Economic Comparisons Between an Even-Aged and an Uneven-Aged Loblolly Pine Silvicultural System

06/17/97

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Thesis submitted to the Faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
in
Forestry

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June 7, 1997

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(ABSTRACT)

This study compares financially optimal uneven-aged and even-aged silvicultural regimes of loblolly pine (*Pinus Taeda*). Uneven-aged regimes which maximize net present value (NPV) are found by quantifying the effects of diameter distribution (Q factor), maximum diameter, cutting cycle, and residual basal area on NPV. For the benchmark inputs, the regime yielding the highest NPV had a maximum diameter of 12 inches, residual basal area of 45 ft^2/acre, and a cutting cycle of 11 years. Financially optimal even-aged regimes are taken from published literature of even-aged silviculture. Even-aged and uneven-aged silvicultural regimes are simulated starting from, 1) bare land, 2) a balanced uneven-aged loblolly pine stand, and 3) a mature even-aged loblolly pine stand. For the three starting conditions and selected benchmark variable values, simulation of even-aged silviculture yields NPVs of $877, $2,152 and $3,400 per acre and simulation of uneven-aged silviculture yields NPVs of $644, $2,084, and $2,569 per acre. Sensitivity analysis shows, for the levels of the variables tested, that even-aged silviculture yields higher NPVs than uneven-aged silviculture when starting from bare land or from a mature even-aged stand. When starting from an uneven-aged stand, for the variable values tested, uneven and even-aged silviculture are financially very competitive.

Aside from the aesthetic benefits of avoiding clearcutting under uneven-aged silviculture, non-timber considerations between loblolly pine silvicultural systems are not well documented. Resource professionals hold opinions often in direct conflict with each other regarding the non-timber costs and benefits of even-aged and uneven-aged silviculture when considering wildlife, soil and water, and catastrophic damage events.

ACKNOWLEDGMENTS

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Chapter 1. - Introduction

The South has over 49 million acres in the loblolly-shortleaf pine type (USFS 1993). These acres supply a major wood processing industry, are habitat for wildlife, provide recreational sites, have aesthetic qualities, and supply other benefits to individuals and society.

Loblolly pine can be managed with either even-aged or uneven-aged silvicultural systems. Even-aged stands are characterized by relatively bell shaped diameter distributions and rotations ending with even-aged regeneration methods. A variety of intermediate stand treatments can be undertaken depending on landowner objectives. Uneven-aged stands contain at least 3 age classes intermingled intimately on the same acre. Age classes in balanced uneven-aged stands occupy an approximate equal area and may function as self-contained, sustained yield units (Smith 1986). Stands maintain similar structural characteristics into perpetuity. Regular regeneration harvests provide wood products and income while maintaining and enhancing stand health and vigor.

These different silvicultural systems supply goods desired by forest landowners in different amounts at different times. The difficulty of measurement, the long time horizon, and the nature of the outputs make understanding the complex financial and environmental differences between systems difficult. Lately, even-aged systems and especially the practice of clearcutting, have come under increased scrutiny from environmental groups and the public. Recent referendums in Maine and Oregon attempted to ban clearcutting on all lands, private and public. Even without laws and regulations, many National Forests are seeking alternatives to clearcutting due to public pressure. Uneven-aged silviculture provides wood products without clearcutting. However, only limited information is available on economic comparisons between even-aged and uneven-aged loblolly pine silviculture, and on how sensitive uneven-aged silviculture optima are to selected variables.

The argument about which system is better has been a recurring theme in forestry. Different studies show different yields of value and volume, leading to differing conclusions. Differences exist in valuation techniques which further complicate comparisons.

For this study, the primary goal is maximization of Net Present Value (NPV), an approach which assures efficient use of capital (Samuelson 1976). Simulated uneven-aged regimes which maximize NPV are compared to simulated even-aged regimes which maximize NPV. Quantity of sawtimber and total volume produced are compared for the NPV-maximizing regimes. Non-timber outputs and differences in silvicultural systems which do not have quantifiable effects on NPV are outlined. The NPV comparison is valid for managers whose primary goal is NPV. For managers with other goals, differences in NPV can help value tradeoffs in the decision making process.

Before making comparisons between silvicultural systems, each silvicultural system is optimized for NPV. Uneven-aged regimes considered use natural regeneration. Even-aged silvicultural systems considered use artificial regeneration. These systems have available growth and yield data and are widely considered to yield the highest financial returns. Uneven-aged systems could incorporate artificial regeneration, but there is no data about how this would effect

yields and log quality. Even-aged systems can use natural regeneration, however these are not included in the direct comparison because previous studies rank artificial regeneration higher financially, and because even-aged systems with natural regeneration require seed tree harvests or shelterwood harvests as the reproductive harvest, both of which have most or all of the negative connotations that clearcutting does.

Recent growth and yield work makes it possible to add to the published body of work surrounding economic optimization of uneven-aged silviculture for pine management. We make preliminary estimates about the effect of differing diameter distribution functions (Q factor) on NPV, quantify the effects of maximum diameter on NPV, and show the sensitivity of NPV to the management variables cutting cycle, maximum diameter, and residual basal area, all previously impossible or not reported in published studies. Also, the new growth and yield data allows analysis of the effects of diameter classes on NPV. The effects of differences in prices by diameter class and harvesting costs by diameter class and volume removed are examined, both not reported in previous studies. The effects of different variables on optimum uneven-aged silvicultural regimes are examined through sensitivity analysis. Optimum even-aged silvicultural regimes are gathered from published optimization studies.

After simulating optimum uneven-aged and even-aged silvicultural regimes, comparisons between the uneven-aged silvicultural regime which maximizes NPV and the even-aged silvicultural regime which maximizes NPV are made. Starting inventories are bare land, an uneven-aged stand, and a mature even-aged stand. Previous studies have compared silvicultural regimes which do not maximize NPV, such as regimes used on research plots and or regimes popular in local areas, and have started from understocked or uneven-aged stands. Sensitivity analysis compares silvicultural systems which maximize NPV when selected variables change across normal ranges.

Objectives

The overall objective is to economically compare even-aged and uneven-aged loblolly pine silviculture and to apply this to a variety of stand conditions. Sub-objectives are as follows.

1.   Develop a theoretically appropriate means for financially comparing even-aged and uneven-aged silviculture.

2.   Prepare simulations showing how the above guidelines can be applied in choosing between uneven-aged and even-aged silviculture for management of loblolly pine.

3.   Summarize current knowledge of non-timber factors affected by different silvicultural methods.

Chapter 2 - Literature Review

Definitions

Balanced uneven-aged stand   A stand where the diameter distribution closely follows a negative exponential probability density function (reverse-J). The ratio of numbers of trees in succeeding dbh. classes (N) is a constant (called Q); $N_i/N_{i+1} = Q$. Where i usually indexes dbh classes by one or two inch increments. Here all Q factors will be based on one-inch diameter increments.

BDQ   "basal area-maximum dbh. - Q." An uneven-aged forest description technique. A unique stock table can be generated for any stand for which these three factors are known.

BDQ regulation   Regulation technique where stand structure is maintained between desired basal area levels, while keeping the Q ratio and maximum diameter constant. This system provides objective control of understory density to ensure a continuous supply of harvestable trees.

Benefit/cost ratio The discounted value of all returns anticipated from a management system divided by the discounted value of all anticipated costs.

Cost efficiency The physical output or yield expected from a terminating management system divided by the discounted value of all costs associated with the system.

