices for softwood in the south increased by 170 percent. The costs of forest regeneration were estimated to be \$90 per acre for land preparation and \$9.00 per hundred trees planted (Dubois et al., 1995).

The analysis was done separately for each discount rate. The discount rates used were four, six, and eight percent. The long term real discount rate used by the USDA Forest Service is four percent and the long term real discount rate used by the Bureau of Land Management and the United States Office of Management and Budget is a ten percent real rate (Loomis, 1993; Klemperer, 1996). The discount rate for private forests in the Southeastern U. S. is assumed to be between five and eight percent (Teeter and Caulfield, 1991). Klemperer (1996) states that the real risk free discount rate is about three percent. For instance, today a thirty year United States government bond yields a nominal rate of just under six percent, therefore with an inflation rate of about three percent, the real rate of return is about three percent. When equation 4.2 was used to adjust the six percent discount rate to a real annual increase of two percent in prices, the result was an adjusted discount rate of 1.98 percent. Therefore, the trend adjusted discount rate will behave like a discount rate of two percent.

Bare land values were determined from examining 116 observations of land sales data from McCurtain County Oklahoma between 1990 and 1994 (Kletke, 1996). McCurtain County is about 75% forested. Each observation was researched by legal description using a county soil survey. Soil types were determined, and through a set of tables in the soil survey were converted to woodland suitability groups, and then to site indices, base age 50 (Reasoner, 1974). Our analysis uses base age 25 for site indices; therefore the site indices were converted from base age 50 to base age 25 using the method described in Baldwin and Feduccia (1987). Since we were interested in determining a value for bare land, observations containing cultivated land were eliminated. In addition, to eliminate the possibility of using observations that may be inter-family transfers, extremely low value sales were eliminated. For example, one observation had a land sales value of $55 per acre. Another concern was improvements and/or land sales where standing timber was sold with the land. Since these facts were not available in our dataset of land sales, land sales values above $600 per acre were eliminated. Table 2.1 shows the relationship between soil productivity and market value of the land.

Volumes of timber were obtained from the COMPUTE_P-LOB loblolly pine growth simulation model. COMPUTE_P-LOB simulates the growth of even-aged loblolly pine plantations through a series of equations developed from measurements of long term thinned and unthinned forests in eastern Texas, central Louisiana, and southwestern Mississippi. An example of output from COMPUTE_P-LOB is shown in Appendix B. It is a whole stand/diameter class simulator (Haight, Brodie, and Dahms, 1985). The primary range addressed by these research plots is the mid-south Coastal Plain region of the United States. Given the appropriate site index, it is assumed that these equations are a fair approximation to the growth of loblolly pine in southeastern McCurtain County, Oklahoma. For a given site index, COMPUTE_P-LOB gives an estimate of pine forest growth on a per-acre basis (Baldwin and Feduccia, 1987). Information required by COMPUTE_P-LOB to approximate forest growth includes the site index, the number of trees surviving at a predetermined age, number of thinnings, amount of basal area remaining after each thinning, and the age of thinnings. COMPUTE_P-LOB estimates the volume of saw timber, volume of chip and saw, and the volume of pulpwood for each management strategy. COMPUTE_P-LOB was validated through comparisons with actual forest production in the coastal plain of the United States, which includes southern McCurtain County, Oklahoma. The model was within five percent of measured volume (Baldwin and Feduccia, 1987). Yields from COMPUTE_P-LOB were consistent with yield tables for planted loblolly pine in McClure and Knight (1984).

Planting densities of 9.3 by 9.3 feet (500 trees per acre), 12 by 12 feet (300 trees per acre), and 14.75 by 14.75 feet (200 trees per acre) were economically analyzed for three site indices. Once the optimal planting density was found for each site index, economic analysis on possible thinning regimes was performed. All planting densities analyzed were within the data range used to estimate equations for COMPUTE_P-LOB, however planting 200 trees per acre was at the outside edge of the data. For each planting density, a single thinning was assumed possible at age 15 or age 20. Several planting density-thinning regime combinations were considered. If 200 trees were planted per acre, and the site index was 61, thinning at age 15 to 55, 60, and 65 square feet of basal area and thinning at age 20 to 60, 65, and 70 square feet of basal area was considered. Site index 61 with 300 trees planted per acre and site index 70 with 200 trees planted per acre included possible thinning at age 15 to 60, 65, and 70 square feet of basal area and thinning at age 20 to 70, 75, and 80 square feet of basal area. If 300 trees were planted per acre, and the site index was 70, thinning at age 15 to 70, 75, and 80 square feet of basal area and thinning at age 20 to 70, 80, and 90 square feet of basal area was considered. A thinning was required to produce at least 300 cubic feet of pulpwood to be feasible.

This study assumes that (1) the firm (individual) is interested in maximizing the net present value, (2) has perfect market information, (3) no non-market goods or other externalities exist, and (4) the firm is risk neutral. Tree growth for the strategies evaluated in this study were derived from use of a computer simulation model, developed by the USDA Forest Service. Here, it is assumed that although the data for the simulation model were collected from the coastal plain of east Texas, Louisiana, and Mississippi, the model accurately determines yields for sites in the coastal plain of southeastern Oklahoma.

Methodology

The objective of this project was to find planting and thinning strategies that would maximize the net present value (WPL_∞) of loblolly pine plantations. The subject has been treated in theory by authors such as Pearse (1967) and Donnelly et al. (1992). Roise (1986) demonstrates that the objective function for this type of problem may be non-convex and contain many local optima.

Roise (1986) indicates that direct search methods such as the Nelder Meade algorithm and Hooke and Jeeves algorithm can be used to obtain an opt6ium when the production surface is non-continuous and non convex. The downside to using these optimization techniques is their large CPU requirement. At the beginning of the research process, a modified Nelder Meade algorithm was used. It was discarded in favor of a spreadsheet generated grid search. Hundreds of different planting density thinning regime combinations were evaluated simultaneously using the grid search. The spreadsheet was programmed so that changes in the discount rate and prices could be made for all forest management strategies considered simultaneously. Optimal planting density-thinning regime combinations were found for each site index and price-discount rate combinations. One advantage to using the grid search is that near optimal strategies can be compared. Not only was the optimal strategy determined, but also that strategy was compared to sub optimal strategies over the range of possible harvest ages. Possible harvest ages were assumed to be ages 21 through 50. The age of rotation, the number and age of each thinning, the amount of basal area removed for each thinning, and WPL_∞, were endogenously determined. The exogenous variables were the planting density and cost, site index, timber price, and the discount rate.

Results

The analysis was conducted separately for each site index. First an analysis of soil expectation values (WPL_{∞},) for various planting densities without thinning is presented. Then for sites that are economically feasible for loblolly pine plantations, results (WPL_{∞},) for thinning age-level-planting density combinations are presented.

Site Index 52

The net present values for three discount rates using constant prices for site index 52 (SI52) are shown in Tables 2.2 through 2.4. As expected, as the discount rate increased, the length of optimal rotation decreased (Perrin, 1972). Figure 2.1 shows that planting 200 trees per acre yielded the highest soil expectation value for possible harvests from age 20 to 50. However, the maximum WPL_{∞}, ($41 per acre at age 35 at the six percent discount rate) for site index 52 was so low (see Table 2.2), site index 52 was not considered suitable for pine plantations. The maximum soil expectation value (WPL_{∞}) was lower than the market value of land ($400) even at the four percent discount rate ($253 per acre at age 41). Because of this, further analysis with site index 52, such as examining thinning regiments, was not conducted.

Site Index 61

Results (WPL_∞) of the planting density analysis for site index 61(SI61) with a six percent real discount rate and constant prices are shown in Figure 2.2. The same analysis using a two percent real increasing timber price trend with a six percent real discount rate is shown in Figure 2.3. For constant prices the best planting density was 200 trees per acre, with a maximum WPL_∞ of $207 at age 32 when the six percent discount rate. With the price trend imposed, as the stand ages, planting 300 trees per acre was only marginally better than planting 200 or 500 trees per acre, with a maximum WPL_∞ of $2184 at age 45. With prices increasing geometrically over time, the result when using successive single rotations is that each optimal rotation is longer than the previous one. The approach used here, infinite replication, forces the optimal rotation to be a single age. Table 2.3 compares the WPL_∞ of different planting densities for constant prices at the four, six and eight percent discount rates. Two facts of interest are shown in Table 2.3. First, as expected, when the discount rate increases, the age of optimal rotation decreases. When the discount rate was four percent, the optimal rotation was age 37 ($606 per acre) and when the discount rate was eight percent the optimal rotation was age 28 ($51 per acre). Second, planting 200 trees per acre yields the highest WPL_∞ for each discount rate. Table 2.4 compares the WPL_∞ of different planting densities with two percent increasing real timber prices and a six percent discount rate. As shown in Table 2.4, there was little difference in the WPL_∞ between planting 200 and 300 trees per acre. Planting 300 trees per acre yielded the highest WPL_∞ ($2184 per acre at age 45) when real timber prices were allowed to increase at a two percent real annual rate and the real discount rate is six percent, however, planting 200 trees yielded nearly 99 percent of highest WPL_∞ when 300 trees per acre were planted ($2,157 per acre).

The effect of thinning the stand is shown in Figure 2.4 through Figure 2.7. The thinning strategies depicted in Figures 2.4 through 2.7 were chosen because they were the two best regimes for each planting density. Thinning results for constant prices and a six percent discount rate are shown in Figure 2.4 for planting 200 trees per acre and Figure 2.5 for 300 trees per acre. Results for a two percent per year real increase in timber prices with a six percent discount rate are shown in Figure 2.6 for planting 200 trees per acre and in Figure 2.7 for 300 trees per acre. The best strategies for the 14.75 x 14.75 foot initial spacing (200 trees) were to thin at age 15 to 60 square feet of basal area (maximum WPL_∞ of $398 at age 31 when the discount rate was six percent) and thin age 20 to 60 square feet of basal area (maximum WPL_∞ of $343 at age 34 when the discount rate was six percent). For the 12 x 12 foot initial spacing (300 trees), the best strategies were to thin at age 15 to 60 square feet of basal area (maximum WPL_∞ of $292 at age 32 when the discount rate was six percent) and thin at age 20 to 70 square feet of basal area (maximum WPL_∞ of $304 at age 34 when the discount rate was six percent). These figures show that the right thinning regime can greatly improve WPL_∞. Table 2.5 shows a comparison of net present values for the planting density-thinning strategies shown in Figures 2.4 and 2.5 (constant prices) for the four, six, and eight percent discount rates. Data in Tables 2.5 and 2.6 are presented as a proportion of the best strategy's WPL_∞. At the bottom of Table 2.5 is a comparison of strategies using a maximin criteria. The maximin criteria shows the minimum of all maximum proportion of the best WPL_∞ for each thinning strategy across all discount rates. Thinning to 60 square feet of basal area at age 15 when 200 trees per acre are planted gave the highest WPL_∞ across all discount rates and prices. At the four percent discount rate, the no-thin option yielded a net present value of 63 percent of the best strategy when 200 trees per acre were planted and 61 percent of the best strategy when 300 trees per acre were planted. As the discount rate is increased to eight percent, the no-thin options fare much worse, yielding 27 percent of the highest yielding strategy when 300 trees are planted and 33 percent when 200 trees are planted. The second best strategy, planting 200 trees per acre and thinning at age 20 to 60 square feet of basal area, was 93 percent as good as the best strategy at the four percent discount rate and 77 percent as good at the eight percent discount rate. As shown in Table 2.6, when a two percent real increase in timber prices is assumed, the no-thin strategies yield 74 percent of the optimal strategy and the second best strategy is within 2 percent of the net present value of the best strategy. Table 2.7 shows the effect of various levels of thinning assuming constant prices with a planting density of 200 trees per acre and Table 2.8 shows the effect of various thinning regimes assuming constant prices with a planting density of 300 trees per acre. Comparing these two tables shows that planting 200 trees per acre and thinning at age 15 to 60 square feet of basal area yields $969 per acre at age 32 when the discount rate was four percent and $398 per acre at age 30 when the discount rate was six percent. These were the highest WPL_∞ of any strategy. Table 2.9 shows the effect of various levels of thinning with a planting density of 200 trees per acre, a two percent increasing timber price trend, and six percent discount rate. Table 2.10 shows the same data as Table 2.9, only with a planting density of 300 trees per acre. Once again, planting 200 trees per acre and thinning at age 15 to 60 square feet of basal area yielded the highest WPL_∞.($2,929 at age 36).

Site Index 70

Results (WPL_∞) of the planting density analysis for site index 70(SI70) with a six percent discount rate and constant prices are shown in Figure 2.8. A planting density of 200 trees per acre yielded the highest WPL_∞ ($449 at age 30) with constant prices (Figure 2.8). At ages beyond 39, planting 200 trees per acre did not perform any better than planting 300 trees per acre with constant prices and a six percent discount rate (Figure 2.8). As shown in Table 2.11, if prices are held constant, a planting density of 200 trees per acre yields the highest WPL_∞ for all discount rates considered ($1,099 at age 34 when the discount rate is four percent and $189 per acre when the discount rate is eight percent). The same analysis using a two percent increasing price with a six percent discount rate is shown in Figure 2.9. With the two percent annual increase in real timber prices at the six percent discount rate, the optimal planting density increased from 200 to 500 trees per acre for site index 70 if the stand was held past age 38 (Figure 2.8). The highest WPL_∞ were $3,672 per acre at age 44 from planting 500 trees per acre and $3,667 per acre at age 42 from planting 300 trees per acre when prices were assumed to increase at a real rate of two percent and the discount rate is six percent (Table 2.12 and Figure 2.9). The planting densities of 200 and 300 trees per acre were substantially better than planting 500 trees per acre at the four, six, and eight percent discount rates (Table

2.11 and Figure 2.8), and planting 500 trees per acre was only marginally better with the price trend ($3,672 versus $3,667).

The two best thinning strategies found here for planting 200 trees per acre with constant prices at the six percent discount rate are shown in Figure 2.10. They were thinning to 65 square feet of basal area at age 15 and thinning to 75 square feet of basal area at age 20. Figure 2.11 shows the best two thinning strategies with constant prices discounted at six percent when 300 trees per acre are planted. They were thinning at age 15 or age 20 to 80 square feet of basal area. The no-thin strategy is included in Figures 2.10 and 2.11 for comparison. Figure 2.10 shows that when 200 trees per acre are planted that thinning at age 15 to 65 square feet of basal are yields the highest WPL_∞ at the six percent discount rate with constant prices ($618 at age 27). Figure 2.11 shows when 300 trees per acre are planted that thinning to 80 square feet of basal area at age 15 (maximum WPL_∞ of $561 at age 32) and thinning to 80 square feet of basal area at age 20 (maximum WPL_∞ of $570 at age 33) perform similarly at the six percent discount rate with constant prices.

The bottom of Table 2.13 shows that the best management strategy across the four, six, and eight percent discount rates with constant prices was planting 200 trees per acre, and thinning at age 15 to 65 square feet of basal area. This strategy yielded a minimum of 98.7 percent of the optimal strategy across the four, six, and eight percent discount rates. Planting 300 trees per acre and thinning the stand at age 20 to 80 square was the best strategy feet of basal area if prices are constant and the discount rate is four percent or with the two percent increasing price trend and a six percent discount rate

(Table 2.13 and Table 2.14). Planting 200 trees per acre and thinning at age 15 to 65 square feet of basal area yielded the highest WPL_{∞} at the six ($618 per acre at age 27) and eight ($296 per acre at age 27) percent discount rates (Table 2.13, Table 2.15, Table 2.16 and Figure 2.10). With the four percent discount rate and the two percent real timber price increase and six percent discount rate, the optimal strategy is to plant 300 trees per acre and thin at age 20 to 80 square feet of basal area (Table 2.13, Table 2.14, Table 2.15, and Table 2.16). At the four percent discount rate planting 300 trees and thinning at age 20 to 80 square feet of basal area yielded a maximum $1,371 at age 35. Figure 2.13 and Table 2.18 show that the same strategy yielded a maximum $4,261 at age 36.

Results here confirm Haight's (1992) findings that the effect of allowing a premium for large sawtimber tends to decrease the planting density of loblolly pine plantations, and found that planting 200 trees per acre may be optimal under these conditions. When analysis was done using the same price for chip and saw and sawtimber, at the six percent discount rate 300 trees per acre was the optimum for SI61 and 500 trees per acre was the optimum for SI70. This because a planting density of 200 trees per acre yields a larger diameter trees during age range when harvest should occur (age 20 to 40), and without a premium for large sawtimber these larger diameter trees are no more valuable than small diameter trees.

Summary

Previous research has shown that reducing planting density increased net present values (Broderick, Thurmes, and Klemperer, 1982; Conrad, 1990). The most sparse planting density they analyzed was 10 by 10 feet (about 500 trees per acre), which also yielded the maximum net present value for both of these studies. These studies involved planting on converted old fields, which required less initial site preparation costs than were involved in this study ($10 to $12 per acre versus $90 per acre).

Thinning stands with initial planting densities of 200, 300, and 500 trees per acre were presented here. Planting 200 trees per acre was at the edge of, but within the data used to develop the simulation model used here to determine timber volumes if the stand was unthinned. Thinning when 200 trees per acre were planted was well outside the range of data collected to develop COMPUTE_P_LOB. However, since planting 200 trees per acre and thinning the stand produced the highest per acre values, but was outside the data range used to develop the simulation, this remains an area for further research.

The results here indicated the existence of rotation strategies for each site index that provide near optimal returns under a range of prices and discount rates. For SI61 and SI70, planting densities and thinning strategies were located that work well across the discount rates considered with constant prices and with a price trend. SI52, which is marginal for commercial timber production because of it's low productivity, had strategies that were more sensitive to changes in the discount rate than were strategies for SI61 and SI70. Because the WPL_{∞} were less than the market value of bare land, SI52 lands have a higher value in uses other than plantation forests.

The optimal strategy for SI61, planting 200 trees per acre, and thinning at age 15 to 60 square feet of basal area, across all the discount rates considered as well as the constant and increasing price trend. For SI70, the optimal planting density was 200 trees per acre for the six and eight percent discount rate. At the four percent discount rate, there wasn't much difference in WPL between planting 200 and 300 trees per acre. With the price trend considered, a planting density of 500 trees per acre yields the maximum WPL, however, the best strategy remains 200 trees per acre up to age 38. When SI70 was thinned, planting 200 trees per acre and thinning at age 15 to 65 square feet of basal area was optimal with constant prices and the six and eight percent discount rates. At the four percent discount rate with constant prices and the six percent discount rate with two percent increasing timber price trend, planting 300 trees per acre and thinning at age 20 to 80 square feet of basal area was the best strategy. It is an extremely hypothetical assumption that a two percent real increasing price trend will continue for nearly fifty years. Economic logic would indicate that substitutes for wood products would at some point in time keep the price of timber products in check.

