Economic Analysis of Pruning and Low-Density Management Compared to Traditional Management of Loblolly Pine Plantations in East Texas

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ABSTRACT: *Economic analyses were conducted to compare traditional loblolly pine (*Pinus taeda *L.) timber management to low-density management combined with pruning in East Texas. Soil expectation values were used to determine the financially optimal thinning and final harvesting schedules (including rotation length, and the timing, frequency and intensity of thinning). Two stumpage price assumptions were made: market price and premium price for pruned, clear sawlogs. Five site indices (50 to 90) and six real alternative rates of return (ARR) (2.5 to 15.0%) were employed. Results indicate that if the market price of sawtimber is $450/mbf, traditional management is more profitable for most landowners. However, if a premium price of $550/mbf is paid for pruned logs, low-density management is more profitable for most landowners. For low-density management, a $100/mbf price increase for sawtimber does not affect the optimal thinning and harvesting schedules in any recognizable pattern. South. J. Appl. For. 28(1):12–20.*

Key Words: Pruning, thinning intensity, low-density management, stumpage price, soil expectation value.

Nonindustrial private forest (NIPF) landowners in Texas are influenced by how the forest products companies manage their lands. Recently, some companies have experimented with low-density management combined with pruning, hoping to increase profits by producing clear wood in a shorter period of time. Some NIPF landowners have become interested in this new management technique and question whether it is more profitable than traditional timber management. Traditional timber management and low-density management differ in the intensity and timing (and sometimes the number) of the thinnings. Low-density management reduces the number of trees and basal area well below that of traditional timber management during thinning operations with the objective of allowing each residual tree to grow faster, resulting in higher sawtimber volume at an earlier age. Pruning is performed so that much of the lumber produced from the rapidly grown trees will be free of knots and, therefore, more valuable.

The need for an economic analysis, which compares traditional timber management to low-density management combined with pruning, is apparent. Studies have recommended optimal rotation age, planting density, number of thinnings, timing of thinnings and intensity of thinnings for loblolly pine (Klemperer et al. 1987, Arthaud and Klemperer 1988, Huang and Kronrad 2002),the most important commercial timber type in the southern United States. However, the attempt to determine the profitability and financially optimal thinning and harvesting schedules for stands that are pruned and managed under conditions of low density has never been done. This research is a followup study of the previous research conducted by Huang and Kronrad (2002), who used dynamic programming to determine financially optimal thinning and final harvest schedules for loblolly pine in a "traditional management" style. That research focused on determining the financially optimal decisions concerning timing, intensity, and number of thinnings. It also considered the timing of final harvest to employ depending on the individual landowner's alternative rate of return (ARR), site index, management costs, stumpage prices, and real price and cost increases. In this study, further layers of complexity were added by considering the silvicultural option of pruning, a differential price for pruned wood, and the removal of a higher basal area at each thinning than is customary in traditional timber management. This new analysis is called low-density management to differentiate it from the traditional management approach applied in the previous study. The two styles were compared to determine which is more profitable and to contrast the optimal thinning and harvesting schedules of each.

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The Benefits of Low-Density Management with Thinning and Pruning

Thinning

Thinning is a basic silvicultural tool used to regulate stand density, to increase diameter growth, to recover wood normally lost to mortality, and to redistribute growth to desirable crop trees (Stearns-Smith et al. 1992). While commercial thinnings generally do not increase total merchantable cubic foot volume yields in fully stocked stands—where mortality resulting from self-thinning is not a factor—they do produce more board-foot volume by shifting the distribution of growth to fewer and more valuable trees (Bennett and Jones 1983, Nebeker et al. 1985). Even though thinnings have rather insignificant effects on tree height growth (Goebel et al. 1974, Zhang et al. 1997), merchantable thinnings have a positive influence on individual tree diameter increment, provide intermediate revenues, and serve as a mechanism for sanitation and salvage operations (Stearns-Smith et al. 1992). Thinning also is used to improve form and species composition of the stand (Zeide 2001), and to manage the production of wood by selected trees such that products of desired quality are obtained within the shortest possible time (Tasissa and Burkhart 1997).

Thinning reduces stand density, which is a major determinant of the pattern of wood deposition along the stem (Tasissa and Burkhart 1997). The development of trees in an established forest is determined by the degree of existing competition. Trees growing under severely competitive conditions exhibit slower diameter growth, higher incidence of mortality, and longer and more limb-free boles than trees growing under less competitive conditions. On the other hand, trees that mature under insufficient competition show increased diameter growth, limited natural pruning and poor general form. As the trees grow, regulation of competition in a forest stand through thinning is an effective way to maintain sufficient competition, to utilize site factors without necessarily limiting the growth of individual trees, and to improve economic development of the stand (NLHFES 1973).