Cutting cycle Number of years between equally spaced selection harvests in an uneven-aged stand, or the rotation age in an even-aged stand.

Equivalent annual annuity (EAA) An equal annual real income with the same present value, over a project's life, as the project's net present value, all computed at the same real discount rate.

Guiding dbh limit Uneven-aged forest regulation technique where trees are harvested largest first, with substitution of deformed or less vigorous trees for larger, more vigorous neighbors. Silvicultural experience is necessary to maintain growth in younger diameter classes so that harvests can be periodically repeated.

Managed forest value (MFV) Present value of a stand in its steady state when perpetual revenues are assumed to occur.
Maximum diameter   The largest size class in a balanced uneven-aged stand. Each harvest in an uneven-aged stand removes all trees greater than the target maximum diameter.

Net present value (NPV) Present value of future revenues minus present value of future costs.

Q factor See balanced uneven-aged stand.

Regulated forest One where age and/or size classes are represented and growing such that nearly equal periodic yields of desired products can be obtained in perpetuity. It may be composed of even-aged stands, uneven-aged stands or both.

Residual basal area Basal area remaining in a stand immediately after a harvest.

Soil expectation value (SEV) Present net worth of bare forestland for timber production calculated over a perpetual series rotations.

SRAT Sawtimber basal area to merchantable basal area ratio. Sawtimber defined as trees with greater than 9.5 inch dbh.

Uneven-aged stand   A stand that contains 3 or more distinct age (size) classes. In practice an uneven-aged stand exhibits a dbh. distribution that tends towards a "reverse-J" in shape rather than the mound-shaped curve typical of an even-aged stand.

Uneven-aged Silviculture

Baker *et al.* (1996) comprehensively outlines the silviculture of uneven-aged loblolly pine. Sections pertinent to this research study are briefly outlined here.

Uneven-aged silviculture of loblolly pine mimics later stages of forest succession, primarily the understory re-initiation phase and the old-growth phase. During these stages, single and small groups of overstory trees are lost to mortality. Understory trees and regeneration grow into the gaps. In management using uneven-aged silviculture, harvesting provides the overstory mortality. Growth is concentrated on desirable regeneration through partial harvests and manual control of understory vegetation.

Stocking is a critical part of maintaining stand characteristics that mimic these stages. Baker et al. (1996) report that the lower acceptable stocking limit for uneven-aged loblolly-shortleaf pine stands on sites >85 feet at 50 years to be 45 ft^2/acre of basal area and the upper limit to be 75 ft^2/acre of basal area. Growth loss due to under-utilization of site occurs below the lower limit of acceptable stocking, and merchantable trees adversely affect the development of reproduction above the upper level of acceptable stocking.

Reproduction. Loblolly pine has been found to regenerate well in openings created by removing a single tree from the overstory, such as are made in single-tree selection regeneration harvests of uneven-aged stands. (Wahlenberg 1948, Grano 1954). In uneven-aged silviculture, Baker et al. (1996) report that if stands are maintained at acceptable stocking levels, and if cyclic cuts are made, and if competition is periodically controlled, then pine seedlings should become established and develop.

Murphy and Shelton (1994) report that without species control in the understory, uneven-aged silviculture will cause a shift to more tolerant species. Competition control promotes

seedling establishment and development (Cain 1992) and aids in intermediate development and survival of pine saplings. (Cain 1993)

Applications. Few areas in the South practice uneven-aged silviculture. Pioneering work began at the Crossett Experimental Forest in 1937 when Russ Reynolds established the "Poor" and "Good" farm forestry forties. Results of this study show that loblolly pine can be managed with uneven-aged silviculture to provide improved stocking and periodic incomes. (Reynolds 1969, Reynolds et al. 1984, Baker 1986). Also on the Crossett Experimental Forest, the "methods of cutting study" showed that cutting cycles of 3, 6 and 9 years could each provide periodic harvests from uneven-aged stands. (Reynolds 1969).

Uneven-aged silviculture of loblolly pine has been practiced at other places across the South. Two forty acre tracts in east central Mississippi were managed under this silvicultural system from the 1950s to 1980. Yearly harvests were conducted on one site and 5 year cuts were made on the other. Growth averaged 230 to 300 bd. feet Doyle per year. In Hope, Arkansas, a 27.5 acre stand of loblolly-shortleaf pine, on site 80 (loblolly pine site base age 50), was managed for 33 years under single tree selection. Again, results show that this system works to improve stocking and provide periodic income. (Farrar et al. 1984.) On the Hitichi experimental forest in Georgia, 548 acres were managed with uneven-aged silviculture using an 8 year cutting cycle. Sites index varied from 73 to 77 (loblolly pine site, base age 50). The study was only maintained for about 20 years. This study provided preliminary insight into the feasibility of uneven-aged silviculture in Georgia, but was not maintained long enough to tell if uneven-aged silviculture fits the Georgia Piedmont (Brender 1973).

Uneven-aged Forest Regulation

There are two recognized methods of regulating uneven-aged forests: the guiding dbh. limit and the BDQ method. (Farrar 1981, Baker et al. 1996)

Guiding dbh limit. To regulate a forest based on the guiding dbh. limit method, the landowner must know the desired forest condition at the end of the cutting cycle and the stand growth capability. Subtracting this growth from the target volume yields the residual stocking level to which the stand is cut. Trees are harvested largest first, except that deformed or less vigorous trees are taken before larger neighbors. Silvicultural experience is necessary to maintain growth in younger diameter classes so this cycle can be perpetuated.

The example given by Farrar (1981), is that of a stand with a desired end-of-cutting-cycle volume of 7 mbf with an annual stand growth potential of 6 percent. Reducing the 7 mbf by a factor of $(1/1.06)^5$ for a 5 year cutting cycle yields an after harvest level of 5.231 mbf. The current volume less the desired residual volume is the volume to be removed (7.000 - 5.231 = 1.769). The volume cut comes from the largest diameter classes. The sub-sawtimber sizes are thinned as necessary for silvicultural need. If this cut is to be repeated every 5 years, the residual stand must grow back to 7 mbf by the end of the cutting cycle.

BDQ Regulation. For BDQ regulation, the stand growth capability, cutting cycle, desired residual basal area, maximum diameter, and Q factor must be known. Trees are harvested to the residual basal area while maintaining the Q factor and the maximum diameter class. The number of trees to leave in each diameter class can be calculated using the maximum diameter, Q factor, and residual basal area. During the cutting cycle, trees will grow up through the diameter classes to provide a sustainable harvest level. This method of regulation provides objective control of the entire diameter distribution, ensuring enough regeneration is left to provide future harvests.

As an example, consider a hypothetical balanced uneven-aged stand that can grow 4 ft^2 of basal area per year. If the desired management regime has a cutting cycle of 5 years, residual basal area of 55 ft^2/acre, maximum diameter of 16 in., and Q factor of 1.2 (1" dbh classes), then the stand should be harvested when the basal area reaches 75 ft^2/acre. The harvest should remove trees so that the 55 ft^2 of residual growing stock follows the 1.2 Q factor and the 16 in. residual maximum tree diameter. The stand can then achieve the 75 ft^2/acre by the end of the cutting cycle. This harvest cycle, as shown in Table 2-1, should be sustainable.