Some caveats need to be made at this point. First, wider spacings (200 trees per acre) are desirable when agroforestry activities such as grazing, are performed in conjunction with timber production (Lewis et al., 1983). Second, one reason for planting a more dense forest (500 trees per acre) is that the cost at planting time is only $9 per acre for each additional 100 trees, and once a stand is growing, it is easier to remove trees (to make the forest less dense) than to add trees. Third, the planting density of 200 trees per acre was within the data range collected for COMPUTE_P-LOB. However, planting 300 trees per acre was the widest spacing used to collect data pertaining to thinnings. Additional research could be made on loblolly pine growth models with wide spacings.

Table 2.1. Bare Land Sale Values by Site Index for McCurtain County, Oklahoma.

site index	number of obs.	per acre value ($)	std. dev.($)
69	1	439	na
65	12	400	165
58	22	454	117
48	14	334	124
37	8	330	137

Note: Land sales data were obtained from Dr. Darrell Kletke, Department of Agricultural Economics at Oklahoma State University.

Table 2.2. Site Index 52 Base Age 25 Soil Expectation Values (WPL_{∞}) for Various Planting Densities and Discount Rates.

Age	200 TPA	300 TPA	500 TPA
Four Percent Discount Rate			
40	234	213	147
41	**253**	216	152
42	250	219	147
43	247	228	160
44	243	212	160
45	234	227	**166**
46	238	**233**	158
47	236	225	164
48	230	216	154
49	232	212	165
50	228	211	164
Six Percent Discount Rate			
30	27	10	-43
31	28	14	-42
32	33	11	-37
33	37	11	-38
34	34	17	-34
35	**41**	**22**	-31
36	36	19	-31
37	39	21	-34
38	37	14	-31
39	37	19	**-27**
40	31	18	-30
Eight Percent Discount Rate			
30	-38	-51	-95
31	-38	**-49**	-96
32	-37	-52	**-94**
33	**-36**	-53	-95
34	-39	-51	-94
35	-36	-50	-94
36	-40	-52	-95
37	-39	-52	-97
38	-41	-56	-97
39	-43	-55	-96
40	-46	-56	-98

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis. TPA = trees per acre.

Table 2.3. Site Index 61 Base Age 25 Soil Expectation Values (WPL_∞) for Various Planting Densities and Discount Rates.

Age	200 TPA	300 TPA	500 TPA
Four Percent Discount Rate			
35	571	560	448
36	589	557	473
37	**606**	564	472
38	590	579	479
39	577	569	493
40	570	572	**506**
41	582	**584**	506
42	563	576	492
43	580	559	498
44	554	563	497
45	548	566	500
Six Percent Discount Rate			
30	194	179	103
31	197	176	100
32	**207**	182	104
33	198	**186**	110
34	191	179	109
35	191	186	112
36	194	180	**119**
37	197	179	114
38	186	181	114
39	176	173	115
40	169	170	117
Eight Percent Discount Rate			
25	45	20	-35
26	42	26	-28
27	47	29	-27
28	**51**	30	-24
29	49	28	-24
30	48	30	**-19**
31	46	**33**	-23
32	45	30	-23
33	45	29	-21
34	43	25	-24
35	41	26	-25

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis. TPA = trees per acre.

Table 2.4. Site Index 61 Base Age 25 Soil Expectation Values (WPL_{∞}) for Various Planting Densities with a Two Percent Increasing Timber Price and Cost Trend and Six Percent Discount Rate.

Age	200 TPA	300 TPA	500 TPA
40	2060	2102	1950
41	2125	2101	1980
42	2095	2118	1961
43	2123	2099	2010
44	2126	2145	2036
45	2157	**2184**	2080
46	**2163**	2125	2080
47	2121	2148	2094
48	2107	2120	2101
49	2080	2098	2100
50	2088	2147	**2108**

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis. TPA = trees per acre.

Table 2.5. Proportion of Optimal Strategy for Site Index 61, Constant Prices, Planting Densities of 200 and 300 Trees Per Acre, and Various Thinning Strategies.

		300TPA			200TPA	
Age	No Thin	15(60) [1]	20(70) [2]	No Thin	15(60) [1]	20(60) [3]
Four Percent Discount Rate						
26	0.436	0.669	0.521	0.462	0.783	0.606
28	0.469	0.742	0.606	0.532	0.890	0.700
30	0.527	0.761	0.686	0.555	0.985	0.785
32	0.554	0.789	0.759	0.583	**1.000**	0.850
34	0.566	**0.790**	0.829	0.613	0.894	**0.934**
36	0.588	0.734	**0.845**	**0.630**	0.815	0.933
38	**0.612**	0.719	0.793	0.619	0.754	0.851
40	0.604	0.723	0.787	0.613	0.714	0.791
MAX	**0.612**	**0.790**	**0.845**	**0.630**	**1.000**	**0.934**
Six Percent Discount Rate						
26	0.391	0.689	0.512	0.423	0.822	0.608
28	0.412	**0.752**	0.596	0.486	0.922	0.698
30	0.461	0.748	0.669	0.493	**1.000**	0.773
32	**0.470**	0.753	0.730	0.503	0.983	0.820
34	0.462	0.727	**0.783**	**0.514**	0.833	**0.883**
36	0.465	0.641	0.773	0.509	0.719	0.851
38	0.467	0.601	0.694	0.475	0.629	0.736
40	0.437	0.581	0.663	0.446	0.563	0.648
MAX	**0.470**	**0.752**	**0.783**	**0.514**	**1.000**	**0.883**
Eight Percent Discount Rate						
26	0.231	0.671	0.427	0.276	0.849	0.550
28	0.234	**0.722**	0.516	**0.334**	0.942	0.641
30	**0.270**	0.678	0.586	0.313	**1.000**	0.704
32	0.253	0.648	0.633	0.295	0.930	0.726
34	0.215	0.578	**0.665**	0.278	0.697	**0.766**
36	0.189	0.440	0.619	0.243	0.520	0.687
38	0.164	0.361	0.493	0.173	0.379	0.514
40	0.103	0.309	0.428	0.113	0.272	0.381
MAX	**0.270**	**0.722**	**0.665**	**0.334**	**1.000**	**0.766**
Minimax across all discount rates						
MIN	**0.270**	**0.722**	**0.665**	**0.334**	**1.000**	**0.766**

Note: Prices were $195.60 per MBF for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per MCF for pulpwood.

[1]Thinning at age 15 to 60 square feet of basal area.

[2]Thinning at age 20 to 70 square feet of basal area.

[3]Thinning at age 20 to 60 square feet of basal area.

Table 2.6. Proportion of Optimal Strategy for Site Index 61, Two Percent Real Annual Price Increase, Six Percent Discount Rate, Planting Densities of 200 and 300 Trees Per Acre, and Various Thinning Strategies.

	300TPA			200TPA		
Age	No Thin	15(60) [1]	20(70) [2]	No Thin	15(60) [1]	20(60) [3]
30	0.549	0.752	0.677	0.575	0.961	0.775
32	0.589	0.798	0.761	0.617	**1.000**	0.856
34	0.618	**0.820**	0.847	0.663	0.924	0.959
36	0.657	0.787	**0.884**	0.698	0.872	**0.983**
38	0.699	0.793	0.854	0.707	0.834	0.926
40	0.711	0.819	0.870	0.720	0.815	0.888
42	0.737	0.843	0.870	0.721	0.819	0.869
44	**0.766**	0.830	0.873	0.732	0.814	0.862
46	0.737	0.824	0.866	**0.744**	0.807	0.829
48	0.735	0.839	0.868	0.724	0.803	0.832
50	0.741	0.834	0.858	0.728	0.816	0.822
MAX	**0.766**	**0.820**	**0.884**	**0.744**	**1.000**	**0.983**

Note: Initial prices were $195.60 per MBF for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per MCF for pulpwood.

[1]Thinning at age 15 to 60 square feet of basal area.

[2]Thinning at age 20 to 70 square feet of basal area.

[3]Thinning at age 20 to 60 square feet of basal area.

Table 2.7. Soil Expectation Values for Various Thinning Strategies, Site Index 61, Planting Density of 200 Trees per Acre, Constant Prices, and Various Discount Rates.

Age	No Thin	15(55)[1]	15(60)[2]	15(65)[3]	20(60)[4]	20(65)[5]	20(70)[6]
Four Percent Discount Rate							
26	$438	$704	$741	$803	$574	$618	$622
27	469	740	789	**814**	641	662	671
28	503	790	843	771	663	681	726
29	513	825	900	720	694	733	752
30	526	869	933	728	744	768	802
31	535	**914**	**969**	724	779	**800**	830
32	552	857	947	683	805	795	**867**
33	572	813	894	701	839	773	734
34	581	802	846	686	885	763	689
35	594	806	803	663	**895**	762	707
36	**597**	802	772	651	884	738	674
Six Percent Discount Rate							
26	164	302	319	**348**	236	256	257
27	176	315	337	347	265	273	276
28	189	334	358	321	271	278	298
29	189	345	379	290	281	298	305
30	194	360	388	289	300	309	323
31	197	**374**	**398**	281	311	**319**	330
32	**207**	342	381	258	318	311	**341**
33	198	316	351	261	328	295	275
34	191	305	323	249	**343**	285	249
35	191	302	298	234	341	279	252
36	194	294	279	224	330	264	233
Eight Percent Discount Rate							
26	42	122	131	**146**	85	95	94
27	47	126	138	142	98	102	102
28	**51**	133	145	124	99	101	111
29	49	136	153	105	102	109	111
30	48	140	154	101	109	112	118
31	46	**145**	**156**	94	111	**114**	118
32	45	125	143	79	112	107	**120**
33	45	108	124	78	114	96	84
34	43	100	107	69	**118**	88	68
35	41	95	92	59	114	82	67

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis.

1. Thin at age 15 to 55 square feet of basal area.
2. Thin at age 15 to 60 square feet of basal area.
3. Thin at age 15 to 65 square feet of basal area.
4. Thin at age 20 to 60 square feet of basal area.
5. Thin at age 20 to 65 square feet of basal area.
6. Thin at age 20 to 70 square feet of basal area.

Table 2.8. Soil Expectation Values for Various Thinning Strategies, Site Index 61, Planting Density of 300 Trees per Acre, Constant Prices, and Various Discount Rates. Values are in dollars per acre.

Age	No Thin	15(60)[1]	15(65)[2]	15(70)[3]	20(70)[4]	20(75)[5]	20(80)[6]
Four Percent Discount Rate							
32	$525	$747	$656	$652	$719	$751	**$724**
33	541	743	672	652	770	774	697
34	536	748	666	658	785	**775**	691
35	560	731	677	666	797	761	699
36	557	696	680	**677**	**800**	747	701
37	564	**697**	**682**	674	763	743	706
38	579	681	681	662	751	745	715
39	569	698	680	667	745	739	715
40	572	685	682	665	745	737	709
41	**584**	667	689	672	732	738	708
Six Percent Discount Rate							
26	152	267	272	**271**	199	202	213
27	162	288	278	266	219	227	232
28	160	292	**279**	259	231	233	241
29	165	292	263	255	249	252	258
30	179	290	257	255	260	267	274
31	176	290	251	247	270	273	**281**
32	182	**292**	249	246	283	296	281
33	**186**	285	251	241	302	**302**	264
34	179	282	244	238	**304**	297	257
35	186	269	244	237	304	286	256
Eight Percent Discount Rate							
26	26	103	105	**104**	66	67	72
27	29	**112**	**106**	99	75	79	80
28	30	111	103	92	80	**80**	83
29	28	108	92	87	**87**	**88**	90
30	30	105	**86**	84	90	93	96
31	**33**	102	81	77	93	93	**97**
32	30	100	77	74	98	**103**	94
33	29	93	75	69	**104**	103	82
34	25	89	69	65	102	**98**	76
35	26	80	67	62	100	90	73

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis

1. Thin at age 15 to 60 square feet of basal area.
2. Thin at age 15 to 65 square feet of basal area.
3. Thin at age 15 to 70 square feet of basal area.
4. Thin at age 20 to 70 square feet of basal area.
5. Thin at age 20 to 75 square feet of basal area.
6. Thin at age 20 to 80 square feet of basal area.

Table 2.9. Soil Expectation Values for Various Thinning Strategies, **Site Index 61**, Planting Density of **200 Trees per Acre**, Two Percent Annual **Increasing Price Trend**, and **Six Percent Discount** Rate. Age of Thinning is Followed by Remaining Basal Area in Parentheses.

Age	No Thin	15(55)[1]	15(60)[2]	15(65)[3]	20(60)[4]	20(65)[5]	20(70)[6]
30	$1670	$2603	$2789	$2226	$2251	$2330	$2436
31	1718	**2763**	**2929**	2244	2379	2452	2549
32	1791	2636	2903	2158	2485	**2469**	**2690**
33	1872	2543	2787	2239	2613	2437	2339
34	1924	2542	2684	2223	2784	2437	2236
35	1990	2590	2589	2185	2850	2466	2320
36	2028	2613	2532	2179	**2853**	2427	2253
37	2010	2575	2454	2256	2751	2416	2287
38	2053	2477	2422	2254	2687	2404	2285
39	2080	2502	2402	2283	2649	2403	2303
40	2060	2452	2366	2324	2577	2415	2333
41	2125	2407	2382	2331	2571	2414	2383
42	2095	2367	2378	2352	2523	2396	2362
43	2123	2388	2361	2371	2440	2428	2381
44	2126	2448	2362	**2412**	2504	2460	2363
45	**2157**	2395	2342	2342	2467	2421	2352

Note: Initial prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood, with a two percent annual increasing real price trend. Values are on a per acre basis.

1. Thin at age 15 to 55 square feet of basal area.
2. Thin at age 15 to 60 square feet of basal area.
3. Thin at age 15 to 65 square feet of basal area.
4. Thin at age 20 to 60 square feet of basal area.
5. Thin at age 20 to 65 square feet of basal area.
6. Thin at age 20 to 70 square feet of basal area.

Table 2.10. Soil Expectation Values for Various Thinning Strategies, **Site Index 61**, Planting Density of **300 Trees per Acre**, Two Percent Annual **Increasing Price Trend**, and **Six Percent Discount** Rate. Age of Thinning is Followed by Remaining Basal Area in Parentheses. Values are in dollars per acre.

Age	No Thin	15(60)[1]	15(65)[2]	15(70)[3]	20(70)[4]	20(75)[5]	20(80)[6]
40	$2102	$2379	$2377	$2334	$2525	$2515	$2445
41	2101	2354	2433	2389	2515	2552	2475
42	2118	2448	2441	2402	2527	2579	2514
43	2099	2396	2415	2420	2513	**2588**	**2559**
44	2145	2408	2427	2377	2535	2515	2559
45	**2184**	**2462**	2382	2426	**2584**	2510	2481
46	2125	2391	2394	2402	2516	2485	2418
47	2148	2447	**2447**	2368	2532	2539	2435
48	2120	2437	2404	**2430**	2522	2493	2459
49	2098	2358	2377	2380	2478	2482	2459
50	2147	2421	2365	2339	2490	2494	2430

Note: Initial prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood, with a two percent annual increasing real price trend. Values are on a per acre basis.

1. Thin at age 15 to 60 square feet of basal area.
2. Thin at age 15 to 65 square feet of basal area.
3. Thin at age 15 to 70 square feet of basal area.
4. Thin at age 20 to 70 square feet of basal area.
5. Thin at age 20 to 75 square feet of basal area.
6. Thin at age 20 to 80 square feet of basal area.

Table 2.11. Site Index 70 Base Age 25 Soil Expectation Values (WPL_∞) for Various Planting Densities and Discount Rates.

Age	200 TPA[1]	300 TPA	500 TPA
Four Percent Discount Rate			
33	$1071	$1074	$963
34	**1099**	1080	978
35	1070	1070	991
36	1074	1063	997
37	1078	**1095**	1016
38	1055	1068	1005
39	1067	1059	1009
40	1019	1056	1016
41	1019	1039	**1020**
42	984	1037	1003
Six Percent Discount Rate			
29	444	418	332
30	**449**	417	339
31	436	418	361
32	433	**423**	**363**
33	426	423	353
34	431	418	353
35	410	406	351
36	405	396	346
37	399	402	347
38	382	383	336
Eight Percent Discount Rate			
25	185	157	93
26	**189**	156	99
27	185	159	101
28	181	**167**	106
29	185	167	104
30	183	163	105
31	172	159	**112**
32	166	157	109
33	159	153	100
34	157	147	96

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis.

1. TPA = Trees per acre

Table 2.12. Site Index 70 Base Age 25 Soil Expectation Values (WPL_∞) for Various Planting Densities Two Percent Increasing Timber Price Trend and Six Percent Discount Rate.

Age	200 TPA[1]	300 TPA	500 TPA
36	$3472	$3454	$3326
37	3530	3601	3432
38	3508	3566	3447
39	**3594**	3587	3507
40	3490	3628	3577
41	3538	3621	3641
42	3476	**3667**	3639
43	3432	3603	3593
44	3422	3579	**3672**
45	3382	3608	3588
46	3431	3542	3627
47	3412	3552	3598
48	3280	3483	3550
49	3276	3412	3594
50	3182	3345	3506

Note: Initial prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood, with a two percent annual increasing real price trend. Values are on a per acre basis.

1. TPA = Trees per acre

Table 2.13. Proportion of Optimal Strategy for Site Index 70, Constant Prices, Planting Densities of 200 and 300 Trees Per Acre, and Various Thinning Strategies.

Age	No Thin	300TPA 15(80) [1]	20(80) [2]	No Thin	200TPA 15(65) [3]	20(75) [4]
Four Percent Discount Rate						
26	0.638	0.839	0.714	0.706	0.936	0.792
28	0.677	0.892	0.784	0.727	**0.987**	0.883
30	0.732	**0.947**	0.859	0.781	0.959	0.920
32	0.757	0.939	0.972	**0.781**	0.916	0.975
34	0.784	0.932	0.997	0.779	0.930	**0.984**
36	0.783	0.919	**1.000**	0.784	0.900	0.946
38	**0.983**	0.923	0.967	0.770	0.878	0.942
40	0.755	0.908	0.944	0.744	0.867	0.888
MAX	**0.983**	**0.947**	**1.000**	**0.781**	**0.987**	**0.984**
Six Percent Discount Rate						
26	0.618	0.862	0.720	0.700	0.973	0.813
28	0.638	0.894	0.778	0.700	**1.000**	0.891
30	0.674	**0.926**	0.835	**0.733**	0.941	0.905
32	0.676	0.890	**0.928**	0.708	**0.868**	**0.937**
34	**0.679**	0.855	0.926	0.681	0.855	0.919
36	0.653	0.815	0.902	0.662	0.798	0.855
38	0.643	0.793	0.843	0.624	0.752	0.825
40	0.579	0.753	0.797	0.576	0.716	0.750
MAX	**0.679**	**0.926**	**0.928**	**0.733**	**1.000**	**0.937**
Eight Percent Discount Rate						
26	0.548	0.862	0.691	**0.657**	**1.000**	0.811
28	0.544	0.868	0.732	0.627	0.996	**0.873**
30	**0.556**	**0.870**	0.770	0.635	0.894	0.859
32	0.530	0.798	**0.842**	0.577	0.780	0.863
34	0.504	0.730	0.809	0.520	0.735	0.812
36	0.450	0.658	0.754	0.473	0.647	0.717
38	0.413	0.608	0.666	0.410	0.573	0.660
40	0.327	0.542	0.595	0.340	0.513	0.562
MAX	**0.556**	**0.870**	**0.842**	**0.657**	**1.000**	**0.873**
Minimax across all discount rates						
MIN	**0.556**	**0.870**	**0.842**	**0.657**	**0.987**	**0.873**

Note: Prices were $195.60 per MBF for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per MCF for pulpwood.