Thinning intensity is generally quantified by the amount or proportion of basal area removed, and the remaining basal area of the stand is used as an indicator of the growth response after thinning (Hasenauer et al. 1997). Thinning intensity should be monitored closely as the stand matures. Successive thinnings from a density of 1,000 trees/ac to a density of 100 trees/ac during the first 8 yr in the life of a loblolly pine stand will lead to inefficient use of the site and development of excessively limb-dense trees (NLHFES 1973).

There are factors, other than small reductions in diameter growth resulting from competition, to be considered when initiating a financially optimal thinning and final harvest schedule. Decisions regarding thinning opportunities are strongly influenced by product objectives and the cost of capital. Evaluating various scenarios to determine optimum silvicultural prescriptions and the influence of silvicultural manipulations on stand development is essential in planning management strategies. Although the effects of thinning operations on diameter distributions of forest stands are well recognized and have been included in growth and yield models (Burkhart and Bredenkamp 1989), the effects of thinning on landowners' financial returns are not easily quantified. Such attempts have to consider physical factors (site quality, original and residual stand density, type of thinning, etc.), and economic variables (interest rates, stumpage prices, management costs, etc.).

Pruning

The goal of pruning is to maximize clear wood production at an acceptable cost. Pruning offers considerable benefits in sawtimber production because it increases wood quality by producing clear wood, which is a more valuable product. It also benefits production by yielding greater utilization of wood from upper stem portions. As the number and size of knots increase with height on the bole, artificial pruning is conducive to the production of longer, clear logs. Yet, because artificial pruning is expensive, it should be limited to a small number of trees per acre and should be coupled with a thinning regime that will maintain rapid diameter growth (Smith et al. 1997).

In order to ensure that only crop trees are pruned and the risk of logging damage to pruned trees is avoided, a pruning operation should not be performed until after the first thinning. The trees to be pruned should be as vigorous as possible but not so vigorous as to have excessively large branches (Smith et al. 1997). Although there is a chance that money spent on pruning may be wasted under some circumstances, the combination of investing in pruning and thinning may present some of the highest long-term returns available in timber-production silviculture (Page and Smith 1994). Smith et al. (1997) stated that it takes rapid growth of substantial amounts of clear material to repay the high compounded cost of an operation that takes 10 to 15 min. per tree with a wait of 15 to 40 yr for the returns. Mann (1951) pointed out that clear lumber is two to five times more valuable than knotty lumber. Pruning western white pine logs may increase their value by 47% and pruning ponderosa pine logs may increase their value by 68% (Huey 1950).

Methods

Dynamic Programming Approach

The economics of commercial thinning is a major topic of discussion. Efficient forest management decision-making depends on the accuracy of information concerning how stands respond to commercial thinning and how the amount and timing of thinning revenues affect landowners' profits. A thorough investigation of intensity, type, timing, and frequency of thinnings and rotation length is needed. Yet, simultaneous determination of these factors is a complex optimization problem. Dynamic programming is a generalized approach for solving problems that involve making a sequence of interrelated decisions to maximize overall effectiveness (Dykstra 1984). It is a useful, efficient tool for financially optimizing forest stand management. It permits practical consideration of a large number of alternatives that require discrete time and stocking interval specifications for the purpose of precisely quantifying and appropriately evaluating the effects of thinning (Brodie et al. 1978). Loblolly pine is a good candidate to use with dynamic programming because it grows in pure stands and its growth and yield information is readily available (Arthaud and Klemperer 1988).

In this study, a dynamic program was developed to simultaneously determine both the optimal rotation age and the optimal timing and intensity of thinning(s) for loblolly pine plantations on nonindustrial private forestland. This program utilized PTAEDA2 (Burkhart et al. 1987), a forest stand simulator, to predict stand growth data on diameter, height, and volume from establishment to final harvest. PTAEDA2 was linked to a financial program that performed cash flow analyses and calculated net present worth and soil expectation values. Data for PTAEDA2 growth and yield model came from 186 permanent plots established in cutover, site-prepared plantations throughout much of the natural range of loblolly pine. Within each of the 186 plots, three test locations were established, with each test location being similar in site index, number of surviving trees, and basal area. The three test locations at each plot were then subjected to randomly assigned treatments of no thin, light thin, and heavy thin. The no thin treatment (control) was used in the development of the growth relationships in the stand simulator. The light thin treatment (approximately 30% basal area removed) and the heavy thin treatment (approximately 50% basal area removed) were later used in the testing and validation procedures.