Prior to 1980, uneven-aged southern pine stands were regulated by the guiding dbh limit technique. Q factor was not regulated in these stands, however stand records show that Q factors were around 1.2 (1 inch diameter classes) in Arkansas (Farrar 1981) and 1.14 in Georgia (Brender 1973). In 1980 a study was installed to investigate how stands developed under different Q factors, residual basal areas, and maximum diameters. The initial 5 year results found that exact Q factors could only be approached through time as deficits in one diameter class had to be made up from surpluses in lower diameter classes.

TABLE 2-1. Calculation of Selection Harvest Cutting Volumes Under BDQ Regulation.

Q factor 1.2, Beginning inventory 75 ft^2 basal area. Harvest 20 ft^2 Basal Area. Maximum Diameter = 16 inches. Cutting Cycle 5 Years

DBH Class	Beginning TPA	Basal area ft^2/acre	Residual TPA	Basal area ft^2/acre	Harvest TPA	Basal area ft^2/acre
4	32	2.8	26.7	2.3	5	0.5
5	27	3.6	22.3	3.0	5	0.6
6	22	4.4	18.5	3.6	4	0.7
7	19	5.0	15.5	4.1	3	0.8
8	15	5.4	12.9	4.5	3	0.9
9	13	5.7	10.7	4.7	2	1.0
10	11	5.9	8.9	4.9	2	1.0
11	9	5.9	7.5	4.9	2	1.0
12	7	5.9	6.2	4.9	1	1.0
13	6	5.7	5.2	4.8	1	1.0
14	5	5.5	4.3	4.6	1	.9
15	5	6.4	3.6	4.4	2	2.0
16	4	6.0	3.0	4.2	1	1.9
17	4	6.6	0	0	4	6.6
Totals	193.7	75.0*	145.2	55.0	35.3	20.0

*A volume-defining function can translate basal area into volume.

The BDQ regulation suggests one Q value across the diameter distribution. Guides in other forest types suggest more than one possible residual structure based on different single Q values (Nyland 1996). Growth and yield modeling and experience in Q values in southern pines is not developed enough to refine Q beyond a single Q value for the entire diameter distribution. Installed growth plots will eventually indicate if deficiencies or excess numbers of trees develop under BDQ regulation.

Growth and Yield Modeling

Uneven-aged Stand Growth and Yield. Most uneven-aged pine growth and yield work is derived from measurements taken in Southern Arkansas and Northern Louisiana. Uneven-aged research in southern pines has been conducted on the Crossett Experimental Forest since 1936.

From these early plots and others, Murphy and Farrar (1982) developed tables to predict stand basal area and cubic foot volume growth for uneven-aged loblolly/shortleaf pine stands. Using the same data set and variables, Murphy and Farrar (1983) developed equations to predict sawtimber volume from initial basal area, initial basal area in sawtimber, and elapsed time. Q factors were not measured, but stands should exhibit J-shaped diameter distributions and be relatively free of hardwood competition. These models predict yields, but do not address the ending structure of the forest or what effects elapsed time and basal area growth might have on understory or future yields. It is up to the land manager to leave a stand structure capable of providing desired future harvests.

Murphy and Shelton (1994, 1996) published regression equations modeling balanced uneven-aged loblolly pine forest growth for stands with a target Q factor of 1.2. These are the initial 5 year growth results of a study established in 1983-85 to examine the effects of residual basal area, site index, and maximum diameter on yields.

Buongiorno and Schulte (1997) developed Southpro, a site- and density-dependent, multi-species matrix model for predicting the development of loblolly pine forests in the Mid-South (Buongiorno *et al* 1997). U.S. Forest Service Forest Inventory and Analysis data were used to build the model. For inclusion, plots had to be classified as within the loblolly pine forest type, be measured at least twice, be classified as "mixed age," and be natural stands. Re-measurement period was between 6 and 11 years and averaged 7.3 years. This growth and yield model allows modeling of irregular diameter distributions, price/diameter relationships, adjustments in harvesting costs for diameter class distributions, and models a range of site classes.

Even-aged Growth and Yield. Examples of even-aged pine growth and yield models include Coyield (Amateis et al. 1984), Ptaeda2 (Burkhart et al. 1987), Pcwthin2 (Weih et al. 1990), Trulob (Zhang et al. 1995), and Tauyield (Amateis, et al. 1996). Tauyield (Amateis et al. 1996) is a stand level growth and yield model for thinned and unthinned loblolly pine plantations which covers the necessary geographical range and allows different thinning regimes. This growth and yield model will be used to estimate yields from even-aged simulations and to help estimate yields from conversion from even-aged to uneven-aged stands. None of the even-aged growth models simulate ingrowth or regeneration beneath an overstory.

Production and Financial Comparisons Between Silvicultural Systems

Past comparisons between silvicultural systems concentrate on financial and volume differences. Benefit/cost ratio, NPV, cost efficiency, volume production and sawtimber production are all used as evaluation criteria. Different findings are the result of different starting inventories, different treatment of inventory value, different assumptions and different silvicultural regimes. None of the studies compare NPV between uneven-aged and even-aged silvicultural regimes optimized for NPV.

Baker (1986) made production and financial comparisons of 2 even-aged and 2 uneven-aged systems. Beginning with 36 ft^2 of basal area, these systems were simulated for 50 years.

For one of the even-aged systems, the initial stand inventory was clearcut at year 0, planted, thinned periodically, and clearcut at year 50. For the other even-aged stand, a similar regime was followed, except that it was naturally regenerated. These were based on case studies where the exact silvicultural practices had been carried out and volumes recorded. For the uneven-aged systems, the initial stand inventory was developed into two different stocking levels. One with high residual volume, and the other with low residual volume. The stands were thinned every 5 years. The highly stocked stand was based on an uneven-aged stand on the Crossett Experimental Forest. The stand with low stocking was simulated. Stand volumes, NPV, benefit/cost ratio, and cost efficiency were evaluated. The best of the even-aged stands evaluated had a 34 percent higher NPV than the best of the evaluated uneven-aged stands. Stumpage prices, which include harvesting costs, did not vary between systems in this study. Also, none of these silvicultural systems were optimized for volume or value.

Guldin and Guldin (1990) compare 8 long term research studies. Yields from each were conservatively extrapolated to 36 years if measurements had not been taken at that age. Silvicultural systems were evaluated with NPV, benefit/cost ratio, and cost efficiency. NPV comparison results hinged on whether or not the initial stumpage value was subtracted as a cost. Even-aged natural stands generally exceeded the uneven-aged and the plantation management in benefit/cost ratio and cost efficiency. The systems evaluated were established for research purposes, not to optimize volume or value.

Redmond and Greenhalg (1990) used NPV to compare a 50 year even-aged rotation with an uneven-aged system, both on a perpetual basis. Beginning inventories were varying levels of severely understocked stands resulting from diameter-limit cuts. The beginning inventory has no liquidation value, and the even-aged scenario incurs a cost for clearing the land before an even-aged regime can be started. A 34 year development period is necessary to sculpt a balanced uneven-aged forest. They evaluate uneven-aged systems with 5 and 7 year cutting cycles, three different maximum diameters, and 2 different residual basal areas (60 ft^2 for 5 year cutting cycle and 54 ft^2 for the 7 year cutting cycle). Higher logging costs for the uneven-aged system are assumed to be offset by a premium for sawtimber logs grown under this system. They determined management utilizing uneven-aged silviculture to be economically preferable for certain levels of understocking, especially with a discount rate above 7.25 percent. None of the systems were optimized; however, the uneven-aged regimes evaluated are close to the optimum regime recommended by Hotvedt, Abernethy, and Farrar (1989).