[1]Thinning at age 15 to 80 square feet of basal area.
[2]Thinning at age 20 to 80 square feet of basal area.
[3]Thinning at age 15 to 65 square feet of basal area.
[4]Thinning at age 20 to 75 square feet of basal area.

Table 2.14. Proportion of Optimal Strategy for Site Index 70, Two Percent Real Annual Price Increase, Six Percent Discount Rate, Planting Densities of 200 and 300 Trees Per Acre, and Various Thinning Strategies.

		300TPA			200TPA	
Age	No Thin	15(80)	20(80)	No Thin	15(65)	20(75)
30	0.709	0.886	0.804	0.749	0.898	0.857
32	0.751	0.902	0.927	0.769	0.880	0.928
34	0.797	0.918	0.973	0.788	0.916	0.959
36	0.818	0.929	**1.000**	0.815	0.911	0.946
38	**0.855**	0.958	0.992	**0.823**	0.914	**0.965**
40	0.835	**0.968**	0.995	0.819	**0.927**	0.935
42	0.832	0.958	0.985	0.816	0.913	0.926
44	0.842	0.931	0.972	0.803	0.899	0.907
46	0.836	0.920	0.954	0.805	0.882	0.916
48	0.812	0.913	0.922	0.770	0.866	0.879
50	0.799	0.903	0.905	0.747	0.816	0.849
MAX	**0.855**	**0.968**	**1.000**	**0.823**	**0.927**	**0.965**

Note: Initial prices were $195.60 per MBF for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per MCF for pulpwood.

[1]Thinning at age 15 to 80 square feet of basal area.
[2]Thinning at age 20 to 80 square feet of basal area.
[3]Thinning at age 15 to 65 square feet of basal area.
[4]Thinning at age 20 to 75 square feet of basal area.

Table 2.15. Soil Expectation Values for Various Thinning Strategies, Site Index 70, Planting Density of 200 Trees per Acre, Constant Prices, and Various Discount Rates.

Age	No Thin	15(60)[1]	15(65)[2]	15(70)[3]	20(70)[4]	20(75)[5]	20(80)[6]
Four Percent Discount Rate							
27	$981	$1255	$1347	**$1280**	$1116	$1117	$1190
28	996	1302	**1352**	1273	1145	1210	1251
29	1045	1338	1343	1240	1197	1255	1288
30	1070	1330	1314	1250	1200	1260	**1319**
31	1059	1334	1285	1253	1259	1320	1315
32	1069	**1340**	1255	1249	1305	1336	1315
33	1071	1338	1263	1230	1291	1327	1303
34	**1099**	1299	1274	1252	1308	**1348**	1304
35	1070	1283	1253	1247	1330	1309	1297
36	1074	1246	1233	1215	**1361**	1296	1317
37	1078	1244	1201	1211	1337	1268	1277
Six Percent Discount Rate							
26	428	561	595	**589**	487	498	520
27	428	576	**618**	581	509	506	541
28	428	590	612	568	517	545	563
29	444	**599**	598	544	535	559	573
30	**449**	587	576	540	529	554	**579**
31	436	580	553	533	550	574	569
32	433	574	531	522	**563**	573	561
33	426	564	527	505	549	561	547
34	431	538	523	507	549	**562**	539
Eight Percent Discount Rate							
25	185	259	283	**287**	221	229	233
26	**189**	271	288	281	229	234	245
27	185	274	**296**	272	238	235	252
28	181	**277**	287	260	238	251	**260**
29	185	277	274	242	244	**255**	260
30	183	265	258	235	237	247	259
31	172	257	241	226	243	253	249
32	166	249	225	216	**246**	249	240

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood, no trend is considered. Values are on a per acre basis.

1. Thin at age 15 to 60 square feet of basal area.
2. Thin at age 15 to 65 square feet of basal area.
3. Thin at age 15 to 70 square feet of basal area.
4. Thin at age 20 to 70 square feet of basal area.
5. Thin at age 20 to 75 square feet of basal area.
6. Thin at age 20 to 80 square feet of basal area.

Table 2.16. Soil Expectation Values for Various Thinning Strategies, Site Index 70, Planting Density of 300 Trees per Acre, Constant Prices, and Various Discount Rates.

Age	No Thin	15(70)[1]	15(75)[2]	15(80)[3]	20(70)[4]	20(80)[5]	20(90)[6]
Four Percent Discount Rate							
30	1003	1245	1258	**1297**	1079	1176	1283
31	1036	1266	1299	1288	1127	1215	1301
32	1037	1311	1297	1287	1153	1331	1316
33	1074	**1317**	**1304**	1282	1185	1354	1316
34	1080	1310	1294	1277	1211	1366	**1319**
35	1070	1312	1298	1268	1215	**1371**	1278
36	1063	1303	1299	1258	1232	1370	1283
37	**1095**	1277	1283	1274	1258	1341	1303
38	1068	1248	1254	1265	1324	1324	1304
39	1059	1233	1230	1248	**1331**	1309	1274
Six Percent Discount Rate							
29	418	547	546	**566**	461	497	**562**
30	417	547	550	566	471	511	556
31	418	549	**561**	554	488	522	557
32	**423**	**561**	551	545	493	568	555
33	423	556	546	534	501	**570**	547
34	418	544	533	523	506	567	540
35	406	537	526	511	501	561	513
36	396	525	519	499	501	552	507
37	402	505	504	497	505	531	508
38	383	485	483	485	**526**	516	500
Eight Percent Discount Rate							
26	156	226	233	248	187	199	205
27	159	230	241	253	196	204	219
28	**167**	235	245	250	201	211	223
29	**167**	**249**	**246**	**255**	203	218	**250**
30	163	244	243	251	205	222	243
31	159	241	244	239	**210**	223	238
32	157	242	235	230	209	**243**	233
33	153	235	227	220	210	239	224
34	147	225	217	210	208	233	216
35	138	217	209	200	202	226	198

Note: Prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood. Values are on a per acre basis.

1. Thin at age 15 to 70 square feet of basal area.
2. Thin at age 15 to 75 square feet of basal area.
3. Thin at age 15 to 80 square feet of basal area.
4. Thin at age 20 to 70 square feet of basal area.
5. Thin at age 20 to 80 square feet of basal area.
6. Thin at age 20 to 90 square feet of basal area.

Table 2.17. Soil Expectation Values for Various Thinning Strategies, **Site Index 70**, Planting Density of **200 Trees per Acre**, Two Percent Annual **Increasing Price Trend**, and **Six Percent Discount** Rate. Age of Thinning is Followed by Remaining Basal Area in Parentheses.

Age	No Thin	15(60)[1]	15(65)[2]	15(70)[3]	20(70)[4]	20(75)[5]	20(80)[6]
35	3384	3963	3891	3905	4052	4019	3999
36	3472	3902	3880	3861	**4195**	4029	4110
37	3530	3946	3834	3899	4175	3992	4039
38	3508	**4005**	3893	3824	4101	**4112**	4024
39	**3594**	3912	**3950**	**4027**	4078	4076	**4111**
40	3490	3861	3948	3850	4086	3982	4080
41	3538	3894	3929	3864	4109	4053	3974
42	3476	3824	3888	3878	4076	3944	4048
43	3432	3880	3820	3845	4039	3955	3942
44	3422	3794	3830	3769	3984	3867	3946
45	3382	3712	3773	3835	3848	3800	3866

Note: Initial prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood, with a two percent annual increasing real price trend. Values are on a per acre basis.

1. Thin at age 15 to 60 square feet of basal area.
2. Thin at age 15 to 65 square feet of basal area.
3. Thin at age 15 to 70 square feet of basal area.
4. Thin at age 20 to 70 square feet of basal area.
5. Thin at age 20 to 75 square feet of basal area.
6. Thin at age 20 to 80 square feet of basal area.

Table 2.18. Soil Expectation Values for Various Thinning Strategies, **Site Index 70**, Planting Density of **300 Trees per Acre**, Two Percent Annual **Increasing Price Trend**, and **Six Percent Discount** Rate. Age of Thinning is Followed by Remaining Basal Area in Parentheses.

Age	No Thin	15(70)[1]	15(75)[2]	15(80)[3]	20(70)[4]	20(80)[5]	20(90)[6]
35	3449	4036	4013	3937	3701	4212	3968
36	3484	**4062**	4070	3958	3795	**4261**	4033
37	3574	4033	4074	4058	3920	4224	4146
38	3642	3997	4036	4083	4171	4227	**4203**
39	3556	4003	4015	4084	4247	4232	4164
40	3558	3986	4056	4126	**4248**	4238	4067
41	**3706**	3997	4016	**4130**	4248	4164	4147
42	3544	4041	**4094**	4080	4228	4196	4133
43	3645	4010	4037	4011	4228	4171	4153
44	3588	4001	3966	3968	4212	4142	4078
45	3630	3908	3898	3976	4162	4105	3939

Note: Initial prices are $195.60 per thousand board feet (MBF)for sawtimber, $93.90 per MBF for chip and saw, and $163.61 per thousand cubic feet (MCF) for pulpwood, with a two percent annual increasing real price trend. Values are on a per acre basis.

1. Thin at age 15 to 70 square feet of basal area.
2. Thin at age 15 to 75 square feet of basal area.
3. Thin at age 15 to 80 square feet of basal area.
4. Thin at age 20 to 70 square feet of basal area.
5. Thin at age 20 to 80 square feet of basal area.
6. Thin at age 20 to 90 square feet of basal area.

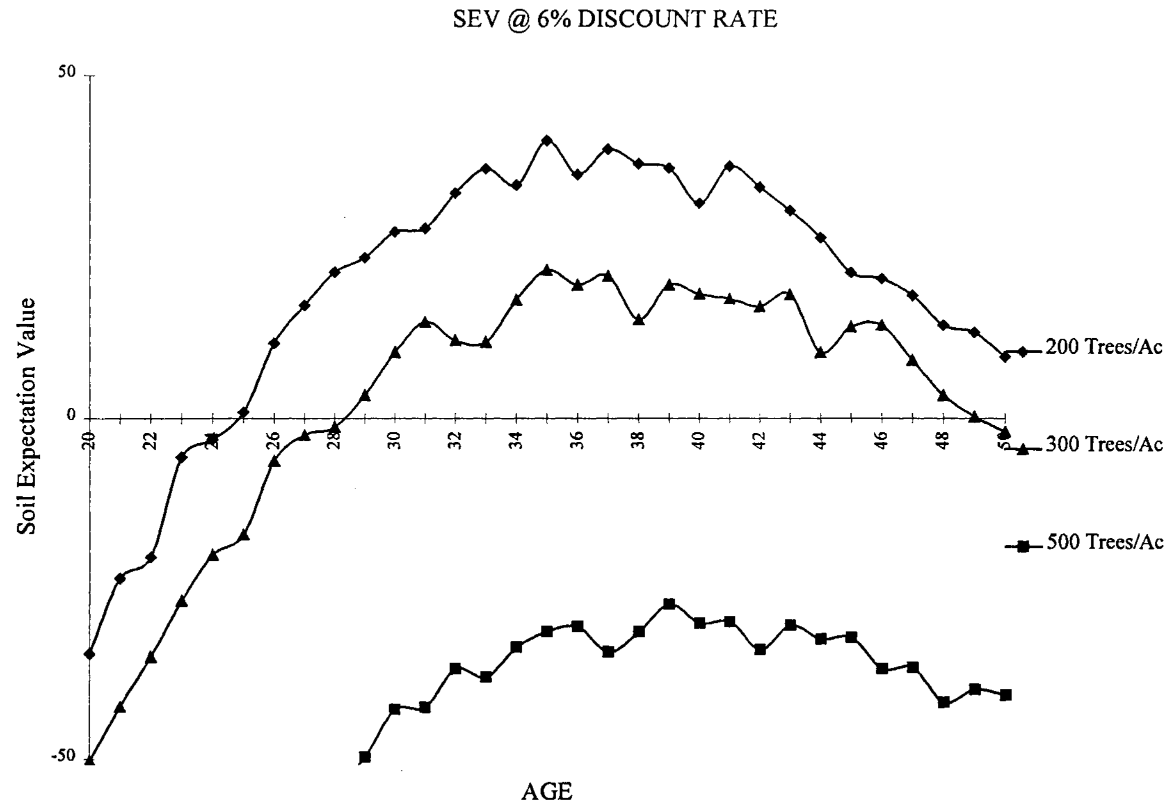

Figure 2.1. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 52 Base Age 25, with Planting Densities of 200, 300, and 500 Trees per Acre. Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood, No Trend is Considered.

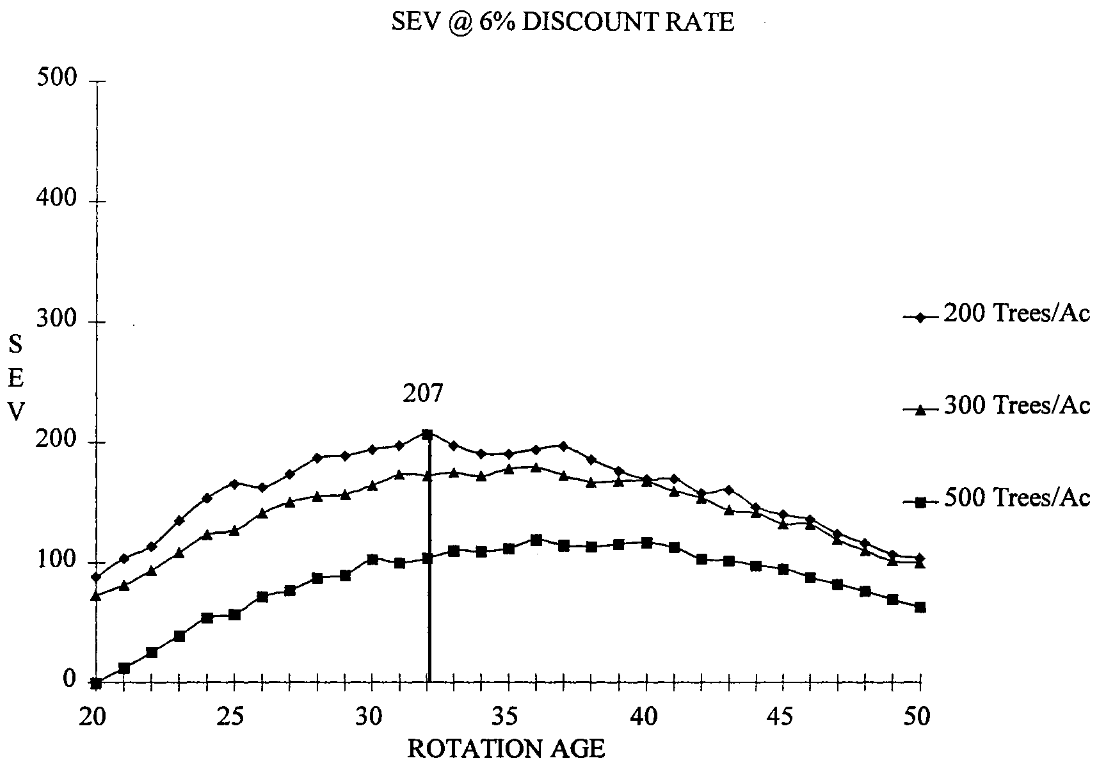

Figure 2.2. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 61 Base Age 25, with Planting Densities of 200, 300, and 500 Trees per Acre. Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

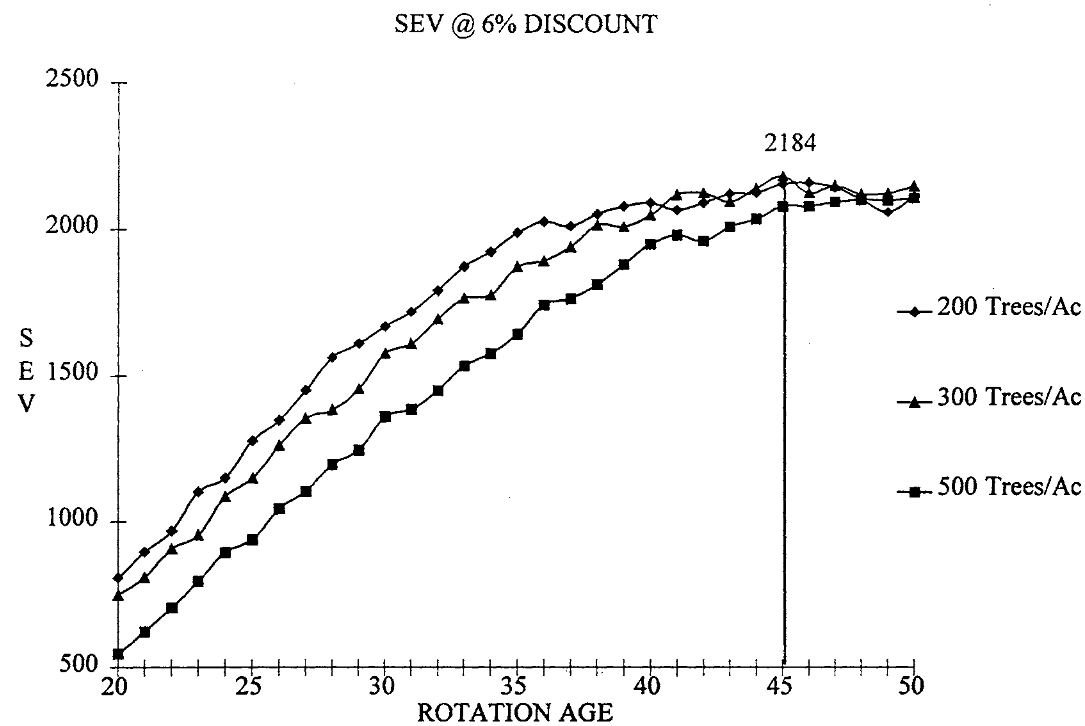

Figure 2.3. WPL∞ (Soil Expectation Values) with a Two Percent Annual Increasing Price and Cost Trend and Six Percent Discount Rate for Site Index 61 Base Age 25, with Planting Densities of 200, 300, and 500 Trees per Acre. Initial Timber Prices Are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