A total of six remeasurements of the original test data have been completed throughout the life of PTAEDA2 (phone interview with H.E. Burkhart on July 24, 2000). At each remeasurement, the collected data were compared to that generated by the model. The results of the six comparisons yielded data that so closely resembled data generated by the original model that there have been no changes to the original growth or mortality equations since the release of PTAEDA2. These data are applicable for a wide range of sites in both the Coastal Plain and Piedmont regions. Twenty-two percent of these plots are located in the West Gulf Coast region that includes Texas. Fifty-six percent of the sites are in the Coastal Plain, which are similar to sites in Texas. The accuracy and reliability of PTAEDA2 have been confirmed with 84 permanent research plots in Texas that have been managed for 22 yr and measured for the last 6 yr (Kronrad 2000).

Management Options

Site indices 50, 60, 70, 80, and 90 (base age 25), well within the possible site index range for PTAEDA2, were used in these analyses. It was assumed the stands were planted with 600 trees/ac at exact regular spacing with the distance between rows and trees of 9 and 8 ft, respectively. It was assumed that bare land would be site prepared and planted, and there would be 480 trees/ac at age 10. The maximum possible rotation length was limited to age 60. The method for the first thinning would be a combination of low and row thinning; the method for the second and third thinning would be a low thinning only. The first thinning could not be conducted until the stand was at least 10 yr. The minimum years between thinnings, or between a thinning and the final harvest, could not be less than 5 yr. For all the dynamic runs, a "thinning and final harvest" regime would be considered to be operable only if it passed the following two threshold constraints: (1) every thinning or final harvest had to yield a minimum of 6 cd/ac of pulpwood and/or sawtimber; and (2) the number of residual trees after each thinning had to be at least 80/ac for traditional management and 60/ac for low-density management. The first constraint was set to guarantee that volume removed during the harvest would be sufficient for an operable cut. In order to procure a logger or harvesting crew, it is crucial to adjust this constraint when the price of pulpwood is depressed, and pulpwood is the only product that loggers will harvest from the stand. The purpose of the second constraint was to avoid problems associated with inadequate residual stand density.

For traditional management, four thinning intensities were employed: 20, 25, 30, or 35% of basal area removal. The number of possible thinnings was zero, one, two, or three. The same thinning intensity was used for all thinnings for a specific optimal solution regardless of the number of thinnings or age of thinnings.

For low-density management, on low and medium site indices 50, 60, and 70 lands, the amount of basal area removed during the first thinning was 40, 45, 50, 55, 60, or 65%. For the higher site indices of 80 and 90, the amount of basal area removed during the first thinning was 40, 45, 50, 55, 60, 65, or 70%. The amount of basal area removed during the second thinning could vary from that removed in the first thinning and ranged from 20 to 60% for all five site indices. Due to the nature of low-density management, which required a minimum of 60 crop trees at final harvest, the number of thinnings was always two.

Product Yields

NIPF landowners in Texas usually are paid only to the nearest half log (8 ft) for the merchantable sawlog portion of their timber. This study acquired the biological variables of diameter at breast height (dbh) and total height from PTAEDA2. It then applied Amateis and Burkhart's taper functions (1987) to estimate upper stem diameters and merchantable heights, and the Doyle log rule to predict board-foot volume. Even though Doyle log rule has a built-in bias, it is the method used by many forest consultants and timber buyers to measure and purchase standing timber from NIPF landowners in East Texas. Cull percentages were not applied because it was assumed that culled trees would be removed in early thinnings before sawtimber harvests. A 10 in. diameter at breast height (dbh) and one 16 ft log were set as minimum sawlog requirements. After the first 16 ft log, the minimum sawlog increment was assumed to be 8 ft. The merchantable height is the number of 8 ft logs that could be cut out of the tree up to a minimum top diameter of 6 in. inside bark. This is the method used by consultants in Texas to tally individual trees. Timber buyers review and determine a bid price based, in part or in whole, on the inventory provided by the consultant. Pulpwood volume was measured in cords to a 4 in. outside bark top diameter for trees in the 5, 6, 7, 8, and 9 in. dbh classes. Cordwood volumes were computed from the 1 in. dbh class conversion factors presented by Burkhart et al. (1972). These conversion factors range from 84 ft^3 ob/cd for the 5 in. dbh class to 95 for the 13 in. and above class (Burkhart et al. 1987). Even though the superior diameter growth induced by thinning usually improves wood quality—because large trees tend to have better quality than small ones (Smith et al. 1997)—any change in the quality of wood resulting from thinning was assumed to be negligible in this study.