Chang (1990) determines that the management objective for both systems is to maximize the net present value of an infinite series of harvests. Independent of initial inventory, Chang finds that management utilizing uneven-aged silviculture can be more profitable than even-aged silviculture when stumpage prices are low, interest rates are high (5 - 8 percent), and the fixed costs for uneven-aged silviculture are low. However, Chang may be ignoring the possible problems in comparing stands with different starting inventories.

Strub et al. (1994) compared data from the uneven-aged silviculture practiced at Hope, Arkansas (Farrar et al. 1984) with 2 even-aged silvicultural regimes. Economic comparisons found both even-aged regimes yielded higher NPV than the uneven-aged silvicultural regime

practiced at Hope. The uneven-aged stand was harvested every three years, maintaining basal areas between 65 ft^2/acre and 85 ft^2/acre. The even-aged regimes were thinned every three years and clearcut at age 32. The even-aged regimes produced more total ft^3 volume and more sawtimber volume than the uneven-aged stand. None of the silvicultural regimes were optimized for NPV or volume production.

The comparative work between silvicultural systems indicates that under certain conditions uneven-aged silviculture may yield higher net present values than even-aged silviculture. None of these analyses compare systems that are practiced to maximize NPV. These comparisons focus on understocked stands, and do not start with well-stocked even-aged stands or bare land. Finally, the difference in harvesting costs, reflected in stumpage prices, is not addressed in the published comparisons.

Harvesting Cost Comparisons Between Silvicultural Systems

Harvesting costs are often pointed to as a major difference influencing NPV of silvicultural systems. Kluender and Stokes (1997), evaluated harvests from 16 stands which were harvested by clearcut, shelterwood, group selection, or single-tree selection methods. Three of these stands had uneven-aged structure, the other single-tree selection regeneration harvests were the first harvests of mature even-aged stands being converted to uneven-aged stands. For both felling and skidding productivity, the average stem size of the harvested trees was more important than harvesting intensity. The authors estimate cost to harvest and deliver cubic meters of wood by harvest intensity and DBH of removed stems. From 25 percent to 100 percent of the basal area harvested, the difference in harvesting costs did not vary more than 13 percent. For most stand conditions, harvesting only a portion of the stand increased costs only 4 or 5 percent. Cost per m^3 to clearcut a stand with average dbh of 12" was 20 percent higher than to clearcut a an 18" stand. The percent of land trafficked in the single-tree selection stands was less than in the even-aged stands. The first thinnings of even-aged stands being converted to uneven-aged stands may or may not reflect the harvesting cost differences which would be incurred in single-tree selection regeneration harvests of uneven-aged stands.

Greene and Wang (1994) studied timber sale size and the economics of logging systems to find the impact of sale conditions on logging costs. Potential production rates of machinery were reduced between 20 and 35 percent in partial harvests. Results were divided into clearcut costs and partial harvest costs. Total tract tonnage, harvested tons per acre, and mean stand DBH were found to influence per ton logging costs. They develop models to estimate per ton logging cost by harvest system, harvest type, and stand harvest conditions. Partial cuts were found to increase costs between 30 and 40 percent.

Greene and Wang (1996) used computer simulation to compare productivity of feller-bunchers in light thinnings, heavy thinnings, and clearcuts of even-aged stands. In this model, a machine image on a computer screen is maneuvered in a simulated harvest activity. Simulating different thinning conditions showed that light thinning was 85 percent as productive as clearcutting and heavy thinning was 93 percent as productive.

Shaffer et al. (1993) compared three logging systems in group selection timber sales in Appalachian hardwood timber stands. Compared to clearcutting, productivity in group selection decreased 15 percent and 21 percent for the feller-buncher operation and the cable skidder operation.

None of these studies quantify differences in harvesting costs between selection harvesting of uneven-aged stands and clearcutting. Efficiency in even-aged thinnings, such as in the study by Greene and Wang (1996), depend on loggers selecting which trees to remove or leave. Much of this efficiency would be lost in harvesting marked stands of uneven-aged trees. Also, machinery which optimizes the harvesting process might differ with harvesting system. In the study by Kluender and Stokes (1997) all harvests used manual tree felling. This may reduce productivity, not only of the felling operation but also of the bunch building and skidding processes, especially in even-aged stands.

Optimization of Uneven-aged Silviculture

Optimal management using uneven-aged silviculture involves selecting management variables to maximize objectives. When implementing uneven-aged silviculture, stands are optimized by choosing the cutting cycle, residual basal area, maximum diameter, and Q factor to maximize objectives.

Adams and Ek, (1974), formulated problems using mathematical programming to find the optimal diameter distribution to maximize value growth for a given stocking level. They then vary the stocking level to find the combination of diameter distribution and stocking level that maximizes value growth. Cutting cycle could also be varied to find the optimal level of all three variables. Examples are presented from a model developed for northern hardwood stands in Wisconsin.

Buongiorno and Michie (1980) use a fixed-coefficient matrix growth simulator to model stand growth. Linear programming can then be used to solve for the stocking level and diameter distribution that maximize a production objective, such as maximum sustained yield or NPV. The cutting cycle can be varied to find optimum level of cutting cycle, stocking level, and diameter distribution. Examples are provided from work done with the same northern hardwood data used by Adams and Ek, (1974).

Chang (1981) shows how comparative static analysis can be used to find the optimal cutting cycle and stocking level, provided growth as a function of residual basal area and time are known.

Hotvedt, Abernethy, and Farrar (1989), present economically and biologically optimum sets of silvicultural regimes for uneven-aged loblolly-shortleaf pine stands. They analyzed residual basal areas between 45 and 65 ft^2 by 5 ft^2 increments, cutting cycles between 4 and 10 years, and

initial sawtimber to basal area ratios (SRAT) between .55 and .85. Combinations which yielded basal areas greater than 80 ft^2 were considered biologically in-feasible. Regimes which yielded harvests less than 1.0 mbf/acre Doyle scale or 4 cords/acre pulpwood were considered in-feasible for economic reasons. The top 5 NPV-maximizing regimes had cutting cycles of 4 or 5 years, residual basal areas between 45 and 65 ft^2/acre and SRATs of .55. As interest rates increased it was generally true that residual basal area and SRAT generally decreased. Under higher and lower price scenarios, the optimum regime was generally the same. Under the assumption that longer cutting cycles yield higher harvest volumes and larger tree sizes, cutting cycles of 8 - 10 years were analyzed with 25 $/mbf higher sawtimber prices than the base scenario. These regimes had higher NPVs than the shorter cutting cycles without the 25 $/mbf premium. This analysis appears to show that differences in logging costs due to volume removed have the potential to lengthen the cutting cycle typically recommended for uneven-aged silviculture. This study does not directly address Q factor or maximum diameter or vary harvesting costs by volume removed.

Hotvedt and Ward (1990) present a general dynamic programming model which optimizes decisions in uneven-aged loblolly pine silviculture. This model addresses the conversion from an existing stand to a balanced uneven-aged stand and the steady state uneven-aged condition. In this model, harvest levels must be above a user set minimum volume/acre, prices are constant for all volumes harvested, and the cutting cycle appears to be constrained to multiples of 5 years. Hotvedt and Ward found that the steady state regime which maximizes NPV depended on the forest's starting condition, but generally the silvicultural optimum residual basal area was 50 or 55 ft^2, SRAT was .50 or .55, and cutting cycle was 5 years. This study also does not directly address Q factor or maximum diameter.