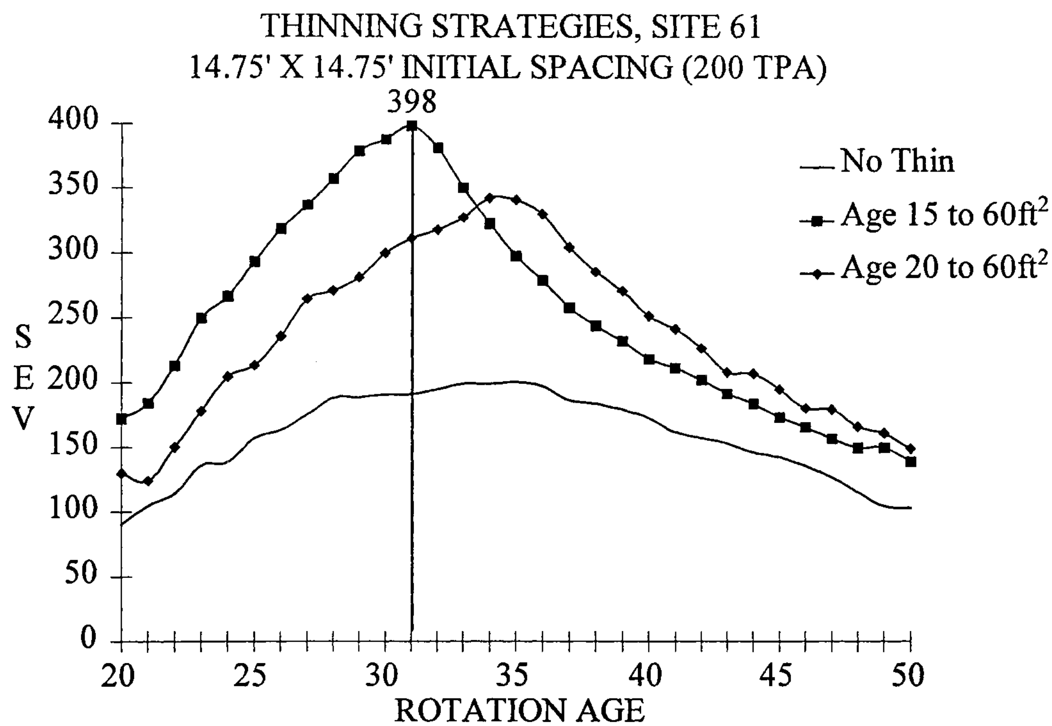

Figure 2.4. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 61 Base Age 25, for Thinning and No Thinning Strategies (200 Trees per Acre). Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

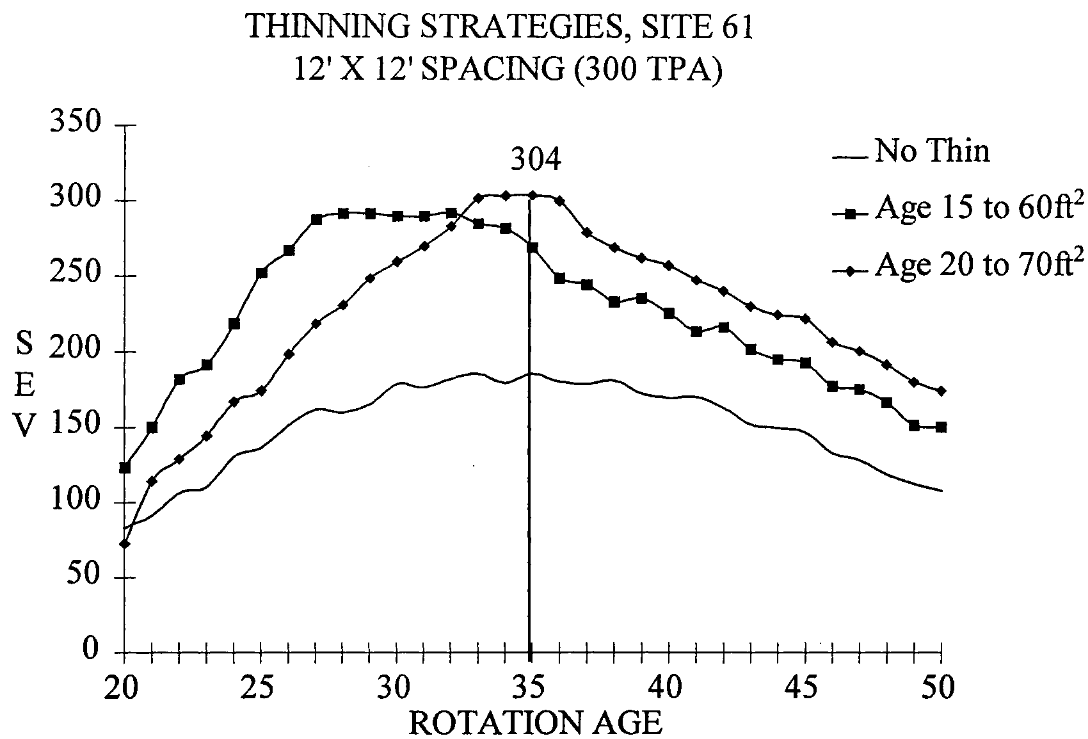

Figure 2.5. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 61 Base Age 25, for Thinning and No Thinning Strategies (300 Trees per Acre). Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

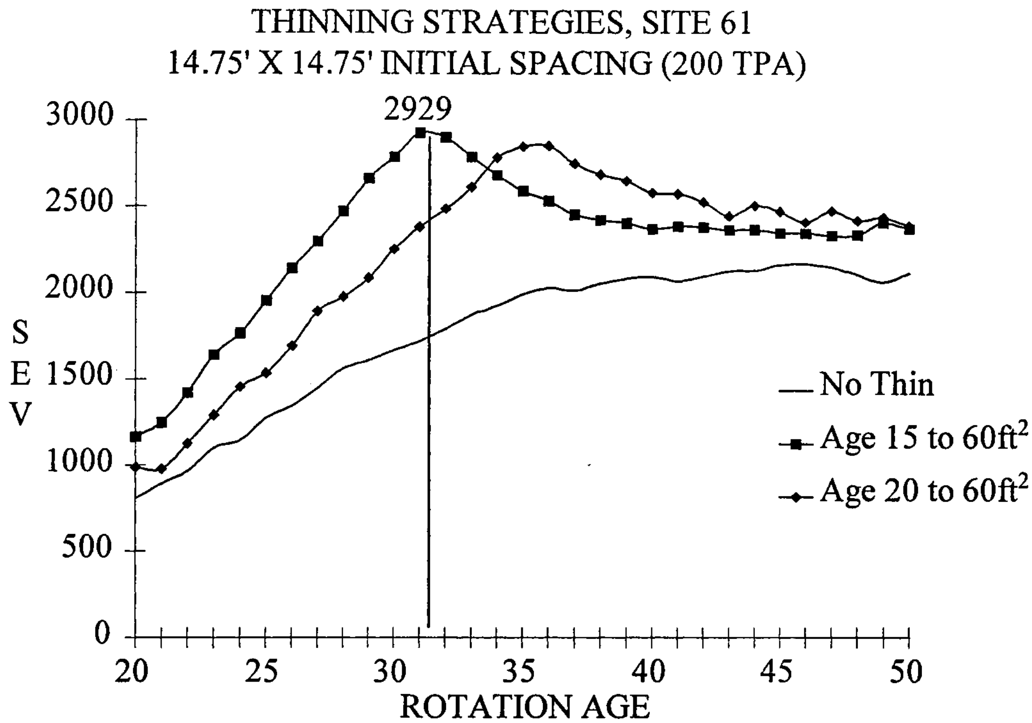

Figure 2.6. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 61 Base Age 25, for Thinning and No Thin Strategies (200 Trees per Acre). Initial Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood, with A Two Percent Increasing Price Trend.

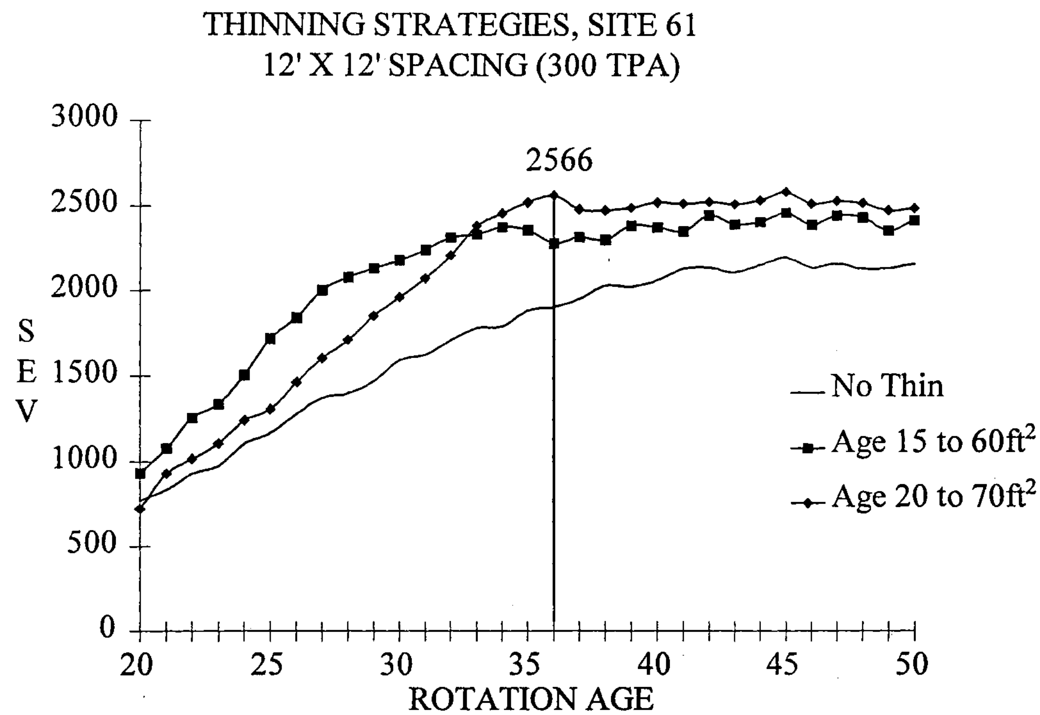

Figure 2.7. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 61 Base Age 25, for Thinning and No Thin Strategies (300 Trees per Acre). Initial Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood, with A Two Percent Increasing Price Trend.

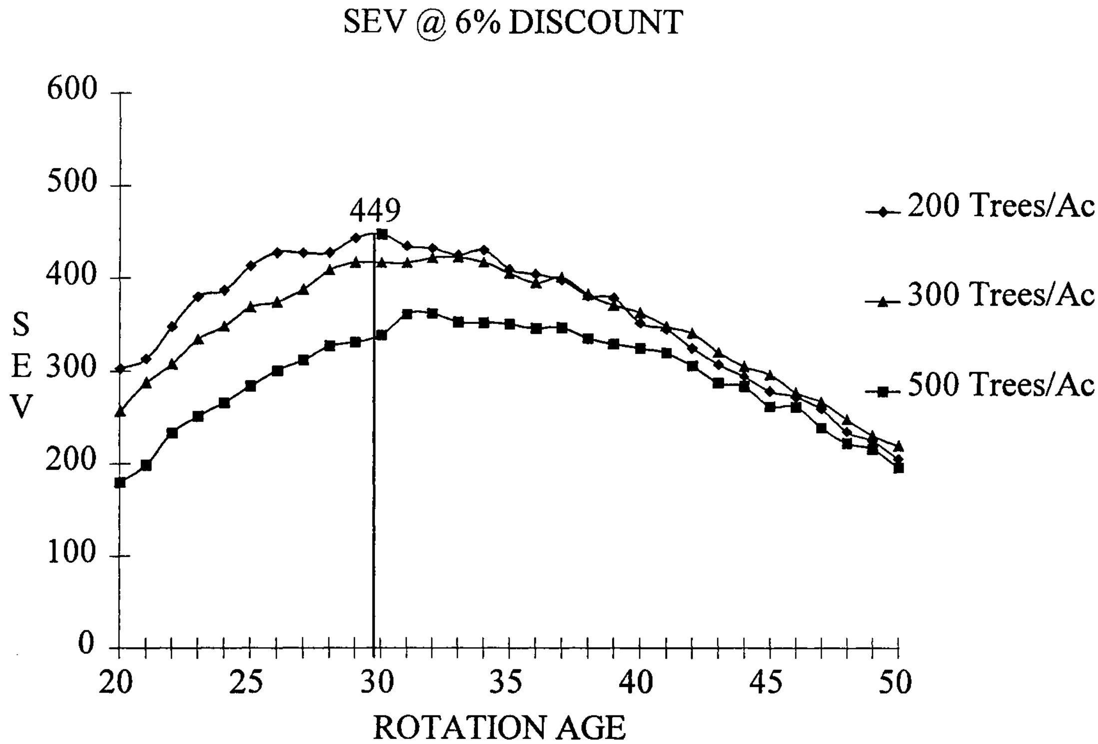

Figure 2.8. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 70 Base Age 25, with Planting Densities of 200, 300, and 500 Trees per Acre. Prices are $195.60 per Thousand Board Feet (MBF) for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

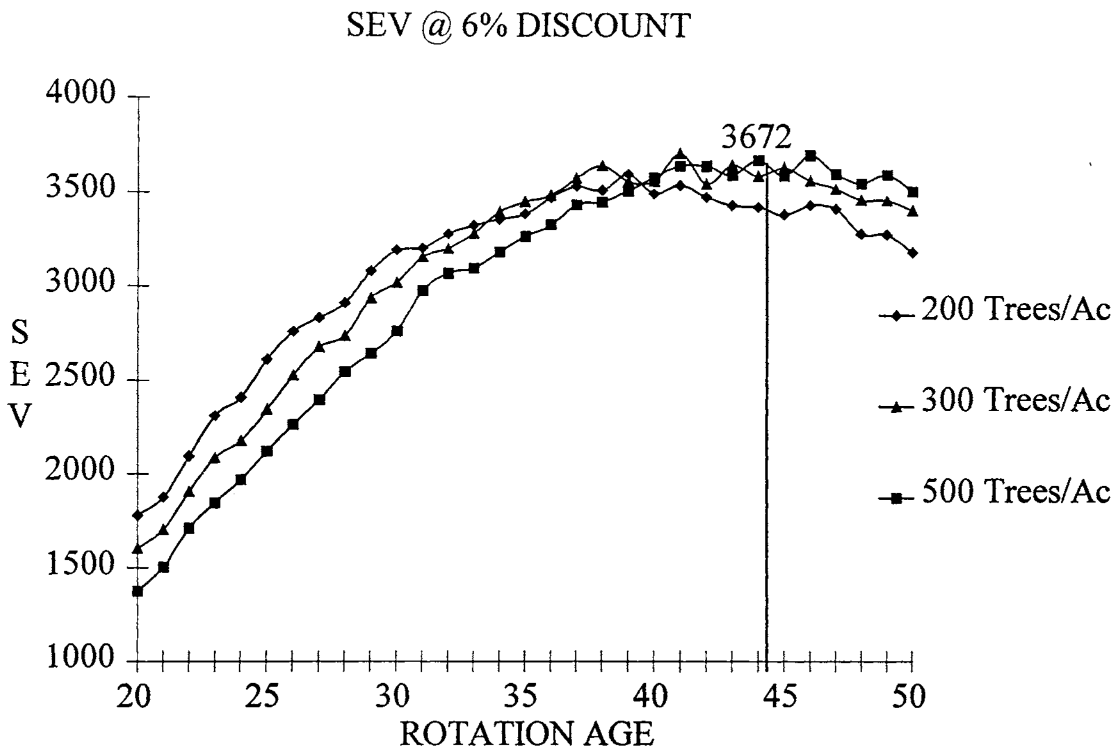

Figure 2.9. WPL∞ (Soil Expectation Values) With a Two Percent Annual Increasing Price and Cost Trend and Six Percent Discount Rate for Site Index 70 Base Age 25, with Planting Densities of 200, 300, and 500 Trees per Acre. Initial Timber Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

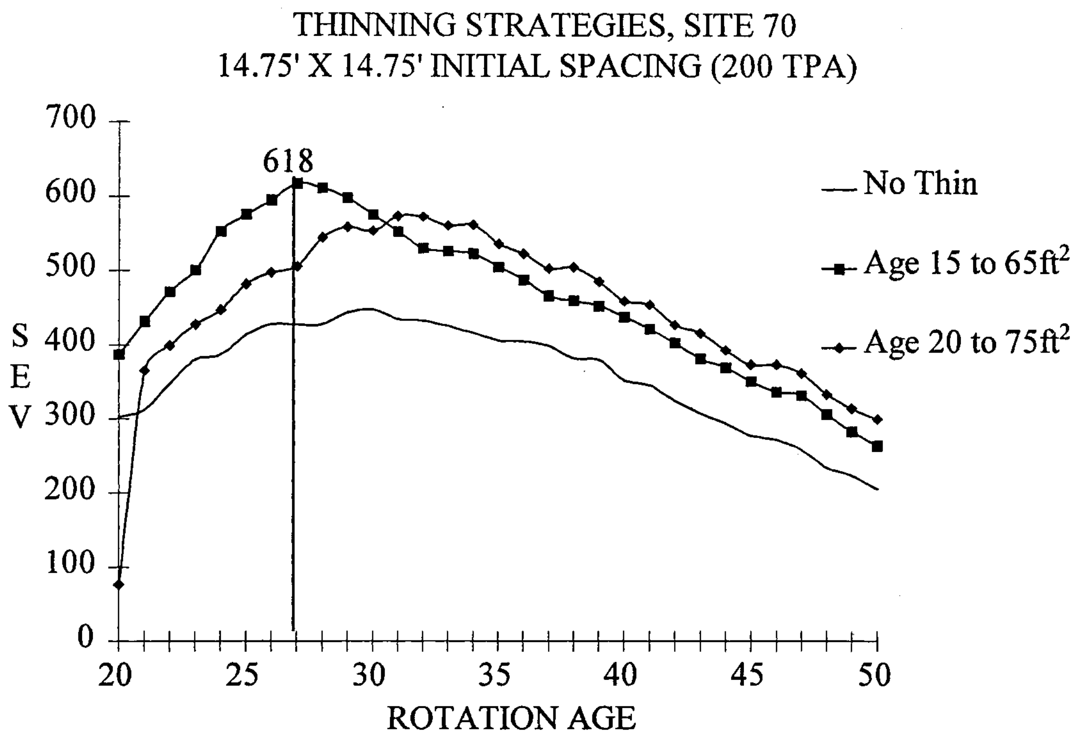

Figure 2.10. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 70 Base Age 25, for Thinning and No Thinning Strategies (200 Trees per Acre). Prices are $195.60 per Thousand Board Feet (MBF)for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

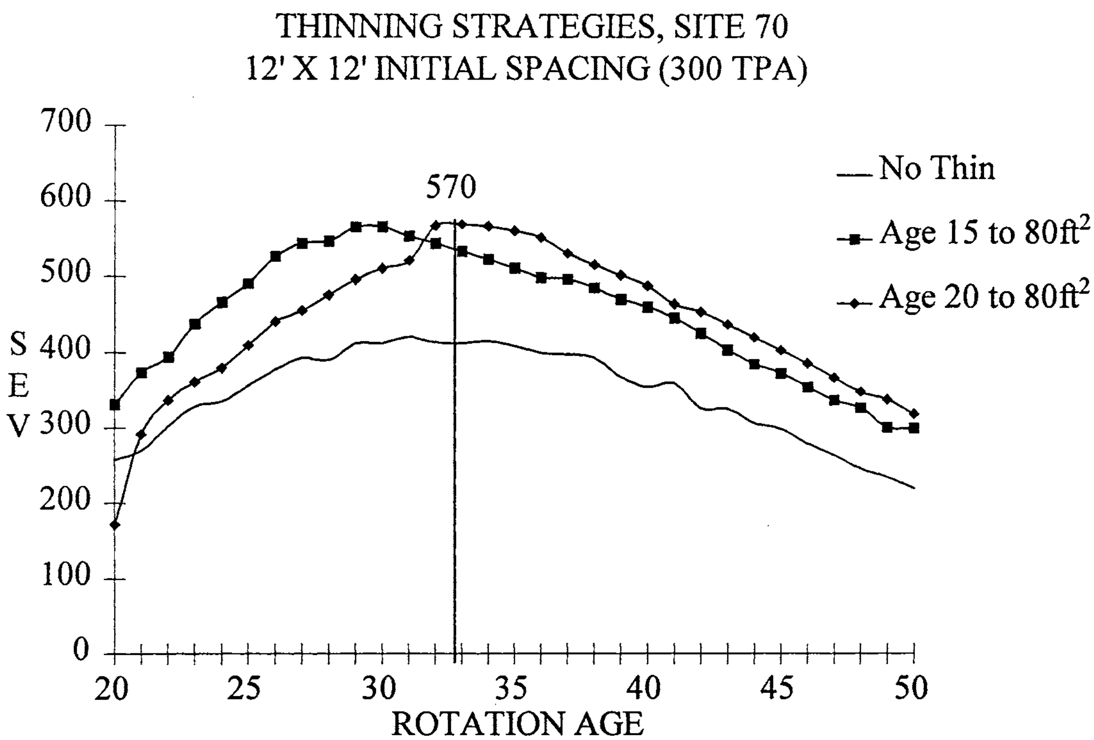

Figure 2.11. WPL∞ (Soil Expectation Values) at Six Percent Discount Rate for Site Index 70 Base Age 25, for Thinning and No Thinning Strategies (300 Trees per Acre). Prices are \$195.60 per Thousand Board Feet (MBF) for Sawtimber, \$93.90 per MBF for Chip and Saw, and \$163.61 per Thousand Cubic Feet (MCF) for Pulpwood.