Economic Evaluation

Six ARRs, which span the range of before-tax earning rates available for most landowners, were chosen for the economic analyses. They were 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0% in real terms, meaning that inflation has been removed from these numbers. Since NIPF landowners in Texas receive timber revenues only from pulpwood and sawtimber sales, only these two products were taken into considerations for economic evaluation. The projection of the average softwood price growth was 0.7%, and the growth rate of softwood sawtimber stumpage prices was projected to be 1.5% in the South over the 1986–2040 period (Haynes and Adams 1992). Later, Adams (2002) projected that real softwood sawtimber prices in the South would rise at a trend rate of about 0.4 % per year from 2005 to 2050, and prices of softwood pulpwood in the South would experience a strong cycle during the period but show no clear trend. Since this low-density management article is a follow-up study of the traditional management conducted in 1998, for the purpose of comparing the profitability of these two management methods, the same real price/cost increases and stumpage prices were used in both studies. The annual real rate of price increase for sawtimber and pulpwood were assumed to be 2.0% and 1.0% (Texas Forest Service 1984–1998), respectively. Labor costs were assumed to increase at a real rate of 1.1% per year (Council of Economic Advisers 1998).

Different economic assumptions were used for traditional management and low-density management. For traditional management, the price of sawtimber was assumed to be $450/mbf (Doyle) (Texas Forest Service 1997–1998), and pulpwood price was assumed to be $35/cd (Texas Forest Service 1998), the same as they were in the previous study. For low-density management, pulpwood price was assumed to be $35/cd, but two scenarios for the price of sawtimber were investigated. The first scenario assumed that the price for pruned, clear sawtimber logs would be the same as that used for traditional management, $450/mbf (Doyle). The second scenario assumed that a premium price of $550/mbf (Doyle) would be paid for pruned, clear sawtimber logs. The $100 premium was a shadow price of clear wood on the stump, calculated internally by Temple-Inland Forest Products Corp. (pers. comm., June 1992).

It was assumed that proper forest management activities would be conducted. In general, management costs are incurred for establishing, maintaining, and harvesting the stand. In this study, all the current management costs came from a survey of local forest consultants. The property tax cost was not included because it was assumed that the revenue from a hunting lease would offset the cost of property taxes. The presumed site preparation methods were herbicide and mechanical (chop) treatments. Results of this site preparation method generate mean levels of hardwood competition, as reflected in the PTAEDA2 model. Assumed management activities, frequency, and labor costs for forestlands in Texas are presented in Table 1.

Depending on stand density and wage paid, the cost to prune loblolly pine plantations to 25 ft ranged from $0.43 to $0.93 per tree in East Texas (Tate 1996). For this analysis, according to a survey of local forest consultants, the current cost of pruning to 25 ft above ground level was assumed to be $1.50 per tree. The pruning operation only occurred once during the rotation, and it was scheduled a year after the first thinning. The number of crop trees pruned was 1.2 times the number of trees cut at final harvest. Trees were not pruned under the traditional management scenario.

Given a range of site indices and real ARRs, discounted cash flow analyses were conducted to obtain net present worth (NPW) for all the operable management regimes. NPW of a project is the present value of its revenues minus the present value of its costs over one rotation. The Faustmann formula was then applied to calculate soil expectation value (SEV). SEV, which is commonly used to calculate the NPW of bare land used for growing a perpetual series of forest crops on that land, was used for comparing forestry investments of unequal rotation lengths. The management regime that had the highest

Table 1. Management activities, frequencies and labor costs for forestland using traditional management and low density management in Texas.

Activity	Cost	Frequency	Start	End
For traditional and low density management				
Boundary location	$20/ac	Once only	Year 0	
Boundary maintenance	$2/ac	Every 10 yr	Year 10	Final harvest
Management plans (initial)	$5/ac	Once only	Year 0	
Management plans (updates)	$10/ac	Every 10 yr	Year 10	Final harvest
Site preparation (chop)	$90/ac	Once only	Year 0	
Site preparation (herbicide)	$85/ac	Once only	Year 0	
Hand planting, labor	$45/ac	Once only	Year 0	
Seedlings	$30/ac	Once only	Year 0	
Burning	$40/ac	Every 5 yr	Year 10	Final harvest
Mark and administer pulpwood/ sawtimber sale (percentage of gross)	10%	As necessary		
For low density management only				
Pruning	$1.50/tree	Once only	1 yr after the first thinning	

SEV was chosen as the financially optimal thinning and final harvest schedule for each combination of site index and landowner's ARR.