Optimization of Stand Conversions

Some of the optimization and comparison articles address the conversion from beginning inventories to balanced uneven-aged stands. Adams and Ek (1974) use mathematical programming to determine the conversion cutting schedule. This is a formulation of the current inventory as a vector, the optimum inventory as a vector, and computing the optimum trajectory to get from one vector to the other. Goals can include maximizing NPV or stand volume or minimizing time to form a balanced uneven-aged stand.

Hotvedt and Ward (1990) assert that the major decisions of converting to uneven-aged silviculture are harvest timing and regeneration considerations. They use dynamic programming to find the optimal conversions from understocked and overstocked stands to a balanced uneven-aged stand. The understocked stand took 30 years and 3 harvests to reach a balanced condition. The overstocked stand took 92 years to bring to a balanced condition.

Redmond and Greenhalg (1990) model the conversion of various levels of severely understocked stands resulting from diameter limit cuts. They use the growth and yield estimates for uneven-aged loblolly-shortleaf pine from Farrar et al. (1984), and from Murphy and Farrar (1982, 1983). Simulated stands in this understocked condition took between 10 and 34 years to

get the first harvest of the conversion period, and a few more years after this to develop balanced uneven-aged stands.

Optimization of Even-aged Silviculture

Literature generally agrees that, for a wide range of economic conditions, and assuming sawlog production, NPV-maximizing rotations should include one thinning and final harvest around age 30. For pulpwood production, thinning generally offers no economic benefit. (Broderick et al. (1982), Flick et al. 1980, Hotvedt and Straka 1987, Klemperer et al. 1987, Roise et al. 1988, Haight 1992). Optima for given sites were fairly insensitive to a reasonable range of input assumptions. More detailed analysis of individual studies is in Chapter 5.

Chapter 3 - Methods

The basic analytical approach has 5 steps:

1).   Identify management objective as net present value (NPV) maximization;

2).   Simulate the even-aged and uneven-aged silvicultural regimes which maximize NPV;

3).   Calculate the NPV from each silvicultural system using the optimal silvicultural regimes;

4).   Compare NPVs between silvicultural systems;

5).   Identify all non-timber differences between systems.

Silvicultural Regimes that Maximize NPV.

Uneven-aged Silvicultural Regimes that Maximize NPV. Uneven-aged systems can have different cutting cycles, different residual basal areas and different maximum diameters. We test residual basal areas between 40 and 70 ft^2/acre , cutting cycles between 3 and 11 years, and maximum diameters between 12 and 20 inches. The biologic basal area limits, between which uneven-aged loblolly pine silviculture can be maintained, are around 40 and 80 ft^2/acre. At levels above 75 - 80 ft^2/acre the merchantable trees adversely affect development of reproduction (Baker et al. 1996) and the stand cannot perpetuate itself.   At levels below 40 ft^2/acre of basal area, the open grown stand develops regeneration throughout the stand. This cohort of regeneration will be even-aged, and the stand will develop as a shelterwood stand, or a two-aged stand should the overstory be retained beyond the regeneration period. Cutting cycles tested maintain basal areas within these acceptable limits. Any cutting cycle/residual basal area combination which generates greater than 80 ft^2/acre of basal area is considered biologically infeasible. Maximum diameters, which define the diameter above which all trees are harvested, is biologically important because the largest trees provide seed for regeneration. Loblolly pine starts producing sufficient seed when it is around 12 inches in DBH. (Pomeroy 1949, Baker 1996), and larger trees produce more seed (Wenger 1954). Considering that at least 12 inch trees must be left for natural regeneration, we test maximum diameters between 12 and 18 inches. Natural regeneration is used for reproduction. Theoretically, artificial regeneration could be used in these stands. The basal area limits would still apply. Growth potential of artificial regeneration in these stands has not been measured.

These biologic limits on basal area and cutting cycle are based on loblolly pine site 90 (base age 50). On poorer sites, cutting cycles could be longer and still maintain the basal area

within these limits. On better sites, cutting cycles may need to be shorter to maintain basal areas between acceptable limits.

Even-aged Regimes that Maximize NPV. Many studies have addressed optimizing even-aged regimes for NPV maximization. Regimes found optimal in prior studies are used for our comparisons.

Sensitivity Analysis. Interest rates, harvesting costs, prices, and site index are held constant for a given optimization. Then selected variables are changed to analyze effects on NPV.

Calculating Net Present Value

Previous authors agree that NPV comparisons are appropriate financial comparisons among silvicultural systems. Differences in published comparisons center on the treatment of time, the treatment of the initial inventory and land value, the treatment of ending inventory, and the exact silvicultural practices implemented.   Table 3-1 contains notation for all calculations.

TABLE 3-1   Notation for NPV Calculations

a = annual income

c = annual costs

C_y = costs that occur in year y.

r = discount rate

R_y = revenues that occur in year y.

t = years in cutting cycle or years in an even aged rotation.

v = years in conversion period

y indexes years from time 0 to v.

z indexes years in the cutting cycle from 0 to t

Uneven-aged NPV. The NPV of the uneven-aged silvicultural option is the discounted future managed forest value (MFV) plus the conversion period value. The MFV is the present value of the stand in a steady state when perpetual revenues and costs are assumed to occur, as calculated in Equation 3-1. The conversion period puts a stand into the desired condition from

which perpetual revenues and costs can be expected. Discounting the MFV by the years in the conversion period and adding the present value of the conversion period harvests, yields the net present value of the stand, as shown in Equation 3-2.

$$\text{MFV} = \frac{\sum_{z=0}^{t} R_z(1+r)^{(t-z)} - \sum_{z=0}^{t} C_z(1+r)^{(t-z)}}{(1+r)^t - 1} \qquad (3\text{-}1)$$

$$\text{NPV} = \sum_{y=0}^{v}\left[\frac{R_y}{(1+r)^y} - \frac{C_y}{(1+r)^y}\right] + \frac{MFV}{(1+r)^v} \qquad (3\text{-}2)$$

Even-aged NPV. The calculation of even-aged NPV is conceptually the same as above. The soil expectation value (SEV), (Equation 3-3), is the value of equal periodic incomes from identical rotations into perpetuity. The conversion period again puts the stand in a position to yield these same equal periodic incomes and permits starting with an existing stand of any condition. The NPV in Equation (3-4) is the value of the conversion period plus the SEV (Equation 3-3).

$$\text{SEV} = \frac{\sum_{z=0}^{t} R_z(1+r)^{(t-z)} - \sum_{z=0}^{t} C_z(1+r)^{(t-z)}}{(1+r)^t - 1} \qquad (3\text{-}3)$$

$$\text{NPV} = \sum_{y=0}^{v}\left[\frac{R_y}{(1+r)^y} - \frac{C_y}{(1+r)^y}\right] + \frac{SEV}{(1+r)^v} \qquad (3\text{-}4)$$

Calculating Volume Yields. Volume yields for the time horizon are summed and divided by the years in the time horizon to get the annual increment.

Comparing Yields Between Systems.

The NPV and sawtimber and total volume yields are calculated for each silvicultural system and directly compared.   The difference in NPV between silvicultural systems is also expressed as an equivalent annual annuity (EAA). The EAA is the yearly amount the non-timber benefits of the silvicultural system with lower NPV must be worth to justify choosing that silvicultural system. Equation 3-5 calculates EAA for a perpetual time period.

$$\text{EAA} = \left(\text{NPV} * \text{Discount Rate}\right) \qquad (3\text{-}5)$$

For making these comparisons, beginning inventory, time, prices, and costs must be on a comparable basis.