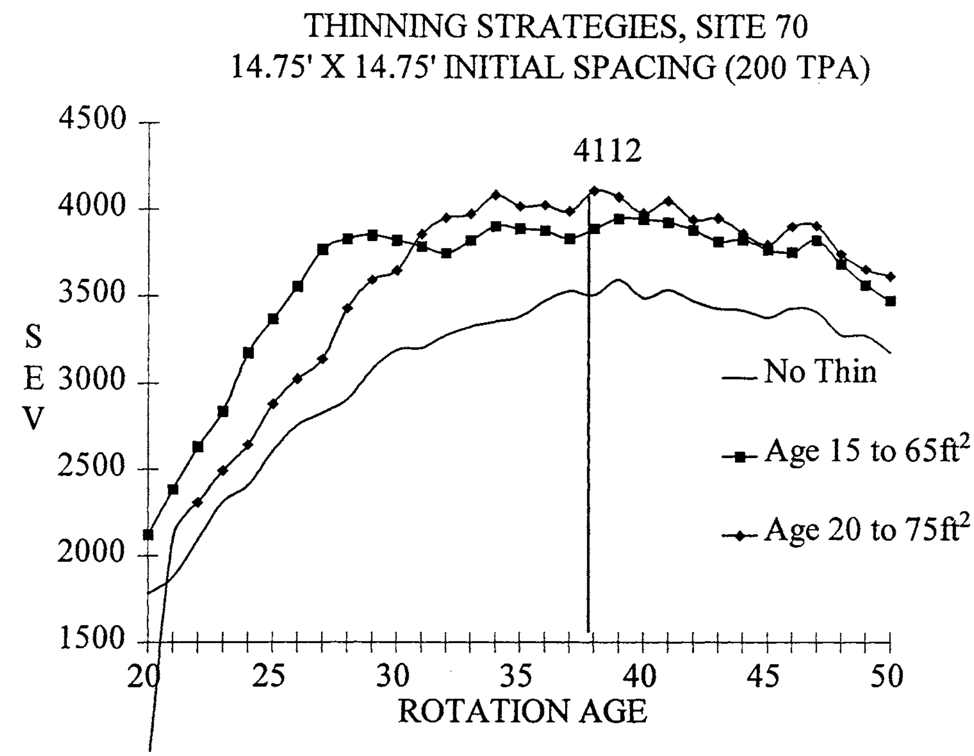

Figure 2.12. WPL∞ (soil expectation values) at Six Percent Discount Rate for Site Index 70 Base Age 25, for Thinning and no Thinning Strategies (200 Trees per Acre). Initial Prices are $195.60 per Thousand Board Feet (MBF) for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood, with a two Percent Increasing Price Trend.

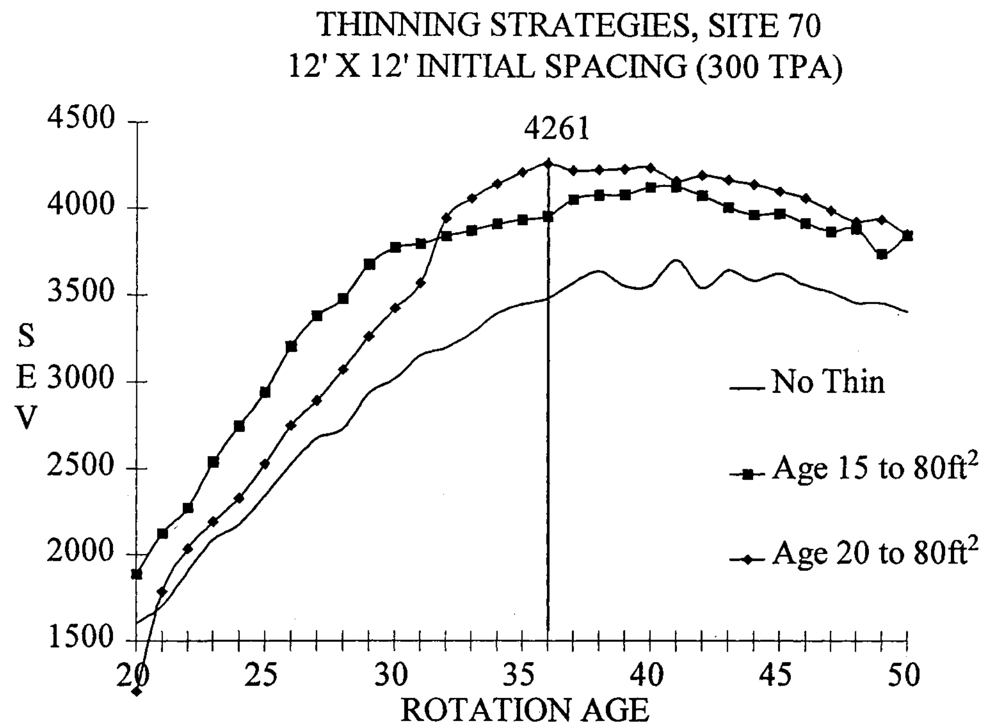

Figure 2.13. WPL∞ (soil expectation values) at Six Percent Discount Rate for Site Index 70 Base Age 25, for Thinning and no Thinning Strategies (300 Trees per Acre). Initial Prices are $195.60 per Thousand Board Feet (MBF) for Sawtimber, $93.90 per MBF for Chip and Saw, and $163.61 per Thousand Cubic Feet (MCF) for Pulpwood, with a two Percent Increasing Price Trend.

CHAPTER 3

OPTIMAL FOREST MANAGEMENT REGIMES WITH MULTIPLE PRODUCTS, STOCHASTIC SAWTIMBER PRICES AND THE CHANCE OF PHYSICAL STAND LOSS

Introduction

In Chapter 2, it was assumed that future timber prices were known with certainty. Here, the assumption of deterministic expected future prices is relaxed. A stand's (of trees) value changes as the trees grow and produce more valuable products. Since timber prices vary over time, deterministic price methods may not provide enough information to forest managers.

Expectations about future stumpage prices are important when considering the financial analysis of forestry investments. Price risk and the probability of loss of the stand due to fire interact with projected timber growth rate complicating the decision process. Planning decisions that the forest manager must make include choosing the stocking rate and the harvest date. Planting density and thinning regiments (components of the stocking rate) greatly influence the yield of various timber products produced by a pine plantation. Previous studies have used narrower spacings for planting, usually a minimum of 500 trees per acre. Here planting densities of 500, and 300trees per acre were compared. Thinning strategies for each planting density were also economically analyzed.

To obtain an optimum, dynamic programming (DP) was used. DP is a computational approach used to solve complex optimization problems. Unlike linear programming, which is basically mathematical modeling, DP is more like simulation, except that DP searches for an optimal solution. DP transforms multistage or sequential decision processes containing many interdependent variables into a series of single-stage problems, each with only a few variables. Then the problem is solved recursively, and the solution indicates an optimum where all decisions are found at the same time (Schreuder, 1968; Kennedy, 1986; Boungiorno and Gilless, 1987). Schreuder (1968) was one of the first to use this approach to solve multistage forestry problems.

Roise (1986) indicates that DP does not necessarily select a global or local optimum, but rather a network optimum. He also indicates that DP is well suited to incorporate uncertainty. Teeter and Caulfield (1991), Haight (1992), and Forboseh et al. (1986) have used DP with stochastic prices in order to determine optimal forest rotations.

This research uses DP to determine strategies for management of even-aged loblolly pine forests that maximize expected discounted returns where prices are stochastic and there is a chance of total loss of the timber stand due to fire or other hazards. The approach used here is different than previous research because a premium for large sawtimber is established and loss of the stand is stochastic. A premium for large sawtimber was an important component in this analysis, because it can significantly alter the optimal planting density. Wider spacings (12 x 12 feet) tend to produce large sawtimber at an earlier age than narrow spacings (6 x 6 feet) (Haight, 1992).

The objective of this study was to determine the optimal planting density and thinning regiments for loblolly pine plantations in southeastern McCurtain county, Oklahoma, given stochastic sawtimber prices, a premium for large sawtimber, and a chance of loss due to fire or other hazards. A further objective was to determine the stand age over which various price levels of sawtimber would be accepted and the stand of trees sold. Site indices considered in this analysis were 61 and 70, base age 25.

Data

Data for yields of sawtimber and pulpwood were generated from COMPUTE_P-LOB, a growth simulation model developed for loblolly pine by the U. S. Forest Service (Baldwin and Feduccia, 1987). COMPUTE_P-LOB was developed as a predictor of loblolly pine plantation growth in the coastal plain area of the United States, and has been validated by the U. S. Forest Service by comparing predictions to actual tree growth. Predictions from COMPUTE_P-LOB were within five percent of observed tree growth (Baldwin and Feduccia, 1987). COMPUTE_P-LOB is deterministic. The user enters the height of dominants and codominants (site index at base age 25), number of thinnings, basal area remaining after each thinning, number of trees planted, and time of clear cut be specified. The model gives the amount of timber by size class from each thinning and final harvest. Projections were made for two site indices (soil productivity measures), site 61 and site 70 with a base age of 25. Tree planting densities of 300 and 500 trees per acre were considered for each site. Timber volumes for seven thinning strategies for each site index-planting density combination were simulated. This included three levels of thinning for each of two possible thinning ages (15 and 20) and one no-thin simulation for each planting density (Table 3.1). These ages and levels of thinning were chosen because they were within the data range of COMPUTE_P-LOB for the planting densities considered. Final harvest data was simulated for each age up to a maximum of 50 years.

Forty years of annual sawtimber prices for sales of privately owned timber in northeast Texas and northwest Louisiana were used. The data were adjusted to 1990 prices using the implicit GDP deflator. Descriptive statistics of price data are in Table 3.2.

Timber products were divided into three classes for this study. These were, large sawtimber, greater than 14 inches diameter; small sawtimber (chip and saw), between 10 and 14 inches in diameter; and pulpwood, diameter less than 10 inches. Sawtimber and CNS were measured using International 1/4 inch log rule.

The four equally spaced price levels for small sawtimber shown in Table 3.2 were used for this analysis. A premium for large timber (timber greater than fourteen inches in diameter) was incorporated into the model. Data available for small sawtimber (10 to 14 inches DBH) and large sawtimber (14 inches DBH and greater) were available for the years 1984 through 1993. Plots indicated the relationship between small and large sawtimber prices is non linear, therefore, a simple model was used regressing the $\log_e$ of the small sawtimber price against the untransformed large sawtimber price (log-linear model). Results are in Table 3.3. Pulpwood prices were fixed at \$0.165 per cubic foot, which was the mean real price from 1984-1995. The probability of total loss of the stand was assumed constant throughout the rotation at zero, two, and four percent.

The real discount rates used were real rates of four, six, and eight percent. The appropriate real discount rate for private foresters in the Southeastern United States is assumed to be between five and eight percent (Teeter and Caulfield, 1991). The USDA Forest Service uses a four percent real discount rate (Loomis, 1993). Regeneration costs were assumed to be $90 per acre for site preparation plus $9.00 per hundred trees planted (DuBois et al., 1995).

Procedures

The objective was to find optimal management strategies that maximized expected discounted long term returns. A finite stage dynamic programming model was used in which the producer is viewed in each period as deciding whether to harvest the forest for a certain reward or to take an action which may increase the expected value of a future harvest. The recursive relationship that describes the producer's decision framework is

$$(3.1) \qquad EV_t\left(P_{it}, Q_{ijkzt}, C_j\right) = \underset{i,j,k,z}{MAX}\left[\pi\left(P_{it}, Q_{ijkzt}, C_j\right) + \beta_t \rho_{t+1} Ep_{it+1} V\left(P_{it+1}, Q_{ijkzt+1}, C_j\right)\right]$$

where

EV_t is the expected net present value of following the optimal management decisions from age t to rotation age,

P_{it} is the price of timber product i for time period t,

Q_{ijkzt} is the quantity of timber product i for stand age t, planting density j, thinning age k, and thinning level z,

C_j is the regeneration cost for planting density j,

MAX is the maximization operator over planting density j, age of thinning k, thinning level z, and harvest age t,

π is the immediate net returns that depend on P_{it}, Q_{ijktz}, and C_j ,

β is a discount factor,

ρ_{t+1} is the probability of stand survival in $t + 1$, and

$E_{p_{it+1}}$ is an expectations operator, which takes expectations over random future prices of product i in time $t + 1$.

A price transition matrix was developed to describe the conditional probability of the sawtimber market moving from the current price level of sawtimber to various sawtimber prices in the next period. Taylor's (1984b) hyperbolic tangent approach was used to derive the conditional probabilities of future timber prices given current timber prices. This approach used a first order Markov process for sawtimber prices. Taylor's (1984b) approach required regression of current sawtimber prices against lagged sawtimber prices. Ordinary least squares was used to estimate equation

(3.2) $$P_{t+1} = \alpha + \beta\ P_t + \varepsilon_t$$

where P_t is the real sawtimber price in time period t, P_{t+1} is the real price of sawtimber one period in the future, α is a constant, β is the slope parameter, and ε_t is the residual term. The residuals from this equation were then used in non-linear maximum likelihood procedure to derive the parameters the hyperbolic tangent probability mass function

(3.3) $$F(\varepsilon_t) = 0.5 + 0.5\, tanh(a + b\varepsilon_t)$$

where a and b are coefficients to be estimated, and ε_t is the error term from equation (3.2) By rearranging terms from (3.2),

(3.4) $$\varepsilon_t = P_{t+1} - \alpha - \beta\ P_t$$

and by substitution of equation (3.4) into equation (3.3), equation (3.5) was obtained. This is the cumulative mass function for the ordered residuals, which is also the conditional probability mass function.

(3.5) $$F(\varepsilon_t) = 0.5 + 0.5\,tanh\left(a + b\left(P_{t+1} - \alpha - \beta\,P_t\right)\right)$$

Table 3.4 includes the parameter values for equation 3.1 and equation 3.2. The following equation (equation 3.5 with parameter values inserted),

(3.6) $$F(\varepsilon_t) = 0.5 + 0.5\,tanh\left(0.0397 + 43.465\left(P_{t+1} - 0.01685 - 0.8907P_t\right)\right)$$

was used to derive the cumulative distribution function for calculation of the price transition matrix. The price transition matrix, shown in Table 3.5, contains the probability of moving from one of four current prices to each of those same four prices in one year.

Results

Figures 3.1 through 3.6 show the minimum price level required to justify liquidation of the stand when the probability of survival is ninety-eight percent. If the current price level was on or above the minimum accepted price line, the stand should be sold. If the current price level was below the minimum accepted price line, the stand should be kept.

Figure 3.1 shows the results for site index 61. The optimal planting density was found to be 300 trees per acre for all discount rates considered. It was optimal to thin at age 20 to 70 square feet of basal area under all discount rates. The expected net present values from following optimal strategies for index 61 sites are shown in the upper part of

Table 3.6. Age ranges for which various price levels would be accepted for various discount rates and probabilities of survival are shown in Table 3.7.

As shown in Figure 3.1, when the real discount rate is four percent, and the probability of stand survival is 98 percent, the stand should be harvested at any age between 33 and 50 (inclusive), if the current price is at $0.210/BF or higher. After the stand reaches age 36, the stand should be harvested if price of sawtimber is $0.194/BF or higher. After the stand reaches age 40, the minimum acceptable price for harvesting declined to $0.177/BF. The timber should be held until the terminal age of 50 if the price continues to be less than $0.161/BF. Age 50 was considered the terminal age.

Figures 3.2 and 3.3 show the results for the six and eight percent discount rate and a 98 percent probability of survival. As the discount rate increased from four to eight percent, the minimum age at which harvest should occur for the various price levels considered decreases. For example, the producer should accept $0.21/BF and harvest if the trees were at least age 33, 29, or 27 if the respective discount rates were 4, 6, or 8 percent. If the price level is at least $0.161/BF the stand should be held until age 50 if the discount rate is four percent, and harvested at age 40 if the discount rate is six or eight percent. Although increasing the discount rate does not affect the price risk, it does affect the value risk, by lowering the expected value. The solutions indicate that it is optimal for producers to exhibit an opportunistic behavior, and sell an immature stand of trees if the price level were high enough. It is not optimal to harvest the forest when prices are well below the expected mean price because the expected future value of the forest is higher than the current value.

Results for site index 70 are shown in Figures 3.4, 3.5, and 3.6 for the four, six, and eight percent discount rate and a 98 percent probability of survival. In the lower part of Table 3.6 the net present values for various discount rates and probabilities of survival are shown.