The SEV formula employed in this study was:

where:

$$SEV = \left[\sum_{y=0}^{n} \left[\frac{R_y}{(1+r)^y} - \frac{C_y}{(1+r)^y} \right] \right] \left[\frac{1}{(1+r)^n - 1} + 1 \right]$$

R_y = revenue in year y

C_y = cost in year y

r = real annual interest rate

n = rotation length

y = year when revenue or cost occurs

Because this study used the Doyle log rule, and management costs and stumpage prices prevalent in Texas, the results of this study are valid only for NIPF landowners in Texas. However, with adjustments for sawtimber measurement and the use of local management costs and stumpage prices, the dynamic program can calculate financially optimal management regimes for nonindustrial and industrial forest landowners across the range of loblolly pine.

Results

A total of 1,897,164 NPWs and SEVs were calculated for all the operable traditional management regimes, and 5,131,710 NPWs and SEVs were calculated for all the operable low-density management regimes. The thinning and final harvest schedules, which maximize SEV for each combination of site index and ARR, are listed on Table 4. Their SEVs and NPWs are shown in Tables 2 and 3, respectively. All monetary values are presented on a per acre basis.

Site Index 50

When a stumpage price of $450/mbf is used for both traditional and low-density management, traditional management is always more profitable (Table 2). If a premium price of $550/mbf is paid for pruned logs, low-density management is more profitable for those landowners who have ARRs of 2.5, 5.0, and 7.5%. Even if a premium price of $550/mbf is paid for pruned logs, traditional management is more profitable for landowners who have alternative investments that yield 10.0, 12.5, or 15.0%. However, forest management only yields a positive profit on site index 50 land for landowners whose real ARR is 2.5 or 5.0% (Tables 2 and 3).

Table 2. Soil expectation value of the financially optimal thinning and final harvest schedules for loblolly pine plantations under traditional management[a] and low density management.

Site index/manage. scenario/price ($/MBF)	Real alternative rates of return (%) 2.5	5.0	7.5	10.0	12.5	15.0
	($)					
50						
Traditional						
450	1,683.14	164.31	–112.15	–202.95	–238.84	–254.79
Low density						
450	1,661.50	121.90	–139.16	–217.05	–247.61	–262.06
550	2,175.01	222.37	–104.41	–203.47	–241.58	–259.03
60						
Traditional						
450	2,939.04	551.81	77.82	–104.21	–183.72	–221.52
Low density						
450	2,854.15	505.44	41.44	–118.84	–188.45	–224.61
550	3,628.33	686.87	104.33	–90.21	–172.74	–216.00
70						
Traditional						
450	4,344.29	1,081.25	322.24	51.24	–83.10	–158.06
Low density						
450	4,234.04	1,005.02	276.61	17.75	–102.97	–167.43
550	5,313.23	1,316.00	404.29	76.78	–72.36	–149.98
80						
Traditional						
450	6,656.63	1,965.76	707.11	249.18	34.30	–84.85
Low density						
450	6,656.98	1,852.09	672.71	223.49	28.84	–80.80
550	8,278.35	2,353.02	883.46	328.79	84.81	–46.69
90						
Traditional						
450	9,406.64	2,870.04	1,168.84	532.53	215.08	35.63
Low density						
450	9,566.56	2,940.76	1,161.21	495.85	189.06	17.93
550	11,819.12	3,671.23	1,486.20	656.88	282.65	72.51

[a] Data from Huang and Kronrad, 2002.

Table 3. Net present worth of the financially optimal thinning and final harvest schedules for loblolly pine plantations under traditional management[a] and low density management.