Beginning Inventory. When comparing yields between silvicultural systems, the starting inventory must be identical while comparing each system. Without this, part of the difference in silvicultural system NPV and volume yields can be attributed to differences in starting inventory, not to the different silvicultural systems being compared. The cost to establish the inventory has been incurred either through land purchase or through management. It is a sunk cost and has no

bearing on future management of the stand. An alternative to implementing or continuing a silvicultural regime is land sale, either before or after inventory liquidation.

Treatment of Time. For comparing silvicultural systems, the highest and best use of the land is forestry and is expected to remain so for the foreseeable future. Each silvicultural system will be evaluated on an infinite time horizon.

Prices and Costs. Prices and costs vary widely across the range of loblolly pine. While making comparisons, the same price and cost environment is used for each silvicultural system.

Non-Timber Differences in Silvicultural Systems. Each silvicultural system has different impacts on a variety of management goals which are difficult to incorporate into a NPV comparison. These are issues such as aesthetics, soil compaction, environmental and price risk, and wildlife habitat. Differences between silvicultural systems are outlined in Chapter 7. These differences can be compared with the differences in value and volume in the decision making process.

Chapter 4 - Data

Data for silvicultural system comparison must be on a comparable basis for use in simulating each system. Stumpage price data comes from Timber Mart South (1996), harvesting cost data come from professionals and recent publications, growth and yield data from appropriate models, and silviculture costs from recent publications (Dubois et al. 1995).

Prices

Benchmark Prices.   Stumpage prices across the loblolly pine region vary by grade and region. Figure 4-1 shows Timber Mart South prices by product and state for second quarter 1996 (Timber Mart South, 1996). A simple average of each grade is used as the benchmark stumpage price scenario. These are presented in Table 4-1.
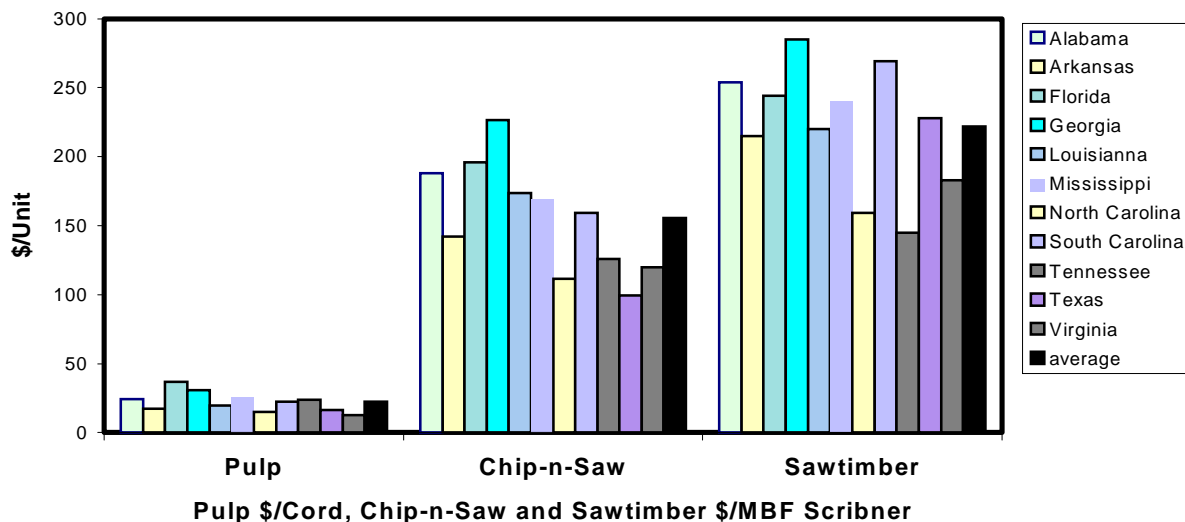
FIGURE 4-1.   Timber Mart South Stumpage Prices by State and Grade for Second Quarter 1996.

**TABLE 4-1. Benchmark Stumpage Prices
by Diameter Class.**

DBH Class	$/Unit
Pulpwood	22.26 $/cord
Chip-n-Saw 10"-12"	155.82 $/mbf Scribner
Sawtimber 14"+	222 $/mbf Scribner

Effects of Stumpage Prices. Stumpage prices can affect the optimal uneven-aged or even-aged regime and NPV comparisons between silvicultural systems. To analyze sensitivity to price changes, two alternative price scenarios are used. The first is the price scenario in Tennessee, where the sawtimber/pulp price ratio is the lowest of all southern states. This represents how different silvicultural systems compare if the price differential between products decreases. The second price scenario is from Virginia, where the price ratio between sawtimber and pulpwood is the highest, representing how silvicultural systems compare when sawtimber is comparatively more valuable than pulpwood. Prices for the high and low option are presented in Table 4-2.

Harvesting Costs.

Differences in harvesting costs are one of the first things many professional foresters think of when discussing differences between silvicultural systems. In this analysis, silvicultural systems are compared under two harvesting cost scenarios: a benchmark case and a low harvesting cost scenario II. More details on harvesting costs are in Appendix B.

TABLE 4-2. Stumpage Prices for the Low Sawtimber to Pulpwood Ratio and High Sawtimber to Pulpwood Ratio Scenarios.

DBH Class	Tennessee	Virginia
	Low Sawtimber to Pulpwood Ratio, $/Unit	High Sawtimber to Pulpwood Ratio, $/Unit
Pulpwood	24.07 $/cord	12.72 $/cord
Chip-n-Saw 10 - 12"	126.00 $/mbf Scribner	119.70 $/mbf Scribner
Sawtimber 14"+	145.00 $/mbf Scribner	183.00 $/mbf Scribner

Benchmark Harvesting Costs. In the benchmark harvesting cost function, compared to clearcutting, harvesting costs are estimated to average 30 percent higher in single-tree selection regeneration harvests of uneven-aged stands. Each harvesting system should be the most efficient possible for the desired harvesting job. For clearcuts, this would likely be a feller-buncher/grapple skidder combination. For single-tree selection regeneration harvests in uneven-aged stands the likely system would be manual felling with a cable or grapple skidder. The 30 percent increase in costs is for removing 25 tons per acre. More or less than 25 tons gets lower or higher harvesting costs. Due to limited published research on costs of single-tree selection regeneration harvests in uneven-aged stands, these estimates are based on consulting with many professionals with experience in timber harvesting. Estimates of cost differences between clearcutting and selection harvesting of uneven-aged stands ranged from no difference to 100% more for selective harvesting.

Estimated increases in harvesting costs reduce prices from the prices expected for clearcutting. Clearcuts receive 100% of the price reported in Timber Mart South (1996). Table 4-3 shows the resulting stumpage prices for the benchmark case with different intensities of cutting.

TABLE 4-3. Stumpage Prices with Benchmark Harvesting Costs.