Table 3.8 shows the age ranges over which various price levels should be accepted. Like the results for site index 61, the optimal planting density was found to be 300 trees per acre. The thinning strategy was the same for all discount rates considered (thin at age 20 to 80 square feet of basal area). As long as prices remain low ($0.161/BF), the timber is held until the terminal age of 50 years.

Changing the probability of survival to 100 percent had lengthened the rotations for both site indices, however the optimal planting density remained unchanged. With no chance of stand loss, the stand would not be thinned if the discount rate were four or six percent. At the eight percent discount rate, the thinning strategy was the same as if there were a four percent probability of stand loss. When there is no chance of stand loss, the age of harvest would be delayed at both sites. Table 3.6 shows the expected net present values for 100 percent chance of survival are more than twice as great as when there is only a 96 percent chance of survival from one year to the next.

Conclusion

Optimal forest management strategies across four discount rates were determined for site indices 61 and 70. The optimal planting density for both sites was found to be 300 trees per acre. The optimal thinning strategy was to thin to 70 square feet of basal area at age 20 for site index 61, and thin to 80 square feet of basal area at age 20 for site index 70 for all discount rates considered.

The results indicate that when prices are stochastic, timber producers should exhibit an opportunistic behavior, as shown in Figures 3.1 through 3.6. That is, they should be willing to harvest the timber at an early age if the current market prices cause the value of the stand to be greater than the value of the stand with future expected prices. Harvests would be delayed when current market prices cause the value of the stand to be below the expected future value. For site index 70, at the six percent discount rate, the harvest age could be as early as age 21, if high prices (at least $0.21/BF) are experienced at that age (Figures 3.4 through 3.6). As the stand ages, the producer becomes more willing to accept a lower price for the timber (Figures 3.1 through 3.6). The minimum acceptable price remained above the low price used in the study ($0.161/BF or less) until the terminal age of 50 years was reached for site index 70 and site index 61 if the discount rate was four percent. If the site index was 61 and discount rate was six percent or eight percent, the stand was held no longer than age 40 even if the price was low. As the discount rate increased, the minimum acceptable price level was reached at an earlier age, with the exception of the lowest price level that remains at the terminal age. This model explains timber producers' opportunistic behavior of harvesting younger trees when timber prices are higher than expected.

Producers tended to hold the stand longer when the chance of loss of the stand was removed from the model. Results here validate those found in chapter 2. That is, thinning the stands using wider than conventional spacings (12 x 12) feet here) produces the highest net present values. Whether stochastic prices using a dynamic programming model or deterministic prices with a direct search, planting 300 trees per acre consistently yields higher net present values than planting 500 trees per acre, assuming that thinnings are performed.

Table 3.1. Age-thinning levels used in the analysis.

Site[a], TPA[b]	Age 15[c], RBA[d]	Age 20, RBA
61, 300	60, 65, 70	70, 75, 80
61, 500	65, 70, 75	75, 80, 85
70, 300	70, 75, 80	70, 80, 90
70, 500	75, 80, 85	80, 90, 100

[a] Site Index.

[b] Trees planted per acre.

[c] Age of thinning.

[d] Basal area remaining after thinning.

Table 3.2. Descriptive Statistics for Deflated Price Data.

Price	Mean	Std. dev.	Min.	Max.
39 obs. 1955-1993.				
Sawtimber	0.1820	0.0582	0.109	0.365
Pulp	0.1397	0.0222	0.108	0.205
12 obs. 1984-1995				
Sawtimber	0.1950	0.0736	0.149	0.379
Chip and Saw	0.0930	0.0353	0.063	0.174
Pulp	0.1653	0.0229	0.132	0.205
Correlation Coefficients				
	Sawtimber	Chip and Saw	Pulp	
Sawtimber	1			
Chip and Saw	0.906	1		
Pulp	0.4856	0.5332	1	

Note: Chip and saw prices were available from 1984. Prices were deflated to 1990 levels using the implicit GDP deflator.

Table 3.3. Regression of Real Sawtimber Price on Real Chip and Saw Price. A Log-Linear Model was used. Resulting Small Sawtimber Prices were used in the Analysis.

Variable	Coefficient	Std. Error
Constant	3.749	0.1564
Slope	0.0038446	0.0007
Resulting Prices $/(BF)		
	Sawtimber	Small Sawtimber
	0.161	0.079
	0.177	0.084
	0.194	0.089
	0.210	0.095

Note: Plots of prices indicated a non-linear relationship exists. These coefficients were used to estimate the price of chip and saw given the price of sawtimber. Twelve observations were available. Adjusted R-squared = .727.

Table 3.4. Parameter Estimates for Equation 3.2 and Equation 3.3.

Variable	Coefficient	Std. error
Equation 2 (OLS):		
Constant	00.89069	0.08316
Lagged Price	00.02247	0.01569
Equation 3 (Hyperbolic Tangent):		
Constant	00.03967	0.13814
Slope	32.59900	4.46800

Note: The adjusted R square for equation 2 was 0.7575. There are 39 annual observations in the data. Maximum likelihood estimation was used to estimate the coefficients for equation 3.

Table 3.5. Conditional Probabilities of Receiving Prices Next Period Given Specified Prices in the Current Period.

Current Large Sawtimber Prices	Price Level Next Time Period			
	$0.161	$0.177	$0.194	$0.210
	Probability			
0.161	0.404	0.498	0.090	0.000
0.177	0.062	0.412	0.450	0.076
0.194	0.006	0.075	0.464	0.435
0.210	0.001	0.008	0.097	0.895

Table 3.6. Expected Net Present Values of Optimal Forest Management Strategies for Site Index 61 and 70 across Various Discount Rates with Chances of Survival of 96, 98, and 100 Percent.

Site Index	Discount Rate	Probability of Survival 0.96	0.98	1.00
		Expected Net Present Value		
61	4%	$320.35	$626.17	$1074.99
61	6%	75.92	225.39	433.11
61	8%	-18.96	63.83	177.77
70	4%	788.31	1149.54	1576.03
70	6%	345.43	543.03	785.56
70	8%	146.46	270.85	420.50

Note: Values are on a per acre basis.

Table 3.7. Stand Age Range over which Various Sawtimber Price Levels would be Accepted for Various Discount Rates and Survival Rates, **Site Index 61.**

Discount Rate	Survival Rate	Large Sawtimber Price	Age Range
4%	100%	$0.210/BF	35 to 50
4%	100%	$0.194/BF	38 to 50
4%	100%	$0.177/BF	40 to 50
4%	100%	$0.161/BF	hold until 50
4%	98%	$0.210/BF	33 to 50
4%	98%	$0.194/BF	36 to 50
4%	98%	$0.177/BF	40 to 50
4%	98%	$0.161/BF	hold until 50
4%	96%	$0.210/BF	29 to 50
4%	96%	$0.194/BF	36 to 50
4%	96%	$0.177/BF	48 to 50
4%	96%	$0.161/BF	hold until 50
6%	100%	$0.210/BF	33 to 50
6%	100%	$0.194/BF	36 to 50
6%	100%	$0.177/BF	40 to 50
6%	100%	$0.161/BF	hold until 50
6%	98%	$0.210/BF	29 to 40
6%	98%	$0.194/BF	36 to 40
6%	98%	$0.177/BF	38 to 40
6%	98%	$0.161/BF	hold until 40
6%	96%	$0.210/BF	27 to 40
6%	96%	$0.194/BF	34 to 40
6%	96%	$0.177/BF	36 to 40
6%	96%	$0.161/BF	hold until 40
8%	100%	$0.210/BF	29 to 40
8%	100%	$0.194/BF	36 to 40
8%	100%	$0.177/BF	38 to 40
8%	100%	$0.161/BF	hold until 40
8%	98%	$0.210/BF	27 to 40
8%	98%	$0.194/BF	34 to 40
8%	98%	$0.177/BF	36 to 40
8%	98%	$0.161/BF	hold until 40
8%	96%	$0.210/BF	24 to 40
8%	96%	$0.194/BF	30 to 40
8%	96%	$0.177/BF	hold until 36
8%	96%	$0.161/BF	hold until 36

Table 3.8. Stand Age Range over which Various Sawtimber Price Levels would be Accepted for Various Discount Rates and Survival Rates, **Site Index 70.**

Discount Rate	Survival Rate	Large Sawtimber Price	Age Range
4%	100%	$0.210/BF	30 to 50
4%	100%	$0.194/BF	43 to 50
4%	100%	$0.177/BF	hold until 50
4%	100%	$0.161/BF	hold until 50
4%	98%	$0.210/BF	27 to 50
4%	98%	$0.194/BF	37 to 50
4%	98%	$0.177/BF	hold until 50
4%	98%	$0.161/BF	hold until 50
4%	96%	$0.210/BF	22 to 50
4%	96%	$0.194/BF	30 to 50
4%	96%	$0.177/BF	42 to 50
4%	96%	$0.161/BF	hold until 50
6%	100%	$0.210/BF	27 to 50
6%	100%	$0.194/BF	41 to 50
6%	100%	$0.177/BF	hold until 50
6%	100%	$0.161/BF	hold until 50
6%	98%	$0.210/BF	23 to 50
6%	98%	$0.194/BF	30 to 50
6%	98%	$0.177/BF	42 to 50
6%	98%	$0.161/BF	hold until 50
6%	96%	$0.210/BF	22 to 50
6%	96%	$0.194/BF	27 to 50
6%	96%	$0.177/BF	37 to 50
6%	96%	$0.161/BF	hold until 50
8%	100%	$0.210/BF	23 to 50
8%	100%	$0.194/BF	30 to 50
8%	100%	$0.177/BF	42 to 50
8%	100%	$0.161/BF	hold until 50
8%	98%	$0.210/BF	22 to 50
8%	98%	$0.194/BF	27 to 50
8%	98%	$0.177/BF	37 to 50
8%	98%	$0.161/BF	hold until 50
8%	96%	$0.210/BF	21 to 42
8%	96%	$0.194/BF	26 to 42
8%	96%	$0.177/BF	30 to 42
8%	96%	$0.161/BF	hold until 42

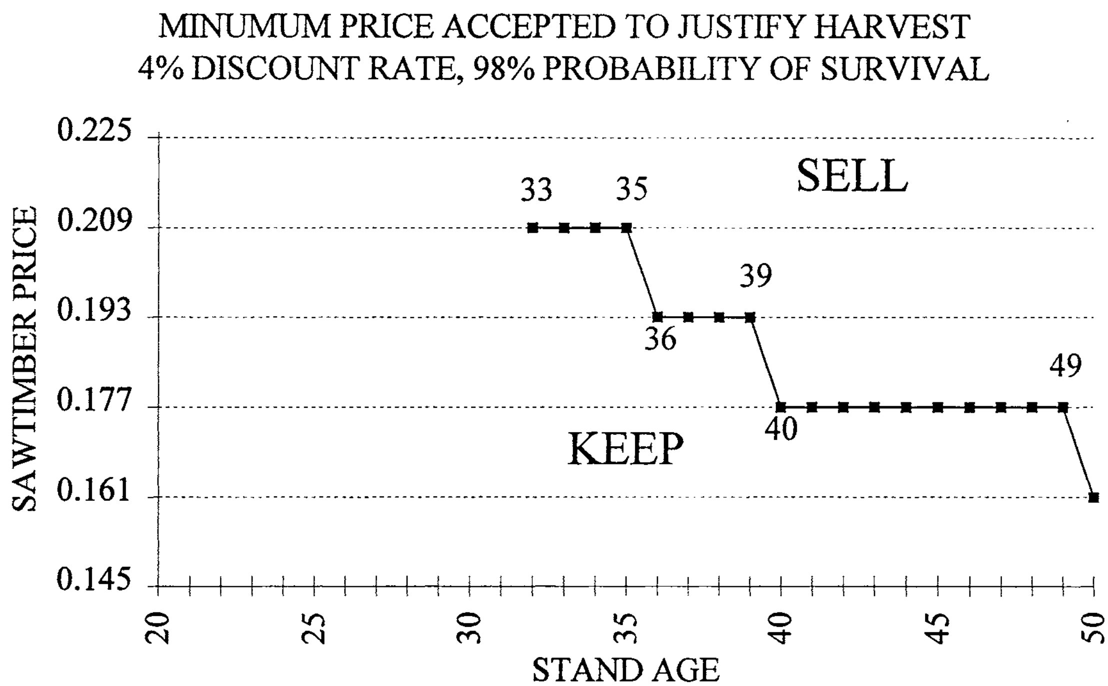

Figure 3.1. Minimum Acceptable Sawtimber Prices for Harvest by Age of Stand for Four Percent Discount Rate. Site Index 61, Planting Density of 300 Trees Per Acre, and Management Strategy of Thinning at Age 20 to 60 Square Feet of Basal Area are Assumed. The Probability of Total Loss of the Stand of Timber was 2 Percent.

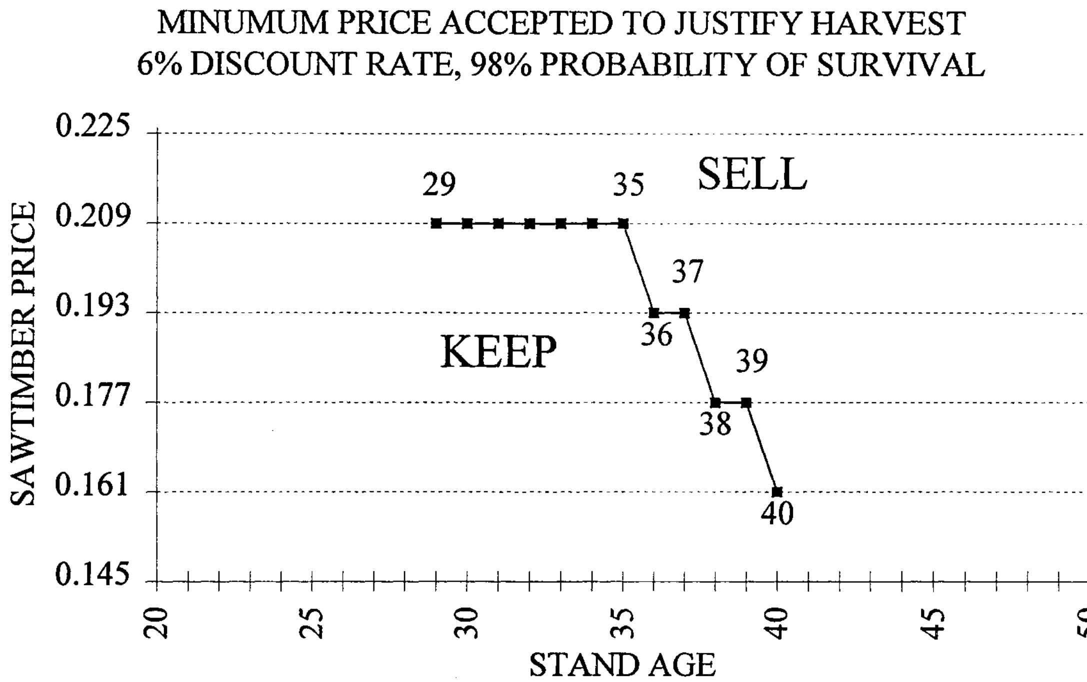

Figure 3.2. Minimum Acceptable Sawtimber Prices for Harvest by Age of Stand for the Six Percent Discount Rate. Site Index 61, Planting Density of 300 Trees per Acre, and Management Strategy of Thinning at Age 20 to 70 Square Feet of Basal Area are Assumed. The Probability of Total Loss of the Stand of Timber was 2 Percent.

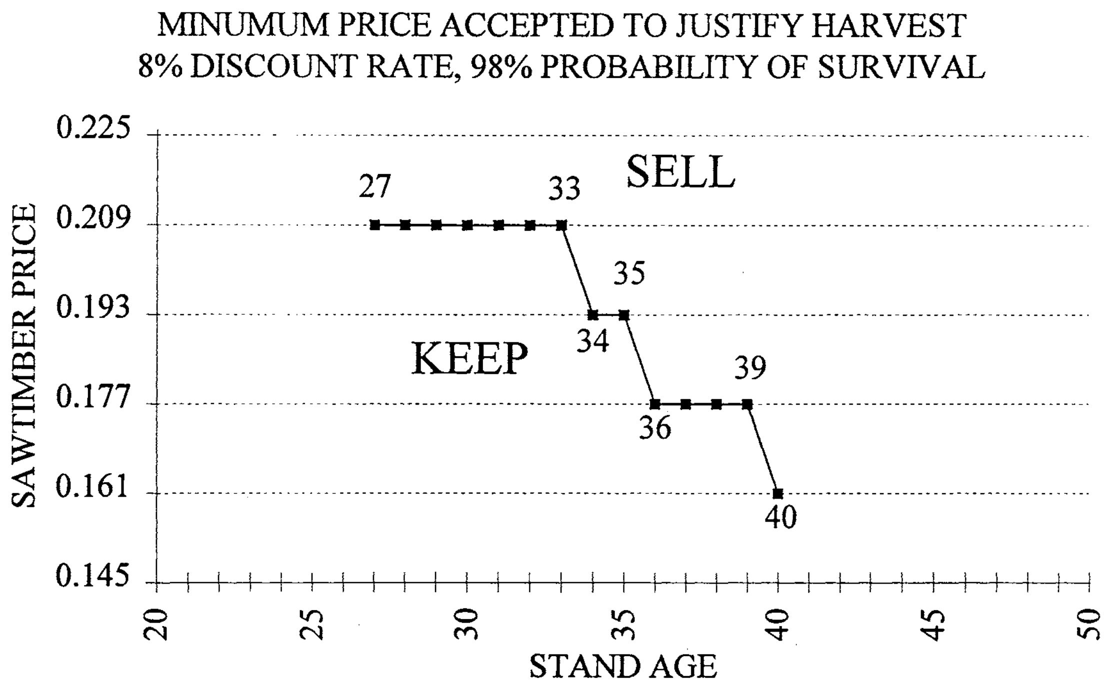

Figure 3.3. Minimum Acceptable Sawtimber Prices for Harvest by Age of Stand for the Eight Percent Discount Rate. Site Index 61, Planting Density of 300 Trees per Acre, and Management Strategy of Thinning at Age 20 to 70 Square Feet of Basal Area are Assumed. The Probability of Total Loss of the Stand of Timber was 2 Percent.