Site index/manage. scenario/price ($/MBF)	Real alternative rates of return (%) 2.5	5.0	7.5	10.0	12.5	15.0
	($)					
50						
Traditional						
450	1,300.59	149.26	–103.23	–191.32	–216.19	–236.89
Low density						
450	1,283.87	107.65	–133.39	–204.61	–240.38	–258.10
550	1,680.66	196.39	–100.08	–191.81	–234.53	–255.12
60						
Traditional						
450	2,183.27	473.43	70.13	–97.64	–176.93	–205.95
Low density						
450	2,205.45	430.05	38.14	–112.03	–182.26	–220.13
550	2,695.30	589.30	96.03	–85.04	–167.07	–212.25
70						
Traditional						
450	2,878.51	875.43	285.43	46.51	–78.73	–153.26
Low density						
450	2,907.46	855.13	254.60	16.40	–98.68	–162.34
550	3,606.91	1,088.78	354.65	71.94	–69.35	–145.42
80						
Traditional						
450	4,296.95	1,609.39	631.98	226.18	32.27	–81.88
Low density						
450	4,858.47	1,562.04	601.23	209.40	27.13	–77.98
550	5,809.62	1,859.20	782.55	305.99	79.79	–45.06
90						
Traditional						
450	5,815.73	2,296.39	1,014.56	473.06	198.96	33.98
Low density						
450	5,914.60	2,323.60	1,028.58	450.09	179.11	17.30
550	7,307.27	2,900.76	1,316.44	596.26	267.77	70.31

[a] Data from Huang and Kronrad, 2002.

Landowners who have ARRs of 7.5, 10.0, 12.5, or 15% should not invest in forest management, either traditional management or low-density management. Their alternative investments are more profitable.

Using low-density management, the financially optimal thinning and final harvest schedules for ARRs of 2.5 and 5.0% remain the same when the price of sawtimber increases from $450 to $550/mbf (Table 4). Optimal regimes for these two ARRs will require a first thinning at age 14 (60% of basal area removed) and a second thinning at age 53 (25% of basal area removed). The final harvest will be conducted at age 59. This financially optimal schedule for an ARR of 2.5% will earn an SEV of $1,661.50/ac (Table 2) with a corresponding NPW of $1,283.87 (Table 3) when the sawtimber price is $450/mbf. If sawtimber price is $550/mbf for pruned logs, the landowner will earn an SEV of $2,175.01 per acre and an NPW of $1,680.66.

Site Index 60

When stumpage price is $450/mbf for both traditional and low-density management, traditional management is always more profitable. If a premium price of $550/mbf is paid for pruned logs, low-density management is always more profitable than traditional management. For site index 60 land, forest management is profitable only for landowners whose real ARR is 2.5, 5.0, or 7.5%.

For low-density management, the financially optimal thinning and final harvest schedules for 2.5% ARR changes when the price of sawtimber increases from $450 to $550/mbf. With a sawtimber price of $450/mbf, the first thinning is at age 47. Yet, when the sawtimber price is $550/mbf, the first thinning occurs 34 yr earlier (at age 13). The optimal thinning and harvest schedule for 7.5% ARR is the same for the two low-density management scenarios. They require thinnings at ages 18 and 27, removing 60% and 35% of the basal area, respectively. The final harvest should be conducted at age 34. These schedules will produce an SEV of $41.44/ac with an NPW of $38.14 when the sawtimber price is $450/mbf, and an SEV of $104.33/ac with an NPW of $96.03 when the price is $550/mbf.

Site Index 70

Traditional management is always more profitable than low-density management when sawtimber is worth $450/mbf. If a premium price of $550/mbf is paid for pruned logs, low-density management is always more profitable than traditional management. For site index 70 land, forest management is profitable for landowners whose real ARR is 2.5, 5.0, 7.5, or 10.0%. Forest management is not profitable for landowners who have alternative investments yielding 12.5 or 15.0%. The per acre SEV ranges from $4,234.04 (2.5% ARR) to $17.75 (10.0% ARR) when stumpage is

Table 4. The economic rotations which maximize soil expectation value for loblolly pine plantations under traditional management[a] and low density management.