Products	Tons Removed Per Acre				
	10	**25**	**50**	**75**	**100+ (clearcut)**
Pulpwood $/cord	$8.48	$12.61	$17.44	$20.65	$22.26
Chip-n-Saw $/mbf Scribner	$110.56	$128.56	$142.06	$151.06	$155.56
Sawtimber $/mbf Scribner	$177.00	$195.00	$208.50	$217.50	$222.00

Low Harvesting Cost Scenario II. Harvesting cost scenario II is based on the study by Kluender and Stokes (1997), showing a relatively small increase in logging costs for uneven-aged stands compared to clearcutting. The study compared identical harvesting systems, chainsaw felling and cable or grapple skidders, clearcutting and selectively harvesting uneven-aged stands. The results showed that differences in harvesting costs were more related to average tree size than volume removed. These costs have a lesser difference between clearcut costs and selective harvesting costs than the benchmark case. This is because the benchmark case considers that the most efficient system would be used for each harvest. Table 4-4 shows stumpage prices for harvesting cost scenario II.

TABLE 4-4. Stumpage Prices by Diameter Class for Low Harvesting Cost Scenario II.

Product	Percent Basal Area Removed			
	25%	**50%**	**75%**	**100 %** **(Clearcut)**
Pulpwood $/cord	$17.44	$19.99	$21.33	$22.26
Chip-n-Saw 10" $/mbf Scribner	$121.09	$129.34	$133.47	$136.57
Chip-n-Saw 12" $/mbf	$143.79	$149.99	$153.50	$155.56
14" Sawtimber $/mbf	$210.81	$216.76	$222.00	$222.00
16" Sawtimber $/mbf	$221.76	$226.52	$229.14	$231.05
18" Sawtimber $/mbf	$229.38	$233.67	$236.05	$237.48

*Difference in harvesting costs by basal area removed derived from Kluender, 1997.
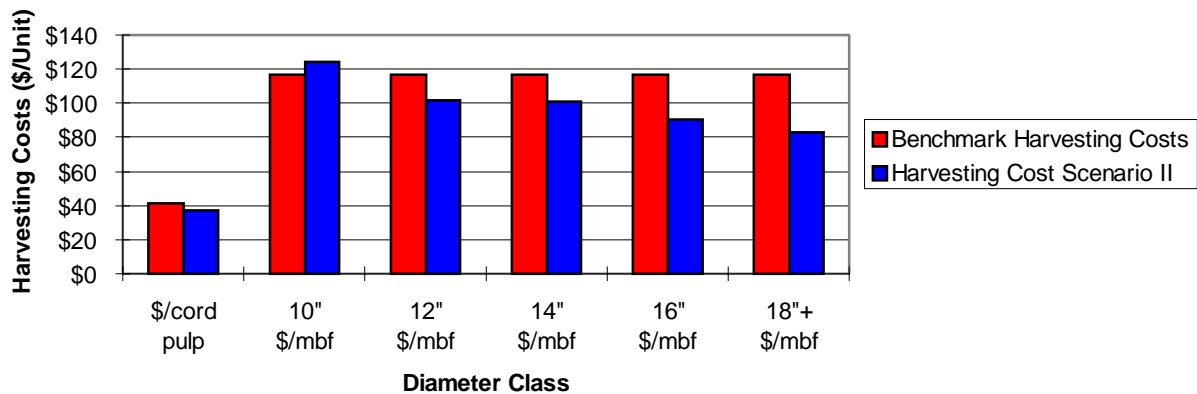
FIGURE 4-2. Comparison Between the Benchmark Harvesting Cost Scenario and Harvesting Cost Scenario II. Harvesting 25 Percent of Clearcut Volumes.

Comparison of the Benchmark Harvesting Cost Scenario and Scenario II. Figure 4-2 shows a direct comparison of harvesting costs for the benchmark harvesting cost scenario and low harvesting cost scenario II. This is for removing 25 tons per acre, or 25 percent of stand basal area. For both scenarios this is about 25% of the volume a clearcut would yield. Figure 4-3 incorporates these harvesting costs into the benchmark prices.
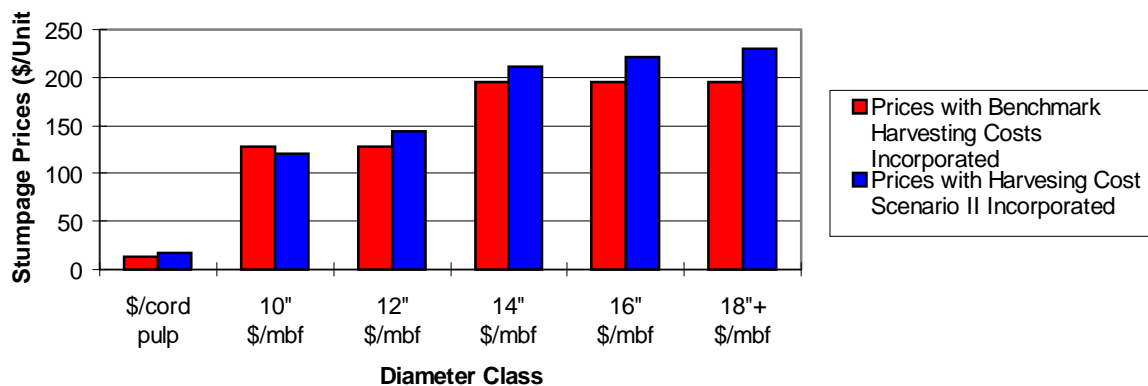
FIGURE 4-3. **Stumpage Price Comparison With the Benchmark Harvesting Cost Scenario and Harvesting Cost Scenario II Incorporated in the Stumpage Prices. Harvesting 25 Percent of Clearcut Volumes.**

Uneven-Aged Growth and Yield Data.

There are 3 uneven-aged growth models available for modeling development of uneven-aged loblolly pine. Two of these are basal area projectors, which calculate basal area growth and sawtimber volume growth based only on basal area at the beginning of the growth period and time. These were developed from well managed uneven-aged research plots in Southern Arkansas and Northern Louisiana on loblolly site 85 - 90 (base age 50) (Murphy and Shelton 1994, Murphy and Farrar 1982). The third model, Southpro (Buongiorno and Schulte 1997), is a site and density dependent multi-species matrix model for predicting the development of loblolly pine forests. Forest Inventory and Analysis data from the United States Forest Service were used to estimate the ingrowth, upgrowth, and mortality equations. For inclusion, plots had to be classified as within the loblolly pine forest type, be measured at least twice, be classified as "mixed age," and be natural stands.

Southpro incorporates diameter distributions, not just basal area. This allows modeling of different diameter classes, price/diameter relationships, and adjustments in logging costs for diameter class distributions not possible with the other growth models. Also, Southpro models sites other than loblolly pine site 90 (base age 50), the only site covered by the other two growth models. For these reasons Southpro is preferred for modeling growth in uneven-aged stands. Figures 4-4 shows merchantable ft^3 growth projections for the three models.
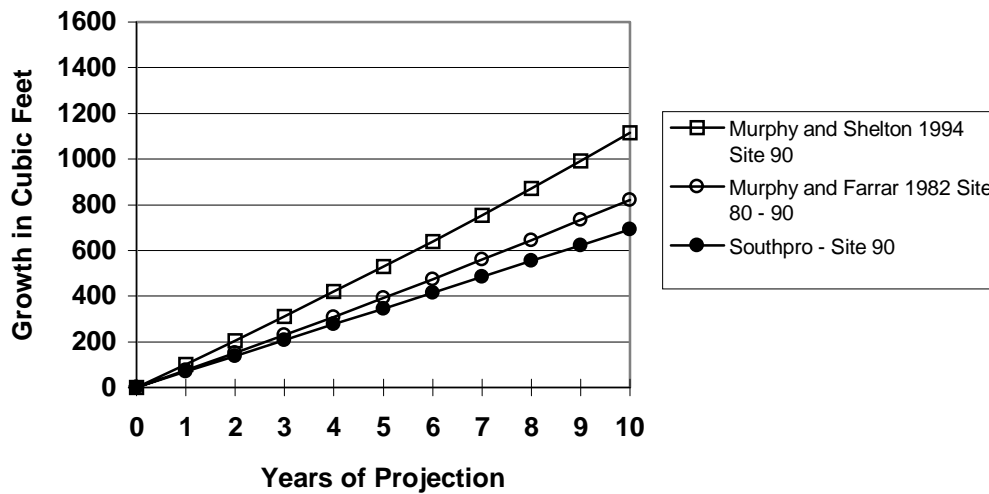
FIGURE 4-4. **Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Starting Condition is an Uneven-aged Stand with 45 ft^2/acre of Basal Area.**

Southpro predicts less growth than the other two models. This should be expected because the data for Southpro come from a wide range of stand conditions that qualify as uneven-aged, while the data for the other two models come from well managed uneven-aged stands.