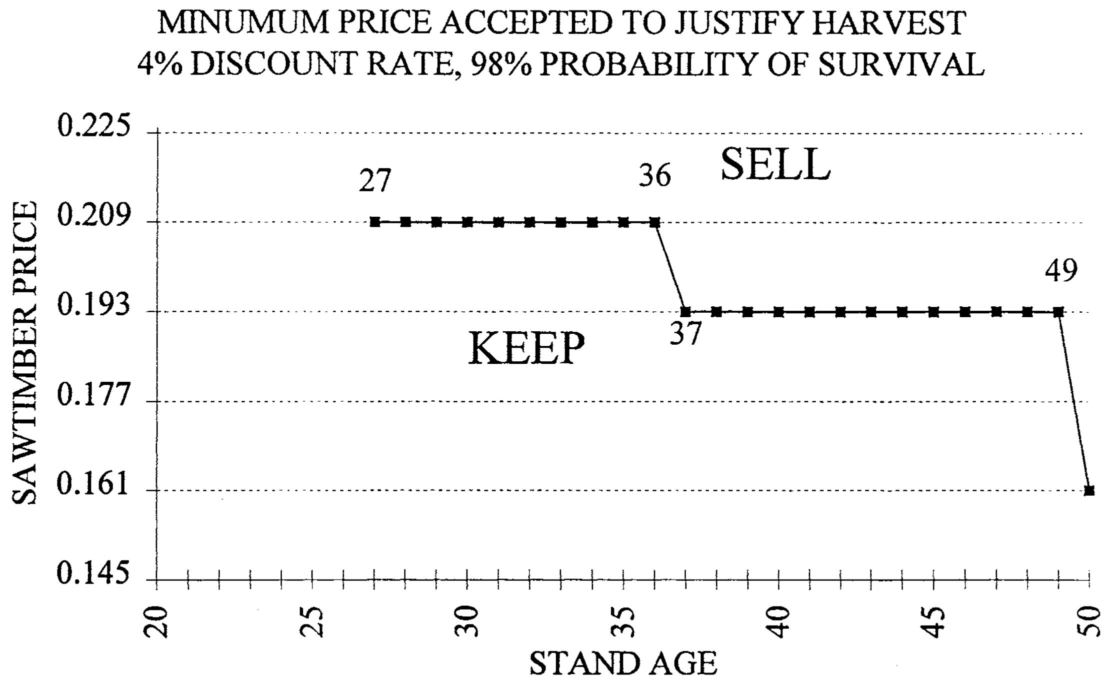

Figure 3.4. Minimum Acceptable Sawtimber Prices for Harvest by Age of Stand for the Four Percent Discount Rate. Site Index 70, Planting Density of 300 Trees per Acre, and Management Strategy of Thinning at Age 20 to 80 Square Feet of Basal Area are Assumed. The Probability of Total Loss of the Stand of Timber was 2 Percent.

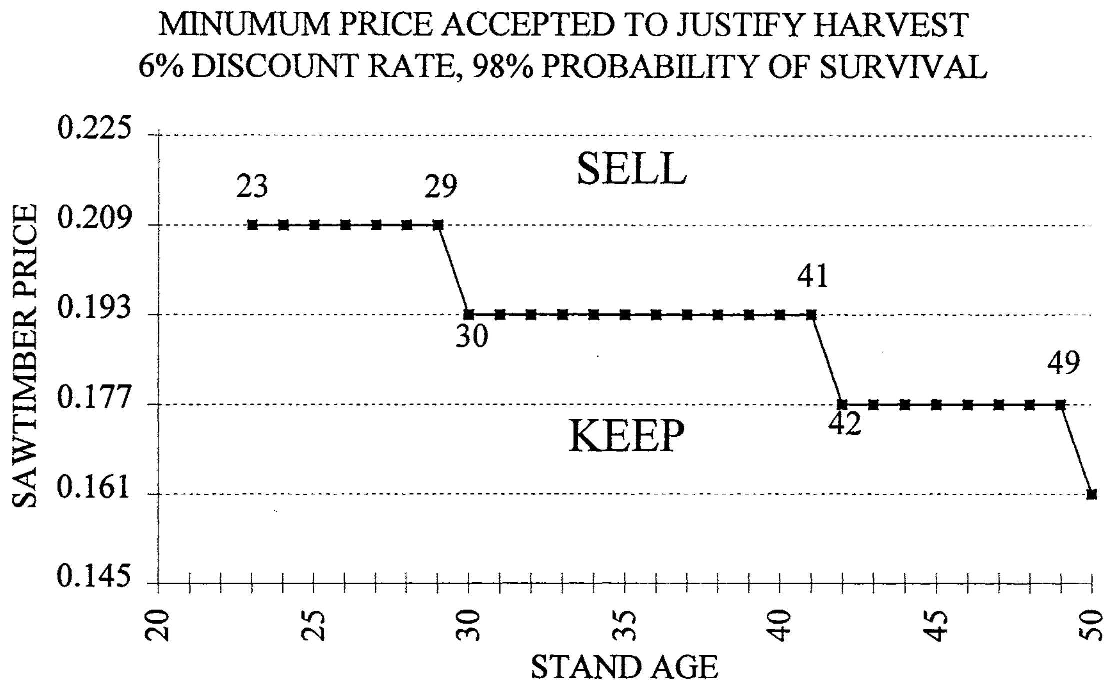

Figure 3.5. Minimum Acceptable Sawtimber Prices for Harvest by Age of Stand for the Six Percent Discount Rate. Site Index 70, Planting Density of 300 Trees per Acre, and Management Strategy of Thinning at Age 20 to 80 Square Feet of Basal Area are Assumed. The Probability of Total Loss of the Stand of Timber was 2 Percent.

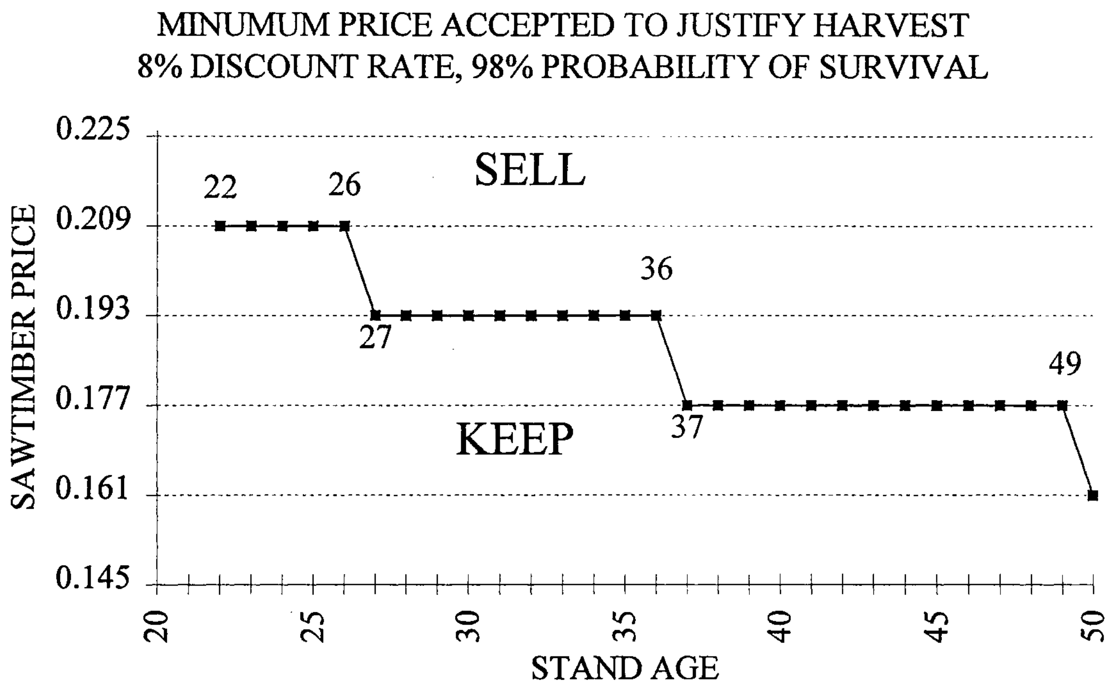

Figure 3.6. Minimum Acceptable Sawtimber Prices for Harvest by Age of Stand for the Eight Percent Discount Rate. Site Index 70, Planting Density of 300 Trees per Acre, and Management Strategy of Thinning at age 20 to 80 Square Feet of Basal Area are Assumed. The Probability of Total Loss of the Stand of Timber was 2 Percent.

CHAPTER 4

THE EFFECT OF TRANSACTIONS COSTS, GRAZING RETURNS, AND HUNTING LEASES ON OPTIMAL RETURNS AND MANAGEMENT STRATEGIES OF INDUSTRIAL AND NON-INDUSTRIAL PRIVATE FOREST OWNERS IN SOUTHEASTERN MCCURTAIN COUNTY OKLAHOMA

Introduction

Previous research has indicated that non-industrial private forest (NIPF) owners receive lower returns on their investment in timber lands than do industrial private forest (IPF) owners (Newman and Wear, 1993; Marcouiller, Lewis, and Schreiner, 1996). Part of this difference in returns may be due to more intensive sivicultural practices by IPF owners (Marcoullier, Lewis, and Schreiner). Returns may also be affected by the amount of timber land owned by NIPFs (Newman and Wear, 1993). de Steiguer (1982), in a study of sales from farmer owned forestland, found per acre values to be inversely related to tract size. Compolli (1981) determined that smaller tracts could be expected to increase rotation length because harvesting costs are higher. Marcoullier, Lewis, and Schreiner found that returns to land and capital from timber in McCurtain County, Oklahoma were 6.4 percent for IPF lands and only 1.1 percent for NIPF lands. NIPF lands accounted for 66 percent of the timber area in southeastern Oklahoma, but only 45 percent of the timber removals in 1993 (Franco, Miller, and Hartsell, 1993). Data from the southern United States indicate that 35 percent of timber removals are from IPF's although they account for 23 percent of the forested acres. The NIPF share of forested acres is 67 percent, but account for 58 percent of the timber harvested (USDA Forest Service, 1988). Lewis and Goodier (1990) expected the acreage of pine plantations in Oklahoma to increase by 300 percent by 2030 (700,000 acres). Much of this projected growth should occur on non-industrial private forest (NIPF) holdings that currently contain a mixed hardwood softwood stands of timber. The inventory of softwood timber owned by farmers in eastern Oklahoma (about 60 percent of NIPF inventory) is expect to double by 2030 (Lewis and Goodier, 1990).

Newman and Wear (1993) suggest that NIPF owners are interested in other outputs besides timber. In these cases, production decisions by NIPF owners involving non-timber goods and services affect the level of timber output from the land (Newman and Wear, 1993; Marcoullier, Lewis, and Schreiner, 1996). Hartman (1976), Binkley (1981), and Boyd (1984) argue that non-timber benefits may be greater than timber benefits for NIPF owners. Industrial forest lands, held by firms that also own wood processing facilities, are managed almost exclusively for timber production (Newman and Wear, 1993).

Lewis and Goodier (1990) estimated that in Oklahoma, the 4.6 million acres of forestland were grazed and 586,200 acres were leased primarily for hunting and fishing in 1984. Green (1997) indicated that pine timber production, cattle, and wildlife habitat can be complementary and profitable to forestland owners in eastern Oklahoma. Livestock grazing has also been suggested as a tool to aid in plantation establishment. It is important that adequate forage be available when grazing a young plantation, so that browsing animals do not disturb trees (Doescher,1987). Pearson (1987) found no significant difference in tree survival for grazed and ungrazed loblolly pine plantations. Lewis et al. (1983) reported a Georgia study where slash pine was planted at 12 x 12 foot spacings (300 trees per acre) and 20 x 20 foot spacings and introduced pasture was planted and fertilized in the plantation. They found that trees benefited from weed control and fertilization. These wider than conventional spacings were found to increase tree diameter and forage production, with most forage production occurring in the first ten years after regeneration. In another study, Clason (1986) found average returns to grazing bermuda grass in a loblolly pine plantation to be $37.50 per acre over 33 years. Clason (1986) suggested that combined timber and cattle production may produce more stable returns, cash flow, and marketing flexibility. Harwell and Dangerfield (1991) in a study of grazing loblolly pine plantations in Georgia found that grazing would add from $13 to $20 per acre to net present values.

Hunting leases have been shown to provide significant income to forest owners. In a Louisiana study, hunting leases were estimated to be worth $5 to $10 per acre (Conrad, 1985). Marsinko (1992) found that additional soil expectation value from hunting leases to be from $29 to $126 per acre over a 25 year rotation at six percent interest. Patterson and Patterson (1989) found that hunting leases were important supplemental income to forest owners. Porter suggests that non-monetary benefits such as reduced trespassing, poaching, theft, and vandalism also are gained from hunting leases.

When the forest is viewed as a multi-product operation, the optimal age of timber harvest (the age of maximum net present value) may be different than when only timber values are considered. Hartman (1976) and Hanley, Shogren, and White (1997) indicate that if non-timber revenues are constant for all years, the age of maximum net present value is the same as without the non-timber revenues, if not, the maximum may occur at a different age. They also have shown that the age of optimal timber harvest is reduced when products such as grazing, which add value early in the rotation are considered. The optimal rotation age is increased when products such as recreation that add value as the trees mature are considered. Both the maximum returns to land and management and the optimal timber management strategy for a NIPF owner with grazing and hunting values should differ from those of an IPF owner concerned with only timber values.

Much of the previous research involving comparison of NIPF and IPF returns to timber land involve aggregate data at the county, state, or regional level (Marcoullier, Lewis, and Schreiner, 1996; Newman and Wear, 1993). In these studies, the differences in quality of land owned by each tenancy group and the tract size was not addressed. Here, the comparison of NIPF and IPF returns to land were made by evaluating how each tenancy group would behave if faced with exactly the same land quality, species, and beginning conditions.

The purpose of this research is to determine the degree to which non-timber benefits from grazing and hunting received by NIPF owners partly or totally compensate for their reduced timber returns relative to IPF owners in southeastern Oklahoma. The research answers the question "What are the differences in income and land management between IPF owners and NIPF owners, if IPF owners are interested solely in timber production and if NIPF owners are interested in timber, forage production, and hunting leases?"

The general objective of this research is to explain part of the difference in returns and forest management practices between IPF owners and NIPFs. Specifically the objectives are to compare the differences in income between IPF and NIPF owners, and to examine the difference in timber management strategies for each forest tenancy group.

Data and Assumptions

A representative 1,000 acre tract of land in southern McCurtain County, was selected. The county soils indicate the tract should contain approximately 500 acres of high quality land (greater than site index 80 base age 50), 400 acres of medium quality land (between site index 60 and 80 base age 50), and 100 acres of low quality land (less than site index 60 base age 50) (Reasoner, 1974). The high and medium quality lands were subdivided into three age classes of trees (stands by age). These classes were seedlings (age zero to fifteen), poles (age 15 to 40), and mature (age 40 to 50). The low quality land was assumed to be bare but could be planted either to trees or pasture. Previous research indicated that it is not economically feasible for NIPFs to produce timber on low index sites (Jacques and Stoecker, 1997). These sites are capable of producing loblolly pine, which was the species used in yield calculations (Reasoner, 1972). Another feature used here is that if it less costly to leave the land idle rather than produce timber or pasture, the producer may choose to do nothing.

The model has a planning horizon of 100 years. Both the IPF owner and the NIPF were assumed to start the planning period with 100 acres of seedlings, 200 acres of poles, and 200 acres of mature trees on high quality land and 100 acres of seedlings, 200 acres of poles, and 100 acres of mature trees on medium quality lands. The IPF owner began with an additional 100 acres of seedlings, and the NIPF begins with 100 acres of either seedlings or improved pasture on low quality land (Table 4.1). Both the IPF and NIPF owner are assumed to inherit these lands at no cost.

Timber products produced will include pine pulpwood, pine chip and saw, and pine sawtimber (Norris, 1995). Growth coefficients for loblolly pine timber production were derived from COMPUTE P-LOB, a growth simulation model developed by the USDA Forest Service (Baldwin and Feduccia, 1987). Coefficients were also developed that allow for thinning at age twenty to 80 square feet of basal area for the high site and at age twenty to 70 square feet of basal area for the medium site. These management strategies were the same ones identified in Chapter 2, using a planting density of 300 trees per acre. Forage production coefficients were adapted from the county soils survey, and from Byrd, Lewis, and Pearson (1984). The NIPF owner has the option to fertilize pasture lands for higher yields.

Values for pulpwood and sawtimber were based on data compiled by Timber Mart South (Norris, 1995). Forage values and hunting lease values were obtained from OSU extension livestock budgets, the McCurtain County OSU extension office, Marsinko (1992), Conrad (1985), and Porter (1982). Costs of sivicultural practices will be taken from Dubois et al. (1995).

These data indicate the following prices for outputs. Timber prices were $195 per thousand board feet for sawtimber, $93 per thousand board feet for chip and saw, and $163 per thousand cubic feet for pulpwood. The price for forage (grazing) was $10 per animal unit month. Annual prices for hunting leases was $5 per acre for seedlings and pasture, $3 per acre poles, and $2 per acre for mature timber (Table 4.2).
Sources (Dubois, et al., 1995) indicate the cost of timber regeneration and thinning for the NIPF was $90 per acre for site preparation, $27 per acre for planting, and $30 per acre for thinning. The cost of timber sales preparation for the NIPF was $32 per acre. Fertilizer and chemical costs for pasture was estimated at $15 per acre annually. The costs of fencing $1.50 per animal unit month for timber and $1.50 annually per acre for pasture (Table 4.2).

Cost of thinning and regeneration was assumed to be 20 percent less for IPF owners. IPF owners also incurred costs of controlled burning for fire protection of $10 per acre per incidence (Table 4.3). Control burning to control the level of fuel due to grasses was assumed to occur twice between stand ages one and ten and once after thinning. Because the NIPF owners graze timberland, controlling the undergrowth, their stands were assumed not to require control burning.

The management practices which maximize the net present value for each land tenancy group over the 100 year planning horizon were determined. This included returns from timber for the IPF owner and returns from timber, forage, and hunting for the NIPF. The IPF tract was managed for maximized net present value of timber. Because industrial forest owners are vertically integrated, and operate with economies of scale, transactions costs (sales preparation costs) are nil. In addition, sivicultural practices such as site preparation, planting, and thinning, are done at lower costs than the NIPF.

The discount rate was be assumed to be six percent for NIPF owners (Teeter and Caulfield, 1991). Marcoullier, Schreiner, and Lewis (1996) indicate that IPF owners have lower costs of capital than do NIPF owners. In addition IPF owners spread their risk of stand loss due to weather, fire, insects, or disease over many thousands of acres. Therefore it is reasonable to assume that IPF owners face a lower discount rate that do NIPF owners. For the purposes here, a six percent discount rate will apply to NIPF owners and a five percent discount rate will apply to IPF owners.

Procedures

The objective was to help explain the difference in forest management of NIPFs and IPF owners. A representative tract of land was selected in southern McCurtain County. The management or production activities which yield maximum net present value was then determined for a representative IPF owner and for a representative NIPF owner.

Linear programming models have been used for many years in forest management and is the approach used here. Linear programming with respect to forest optimization is explained at length in Davis and Johnson ((1987) pp. 206-232; pp. 592-715) and in Buongiorno and Gilless (1987). Forest management planning considers the entire forest, which is made of many stands of various ages of trees on various soils. The complexity of this problem when forest production is treated as a multi product enterprise where timber and non-timber flows are considered can make the problem difficult to simultaneously optimize. Linear programming (LP) can successfully handle this problem, and provides a mechanism for sensitivity analysis. Sensitivity analysis can be used as a way to consider risk and uncertainty (Davis and Johnson (1987), p. 206). Non-linear equations, such as tree growth, are represented in a LP model through segmentation of the equations.