Site index/manage. scenario/price ($/MBF)	Real alternative rates of return (%) 2.5	5.0	7.5	10.0	12.5	15.0
50/traditional						
450	33–**59**[b]	23–28–**48**	<19[c]–25–**34>**	<19–24–**29>**	**<19>**	**<18>**
	25%[d]	30%	35%	35%	—[e]	—
50/low density						
450	14–53–**59**	19–38–**43**	<19–38–**43>**	<18–23–**29>**	<17–23–**29>**	<17–23–**29>**
	60%, 25%[f]	60%, 30%	60%, 30%	45%, 50%	55%, 45%	55%, 45%
550	14–53–**59**	19–38–**43**	<19–38–**43>**	<18–23–**29>**	<18–23–**29>**	<17–23–**29>**
	60%, 25%	60%, 30%	60%, 30%	45%, 50%	45%, 50%	55%, 45%
60/traditional						
450	47–**54**	19–25–**39**	19–24–**31**	<17–22–**28>**	<16–21–**27>**	**<18>**
	30%	30%	30%	35%	35%	—
60/low density						
450	47–53–**59**	19–31–**38**	18–27–**34**	<17–24–**29>**	<15–23–**28>**	<15–20–**27>**
	40%, 20%	50%, 40%	60%, 35%	60%, 35%	60%, 40%	60%, 40%
550	13–40–**54**	27–32–**39**	18–27–**34**	<17–24–**29>**	<15–23–**28>**	<15–23–**28>**
	50%, 35%	50%, 25%	60%, 35%	60%, 35%	60%, 40%	60%, 40%
70/traditional						
450	25–36–**43**	16–21–**33**	13–18–**29**	13–18–**24**	<13–18–**24>**	<13–18–**24>**
	20%	30%	35%	35%	35%	35%
70/low density						
450	11–39–**46**	11–32–**38**	16–29–**34**	14–21–**26**	<14–21–**26>**	<13–19–**24>**
	60%, 25%	60%, 30%	50%, 45%	60%, 40%	60%, 40%	65%, 35%
550	11–40–**45**	11–30–**35**	11–22–**28**	13–22–**28**	<14–21–**26>**	<13–19–**24>**
	60%, 25%	55%, 20%	55%, 30%	55%, 45%	60%, 40%	65%, 35%
80/traditional						
450	14–20–35–**41**	13–18–**34**	19–25–**30**	13–18–**24**	13–18–**23**	<12–18–**23**>
	30%	30%	35%	30%	30%	35%
80/low density						
450	11–46–**52**	24–32–**37**	17–25–**30**	12–23–**28**	13–18–**23**	<13–18–**23>**
	55%, 20%	40%, 35%	45%, 50%	55%, 45%	60%, 40%	60%, 40%
550	10–41–**48**	10–20–**31**	11–22–**29**	12–22–**27**	13–18–**23**	<13–18–**23**>
	50%, 20%	55%, 20%	55%, 40%	50%, 50%	60%, 40%	60%, 40%
90/traditional						
450	13–19–28–**38**	14–22–27–**32**	11–16–22–**27**	11–16–**22**	11–16–**21**	11–16–**21**
	25%	25%	30%	30%	30%	30%
90/low density						
450	10–25–**38**	10–26–**31**	10–23–**29**	12–19–**24**	12–19–**24**	13–18–**23**
	55%, 25%	55%, 40%	50%, 45%	50%, 45%	50%, 50%	55%, 45%
550	10–25–**38**	10–26–**31**	10–23–**29**	12–19–**24**	12–19–**24**	12–19–**24**
	55%, 25%	55%, 40%	50%, 45%	50%, 45%	50%, 50%	50%, 50%

[a] Data from Huang and Kronrad 2002.
[b] Bold type indicates the age of final harvest, and the number(s) to the left indicates age(s) at thinning(s).
[c] Brackets indicates a negative SEV. Schedule shown minimizes losses.
[d] Percentage number for traditional management indicates the percentage of basal area removed during thinnings. The same thinning intensity was used for all thinnings for a specific solution.
[e] "—" indicates that no thinnings were required for this specific optimal solution.
[f] Percentage numbers for low density management indicate the percentage of basal area removed during the first and second thinning, respectively.

valued at $450/mbf; and from $5,313.23 (2.5%) to $76.78 (10.0%) when stumpage is valued at $550/mbf. The final harvest ages for the optimal schedules are in the range of 24 to 43 for traditional management, and 24 to 46 for low-density management.

Site Index 80

Traditional management is more profitable than low-density management when sawtimber is valued at $450/mbf for landowners whose ARR is 5.0, 7.5, 10.0, or 12.5%. If a premium price of $550/mbf is paid for pruned logs, low-density management is more profitable than traditional management. For site index 80 land, forest management is profitable for landowners whose real ARR is 2.5, 5.0, 7.5, 10.0 or 12.5 %. Forest management is not profitable for landowners who have alternative investments yielding 15.0%.

When ARR is equal to 12.5%, the timing of thinnings and final harvest for the financially optimal schedules is the same for both traditional and low-density management. However, for traditional management, 30% of the basal area is removed at each thinning. For low-density management, 60% percent of the basal area should be removed at the first thinning and 40% during the second thinning. As shown in Table 4, as alternative rate of return increases, the rotation length decreases.

Site Index 90

Traditional management is more profitable than low-density management for landowners whose ARR is 7.5, 10.0, 12.5, or 15%, given a sawtimber price of $450/mbf. Low-density management is more profitable for landowners who have ARRs of 2.5 or 5.0%. If $550/mbf is paid for pruned logs, low-density management is always more profitable than traditional management. On site index 90 land, forest management is profitable for landowners whose real ARR is 2.5, 5.0, 7.5, 10.0, 12.5, or 15%.