To achieve the objective outlined here, a multiperiod linear programming system, Spectrum, was used. Spectrum evolved from FORPLAN, a linear programming based model used to develop the USDA Forest Service's first set of strategic forest plans for the national forests of the United States (USDA Forest Service, 1997). FORPLAN Version 1 was first released in 1980 in an effort to merge timber and land management planning (Iverson and Alston, 1986). FORPLAN became the "required primary analysis tool" for use in integrated planning for national forests. As computer power increased, FORPLAN was improved throughout the 1980's and early 1990's (Kent et al., 1993). Spectrum builds on the capabilities of FORPLAN, focusing on the needs of forest ecosystem planning and management (USDA Forest Service, 1997).

The Spectrum system includes modules for a data entry system, model management, matrix generation, linear programming, and report writing. C-Whiz, a linear programming algorithm developed be Ketron, Inc., is used to solve the linear programming matrix generated by Spectrum. The linear programming component determines an optimal land allocation with activity and output scheduling for a forest over a specified planning horizon.

The objective function is

(1) $$Max\ Z = \sum_{j=1}^{n}\sum_{t=1}^{100} \rho^t \left(r_{jt} - c_{jt}\right) X_{jt}$$

(2) $$\sum_{j=1}^{n} a_{ijt} X_{jt} \leq b_{it}; i = 1,..,m; t = 1,2,\ldots,100$$

(3) $$X_{jt} \geq 0$$

where ρ^t is the present value of a dollar received in period *t*,

r_{jt} are returns to output *j* in time period *t*,

c_{jt} are costs associated with output *j* in time period *t*,

X_{jt} is the level of output *j* in time period *t*,

a_{ijt} are coefficients describing the affect of activity *i* on output *j* in time period *t*,

and b_{it} are a set of constraints on activity *i* in time period *t*.

The a_{ijt} coefficients describe acreage in each site class, in each age class, site preparation, planting, thinning, and sales preparation. These particular coefficients are generally either one or negative one. Other parts of the matrix include yield tables. There are yield tables for sawtimber, chip and saw, pulpwood, and forage by age on high and medium site lands. This includes existing stand yield tables, regenerated stand yield tables, thinned existing stand yield tables, and thinned regenerated stand yield tables for high and medium sites. Low site timber production includes existing age class (seedling) and regenerated stand. Thinning strategies were not explored on low productivity land classes. Time dependent yields for the NIPF lands included pasture on low sites and hunting leases for all sites.

The right hand side values, b_{it}, insure that solutions remain within the feasible region (cannot have more than 1,000 acres at any one time, no more than 500 acres of high site at any one time, etc.).

Results

Prices used to derive the net present values (NPVs) for NIPF owners are shown in Table 4.2. NIPF owners management results are shown in Table 4.4. The NPV from grazing was $131 thousand and from hunting was $52 thousand. As shown, about 10 percent of the NPV was derived from non-timber production.

IPF results are shown in Table 4.4. Prices of outputs and inputs for the IPF owner are shown in Table 4.3. At the six percent discount rate, using costs of site preparation, planting, and thinning that were 20 percent less than for the NIPF and no cost for sales preparation, the NPV for the IPF owner was $1,837 thousand. This is considerably less than the NPV of $1,997 thousand for the NIPF owner. The IPF produced more timber than the NIPF because the IPF used the low site to produce timber instead of grass. Marcoullier et al. (1995) suggested that IPF owners have access to capital at lower rates than do NIPF owners. Certainly large vertically integrated timber companies borrow money at lower rates than do small farmers. IPF owners also spread their risk of weather, fire, and disease over many thousands and even hundreds of thousands of acres. The discount rate is a function of the level of risk, and other factors such as alternative investments. Therefore the assumption of a lower discount rate for the IPF seems reasonable. In this study, it was assumed the real discount rate was five percent for IPF owners and six percent discount rate for NIPF owners. Table 4.4 shows the result of using a five percent discount rate for the IPF owner. As shown, the difference of a one percent lower discount rate has a larger effect on the NPV of the IPF owner than do their cost advantages (as expected). At the five percent discount rate, the IPF produced slightly more timber than at the six percent discount rate. This was because the low site timber harvest was delayed five years to age 35 (Table 4.6).

Table 4.5 shows how the various land areas were managed by the NIPF owner. Existing stands of seedlings and poles on high and medium sites were thinned at age 20, harvested at age 35 and regenerated. Existing mature stands on high and medium sites were harvested immediately (age 40) and regenerated. Regenerated stands that were originally seedlings were thinned and harvested at age 30 for both the medium and high sites. Regenerated stands that were originally poles or mature trees were thinned and harvested at age 35. Low sites were left in improved pasture and fertilized to increase forage production.

Table 4.6 shows the timber management regimes that were optimal for the IPF owner at the five and six percent discount rates. Results for the five and six percent discount rates, as discussed below, were the same unless otherwise stated. Existing mature stands were harvested immediately (age 40) and regenerated. Existing seedling and poles on medium and high sites were thinned, harvested at age 35, and regenerated. Existing trees (seedlings) on low sites were harvested at age 30 and regenerated if the discount rate was six percent and age 35 and regenerated if the discount rate was five percent.

Regenerated stands of high sites that were originally seedlings were harvested at age 30 and on medium sites at age 35. High and medium sites that were originally poles or mature trees were regenerated, thinned, and harvested at age 35.

Summary

As shown in Tables 4.5 and 4.6, the NIPF owner and IPF owner managed lands devoted to timber production in the same way with the exception of medium site seedlings, which were harvested at age 30 for the NIPF and age 35 for the IPF. This caused the ending inventory to be larger and therefore the added NPV to be larger for the IPF, as shown in Table 4.4. The ending conditions had a small, but measurable effect on NPVs for both tenancy groups.

Non-timber outputs of hunting and grazing provide significant income to the NIPF owner. When the same discount rate was used, the NIPF owners in this study received a higher NPV than did IPF owners. Results indicate that NIPF owners would choose to put marginal timber producing land in improved pasture, therefore NIPF do produce less timber from the same lands than do IPFs, even under the assumption that both use similar sivicultural practices.

The real economic advantage IPF owners have is that they likely face a lower discount rate than NIPF owners. In this study, when the IPF owner faced a five percent real discount rate, and the NIPF faced a six percent real discount rate, the IPF owners NPV was slightly higher than the NIPF owners NPV ($2.1 million vs. $1.97 million). This was in spite of the hunting and grazing income to the NIPF.

This analysis was limited to NIPF outputs that could be measured by market forces. If non-market timber outputs such as scenery and wildlife viewing were included here, it is not difficult to see that NIPF owners may receive more benefits from timber land than IPF owners.

Table 4.1. Acreage by Site Index and Age Class.

Site Index	Age Class	Acres
High	Seedling (0 - 15 Yrs.)	100
High	Poles (15 - 40 Yrs.)	200
High	Mature(40 - 50 Yrs.)	200
Medium	Seedling	100
Medium	Poles	200
Medium	Mature	100
Low	Seedling or Pasture	100

Table 4.2. Prices of Outputs and Activities for Non-Industrial Private Forest Owners.

Activity/Output	Units	Land Type	Price($)
Pulp wood	MCF	Timber	163.00
Chip and Saw	MBF	Timber	93.00
Sawtimber	MBF	Timber	195.00
Forage	AUM	Timber/Pasture	10.00
Hunting	Acre/year	Pasture	5.00
Hunting	Acre/year	Timber seedlings	5.00
Hunting	Acre/year	Timber poles	3.00
Hunting	Acre/year	Timber mature	2.00
Fencing	Acre/year	Pasture	1.50
Fencing	AUM	Timber	1.50
Fertilizer	Acre/year	Pasture	15.00
Site Preparation	Acre	Timber	90.00
Planting	Acre	Timber	27.00
Thinning	Acre	Timber	30.00
Sales Preparation	Acre	Timber/Clear cut	32.00
Sales Preparation	Acre	Timber/Thinning	14.00

Note: MCF equals 1,000 cubic feet. MBF equals 1,000 board feet, International 1/4 inch log rule.

Table 4.3. Prices of Outputs and Activities for Industrial Private Forest Owners.

Activity/Output	Qualifier	Land Type	Price($)
Pulp wood	MCF	Timber	163.00
Chip and Saw	MBF	Timber	93.00
Sawtimber	MBF	Timber	195.00
Control Burning	Acre	Timber	10.00
Site Preparation	Acre	Timber	72.00
Planting	Acre	Timber	21.00
Thinning	Acre	Timber	24.00

Note: MCF equals 1,000 cubic feet. MBF equals 1,000 board feet, International 1/4 inch log rule.

Table 4.4. Net Present Values (NPVs) and Levels of Activities and Outputs from NIPF Owners and IPF Owners.

Type	Units	NIPF @ 6%1	IPF @ 6%2	IPF @ 5%3
NPV from Forage	$1K	131	na	na
NPV from Hunting	$1K	52	na	na
NPV from Timber	$1K	1,815	1,837	2,137
NPV of Ending Inventory	$1K	2	3	7
NPV Total	$1K	1,999	1,840	2,144
Outputs (over 100 yrs.)				
Pulp wood	MCF	2,820	2,950	2,950
Chip and Saw	MBF	23,300	24,050	24,230
Sawtimber	MBF	33,900	35,130	35,530
Forage	AUM	114,500	na	na
Activities (over 100 yrs.)				
Control Burn	Total Acres	na	8,500	8,500
Fencing on Pasture	Total Acres	10,000	na	na
Fencing on Timber Land	Total AUM	59,550	na	na
Fertilizer(Pasture)	Total Acres	10,000	na	na
Site Preparation (Timber)	Total Acres	2,000	2,100	2,100
Planting	Total Acres	2,000	2,100	2,100
Thinning	Total Acres	2,700	2,700	2,700
Sales Preparation	Total Acres	3,000	na	na

[1] Six percent discount rate.
[2] Six percent discount rate.
[3] Five percent discount rate.

Table 4.5. Optimal Management Regime for NIPF Owner.

Site Index/Age Class	Stand Type	Management Action
High/Seedling	Existing	Thin and Harvest at Age 35
High/Poles	Existing	Thin and Harvest at Age 35
High/Mature	Existing	Harvest at Age 40
Medium/Seedling	Existing	Thin and Harvest at Age 35
Medium/Poles	Existing	Thin and Harvest at Age 35
Medium/Mature	Existing	Harvest at Age 40
Low	Existing	Fertilized Pasture
High/Seedling	Regenerated	Thin and Harvest at Age 30
High/Poles	Regenerated	Thin and Harvest at Age 35
High/Mature	Regenerated	Thin and Harvest at Age 35
Medium/Seedling	Regenerated	Thin and Harvest at Age 30
Medium/Poles	Regenerated	Thin and Harvest at Age 35
Medium/Mature	Regenerated	Thin and Harvest at Age 35
Low	Regenerated	Fertilized Pasture

Table 4.6. Optimal Management Regime for IPF Owner.

Site Index/Age Class	Stand Type	Management Action
Six Percent Discount Rate		
High/Seedling	Existing	Thin and Harvest at Age 35
High/Poles	Existing	Thin and Harvest at Age 35
High/Mature	Existing	Harvest at Age 40
Medium/Seedling	Existing	Thin and Harvest at Age 35
Medium/Poles	Existing	Thin and Harvest at Age 35
Medium/Mature	Existing	Harvest at Age 40
Low/Seedling	Existing	Harvest at Age 30
High/Seedling	Regenerated	Thin and Harvest at Age 30
High/Poles	Regenerated	Thin and Harvest at Age 35
High/Mature	Regenerated	Thin and Harvest at Age 35
Medium/Seedling	Regenerated	Thin and Harvest at Age 35
Medium/Poles	Regenerated	Thin and Harvest at Age 35
Medium/Mature	Regenerated	Thin and Harvest at Age 35
Low/Seedling	Regenerated	Harvest at Age 30
Five Percent Discount Rate		
High/Seedling	Existing	Thin and Harvest at Age 35
High/Poles	Existing	Thin and Harvest at Age 35
High/Mature	Existing	Harvest at Age 40
Medium/Seedling	Existing	Thin and Harvest at Age 35
Medium/Poles	Existing	Thin and Harvest at Age 35
Medium/Mature	Existing	Harvest at Age 40
Low/Seedling	Existing	Harvest at Age 30
High/Seedling	Regenerated	Thin and Harvest at Age 30
High/Poles	Regenerated	Thin and Harvest at Age 35
High/Mature	Regenerated	Thin and Harvest at Age 35
Medium/Seedling	Regenerated	Thin and Harvest at Age 35
Medium/Poles	Regenerated	Thin and Harvest at Age 35
Medium/Mature	Regenerated	Thin and Harvest at Age 35
Low/Seedling	Regenerated	Harvest at Age 35

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APPENDICES

APPENDIX A

DEFINITIONS

Remaining basal area or residual stand is the part of a stand of growing stock retained after an intermediate cutting, such as thinning, or partial cutting.

Basal area is cross-sectional area of a tree, in square feet, measured at breast height, 4.5 feet above the ground. Used as a method of measuring the volume of timber in a given stand, or the relative density of a stand.

Clearcutting is a harvest and regeneration technique which removes all the trees on an area with one operation. Clearcutting is commonly used with shade-intolerant species like loblolly pine, which require full sunlight to reproduce and grow well. Clearcutting produces an even-aged stand.

A **rotation** is the planned number of years between the regeneration of a stand and its final cutting at a specified stage of maturity.

Saw timber is those trees cut to yield log, which are of suitable size and quality for producing lumber cut by a saw to and dimension; usually 10 inches in d.b.h. or larger for pine, 12 inches for hardwood.

Diameter Breast Height (DBH) - The diameter of a tree at 4.5 feet above the ground level on the high side of the tree.

Pulp wood is wood to be converted into pulp for the manufacture of paper, fiberboard, or other wood-fiber products. Pulp wood size trees are usually 4 to 9 inches d.b.h. or are too poorly formed to make lumber.

Site Index is a relative measure of productivity of a given site to grow a particular species. Site Index is based on the height of the dominant trees of a particular species at either 25 or 50 years of age.

Thinning is generally, a partial harvest in an immature stand to reduce the number of trees per acre and encourage the remaining trees to grow faster and produce higher quality wood.

APPENDIX B

COMPUTE_P-LOB OUTPUT.

1

Original inputs:
Age = 10
Height of dominants and codominants = 35.0
Trees surviving = 268.
Previously unthinned stand

LOBLOLLY PINE
BEFORE THINNING INFORMATION
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.5 FEET
QUADRATIC MEAN DBH= 7.654 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
3	1	.0	28	1.	1.	0.	0.	0.	0.	0.
4	8	.7	34	13.	9.	0.	0.	0.	0.	0.
5	23	3.1	38	62.	45.	41.	28.	0.	0.	0.
6	42	8.2	41	173.	127.	145.	105.	0.	0.	0.
7	57	15.2	43	331.	246.	303.	223.	0.	0.	0.
8	57	19.9	45	446.	334.	426.	318.	0.	0.	0.
9	41	18.1	46	410.	309.	399.	300.	177.	126.	0.
10	20	10.9	47	250.	189.	246.	185.	150.	109.	588.
11	6	4.0	48	92.	70.	91.	69.	66.	49.	266.
12	1	.8	49	18.	14.	18.	14.	15.	11.	61.
	256	81.0		1796.	1344.	1669.	1242.	408.	295.	915.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 9.889
WEIBULL PARAMETERS: "A"= 2.204; "B"= 5.854; "C"= 3.593

LOBLOLLY PINE
RESIDUAL STAND -- AFTER THINNING
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.5 FEET
QUADRATIC MEAN DBH= 7.887 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
4	3	.3	34	5.	3.	0.	0.	0.	0.	0.
5	13	1.8	38	35.	25.	23.	16.	0.	0.	0.
6	29	5.7	41	120.	88.	100.	72.	0.	0.	0.
7	46	12.3	43	267.	198.	245.	180.	0.	0.	0.
8	52	18.2	45	407.	305.	389.	290.	0.	0.	0.
9	39	17.2	46	390.	294.	380.	285.	168.	120.	0.
10	18	9.8	47	225.	170.	221.	167.	135.	98.	529.
11	5	3.3	48	76.	58.	76.	57.	55.	41.	222.
12	1	.8	49	18.	14.	18.	14.	15.	11.	61.
	206	69.3		1543.	1155.	1452.	1081.	373.	270.	812.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 9.942
WEIBULL PARAMETERS: "A"= 2.628; "B"= 5.659; "C"= 3.812

LOBLOLLY PINE
STAND COMPONENT REMOVED BY THINNING
(PER ACRE)

AGE= 15
DOMINANT HEIGHT= 45.5 FEET
QUADRATIC MEAN DBH= 6.556 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
3	1	.0	28	1.	1.	0.	0.	0.	0.	0.
4	5	.4	34	8.	6.	0.	0.	0.	0.	0.
5	10	1.4	38	27.	20.	18.	12.	0.	0.	0.
6	13	2.6	41	53.	39.	45.	33.	0.	0.	0.
7	11	2.9	43	64.	48.	58.	43.	0.	0.	0.
8	5	1.7	45	39.	29.	37.	28.	0.	0.	0.
9	2	.9	46	20.	15.	19.	15.	9.	6.	0.
10	2	1.1	47	25.	19.	25.	18.	15.	11.	59.
11	1	.7	48	16.	12.	15.	12.	11.	8.	44.
	50	11.7		253.	189.	217.	161.	35.	25.	103.

LOBLOLLY PINE
BEFORE THINNING INFORMATION
(PER ACRE)

AGE= 25
DOMINANT HEIGHT= 61.3 FEET
QUADRATIC MEAN DBH= 10.674 INCHES

DBH CLASS	STEMS	BASAL AREA	AV. HT.	CUBIC FOOT VOLUME OF STEMS TO AN O.B. TOP DIAMETER OF 0 INCHES		4 INCHES		8 INCHES		INTER.1/4 B.F. VOL. 8-IN. TOP
in.	no.	sq. ft.	ft.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	i.b.
6	4	.8	51	19.	15.	16.	12.	0.	0.	0.
7	10	2.7	55	72.	54.	65.	49.	0.	0.	0.
8	18	6.3	57	175.	134.	167.	128.	0.	0.	0.
9	28	12.4	60	363.	281.	354.	274.	144.	104.	0.
10	35	19.1	61	571.	445.	564.	438.	336.	252.	1486.
11	35	23.1	63	715.	560.	710.	555.	519.	398.	2317.
12	28	22.0	64	694.	545.	690.	542.	566.	439.	2516.
13	18	16.6	65	533.	420.	531.	419.	466.	365.	2095.
14	8	8.6	66	279.	221.	279.	221.	255.	201.	1160.
15	3	3.7	67	122.	97.	122.	97.	115.	91.	526.
16	1	1.4	67	46.	37.	46.	37.	44.	35.	204.
	188	116.5		3589.	2809.	3544.	2772.	2445.	1885.	10304.

SI(BASE AGE 25)= 61 FEET; 93RD PERCENTILE= 13.443
WEIBULL PARAMETERS: "A"= 3.789; "B"= 7.416; "C"= 3.708

VITA

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