Regardless of the price paid for sawtimber, all financially optimal management regimes for low-density management are identical except for those landowners who have an ARR of 15.0%. When ARR is 15.0% and stumpage price is $450/mbf, the optimal schedule requires thinnings at ages 13 and 18 followed by a final harvest at age 23. If stumpage sells for $550/mbf, the optimal regime requires thinnings at ages 12 and 19 and a final harvest at age 24.

Discussion

Forest business is a long-term investment. Efficient forest management decision-making depends on evaluating the influence of silvicultural alternatives on stand development and financial revenues. Productivity of low-density managed forests is only maximized when optimal stand density and pruning levels are maintained throughout the entire rotation (Leduc and Zeide 1987). Increasing the accuracy of predicting optimal thinning and final harvest schedules will benefit NIPF landowners who want to maximize financial returns. However, variations in tree age, spacing, vigor, site quality, and economic goals of forest landowners, who have different alternative rates of return, make blanket recommendations for thinning practices difficult (Goeble et al. 1974).

Results of this study show that when the price of sawtimber is $450/mbf for both traditional and low-density management, low-density management is only more profitable in three ARR-site index combinations. The first ARR-site index combination is ARR equal to 2.5% and site index 80. The maximum SEV earned from low-density management is only $0.35/ac higher than that earned from traditional management (Table 2). The second and third combinations occur when ARR is equal to 2.5 and 5.0% and site index is 90. The SEVs from low-density management are $159.92 and $70.72/ac higher than those from traditional management, respectively. This shows that, compared to traditional management, low-density management becomes more profitable at the higher site indices and low ARRs. The reason for this trend is because the scenario of low-density management performs heavy thinning (40 to 70% of basal area removed) during the first thinning. This permits thinning to occur at an earlier age by meeting the minimum volume threshold constraint set in the program. When site quality is high, and interest rate is low, the higher amount of product removed at earlier ages will generate more revenue. As a result, the cost of pruning is offset and low-density management appears to be more profitable.

Results indicate that pruning combined with low-density management will not be profitable for most landowners—unless the value of clear wood is increased by a premium that is high enough to offset the cost of pruning and the wasted growing space due to heavy thinnings. If a premium price is paid for pruned wood, low-density management appears to be more profitable than traditional management in most cases. As site productivity increases, the net revenue earned with premium sawtimber prices increases as well. Compared to traditional management, a $100/mbf increase in sawtimber price, for landowners with an ARR of 2.5%, can result in an increase in SEV of $491.87, $689.29, $968.94, $1,621.72, and $2,412.48 on site indices 50, 60, 70, 80, and 90 land, respectively (Table 2). If the pruned timber is truly of higher value and more expensive to produce, the principles of supply and demand would dictate a premium price as assumed in this study. Yet, a premium price is not paid for pruned logs in Texas at the present time. It is difficult for a buyer to determine if a tree was artificially pruned once it heals over, and buyers are unwilling to pay for "the promise" of clear wood. The buyer's uncertainty as to whether a tree has been pruned hinders the establishment of a market for pruned trees. This market failure may be corrected by setting up a certification system in which certified foresters document and notarize pruned logs, and keep records until the timber is sold. This will allow landowners to receive higher stumpage prices for pruned trees and increase their financial returns.

The major differences in the financially optimal thinning and harvesting schedules between traditional and low-density management are the number of thinnings and thinning intensity. The financially optimal schedules for low-density management with two price scenarios—$450 and $550/mbf—appear to be similar in terms of the timing of the first and second thinning, thinning intensity, and rotation length. There is no obvious pattern to the changes in timing and intensity of thinning when the sawtimber price is increased by $100.

As stated earlier, this low-density management article is a comparison study of the previous traditional management research conducted in 1998. In order to determine the effects of thinning intensity and cost of pruning on landowners' profitability and financially optimal rotations, some economic assumptions were held constant and may be argumentative due to the current depressed timber prices. First, real sawtimber and pulpwood price growth rates for loblolly pine in East Texas were assumed to be positive. Future studies will investigate the assumptions of real stumpage price remaining flat or declining. Second, the stumpage prices of sawtimber and pulpwood in 1997–1998 were used in both studies. These prices may seem high compared with the current stumpage prices. Therefore, further investigation of the impacts of fluctuating stumpage prices and management costs on financially optimal management regimes are recommended.

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