Since we wish to model well stocked, well managed, uneven-aged stands free of hardwood competition with Southpro, the site index is increased in Southpro until its growth predictions fall between the other two available growth models as shown in Figure 4-5.

Growth and yield data for uneven-aged stands and benchmark conditions come from the uneven-aged growth model Southpro (Buongiorno and Schulte, 1997) with the site index set at 105 (loblolly pine base age 50) to model site loblolly pine site 90 (base age 50). Site index is increased to site 130 (loblolly pine base age 50), to model site 110 (loblolly pine base age 50), a high site quality. More details and explanatory graphs are in Appendix B
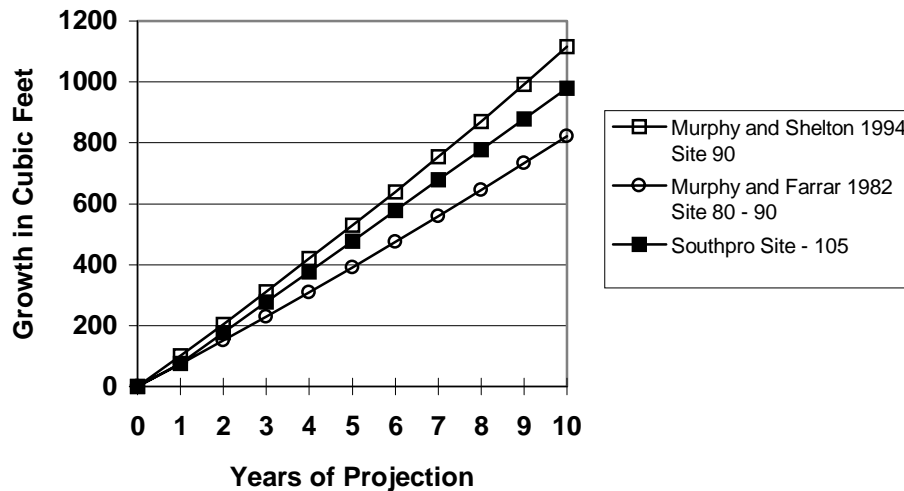
FIGURE 4-5.   Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Southpro Site Index set at 105. Starting Condition is an Uneven-aged Stand with 45 ft^2 of Basal Area

Even-Aged Growth and Yield Data

Data for even-aged stands comes from Tauyield (Amateis et al. 1996), a stand level growth and yield model for thinned and unthinned loblolly pine plantations.

Conversion Strategy

We make comparisons of even-aged and uneven-aged silviculture from different starting inventories. Converting each starting inventory to the regime which maximizes NPV for each silvicultural system requires growth and yield data not commonly modeled. Southpro and Tauyield are used as appropriate. These are not optima conversion strategies because not enough data exists to evaluate a range of conversion possibilities. The conversion strategy between bare land and uneven-aged silviculture is one way we believe this could be accomplished. The conversion from a fully stocked stand to uneven-aged silviculture is the method described by Baker et al (1996).

Converting From Bare Land to an Uneven-Aged Stand. There is no data or recommended silvicultural plan for converting from bare land to an uneven-aged stand. The following schedule is one way this could be accomplished.

We suggest planting bare land as an even-aged stand at 10 X 10' spacing. At age 20, trees average 7.9 inches in diameter and the largest are 12 inches. Some of this area can be clearcut and regenerated to start another age class. We suggest cutting swaths 3 trees wide through the plantation totaling 25% of the area. Natural regeneration may be used to regenerate this area if the surrounding trees are producing enough seed. In case they are not, we include artificial regeneration costs in our simulation. The rest of the 20 year old plantation is thinned as it would be for an even-aged rotation. The stand now has 2 age classes.

After 10 more years and another thinning, the third age class is established. This thinning, of the now 30 year old trees, should encourage natural regeneration by reducing basal area to 50 ft^2/acre. Residual trees average 11 inches in diameter. With the overstory as a seed source and site preparation from the harvesting activity, sufficient natural regeneration should be established to utilize the site. The stand should have 3 age classes at age 40. The 40 year old overstory, the 20 year regeneration in strips through the stand, and the 10 year old natural regeneration started at the second thinning. We include a precommercial thinning expense to select well-spaced vigorous saplings in areas where there may be too much natural regeneration. Figure 4-6 shows diameter distribution predicted after 40 years.
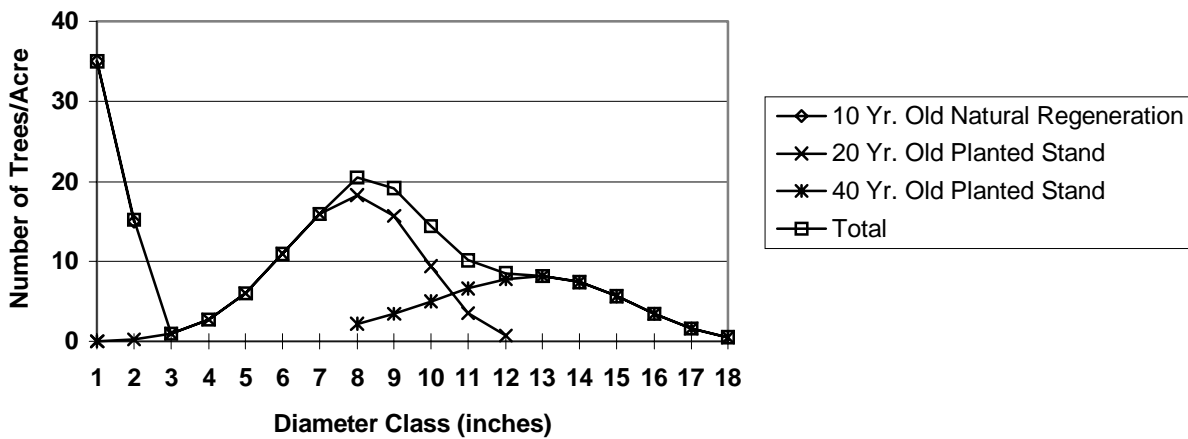
FIGURE 4-6. Diameter Distribution 40 Years After Planting Bare Land.

After 40 years, selection harvests replace the even-aged silviculture. This stand can now be modeled in Southpro as an uneven-aged stand. Each further entry will help ameliorate the distinct age classes, and the diameter classes will begin to blend together. Over time the diameter distribution will approach the target reverse J shape of uneven-aged stands.

Figure 4-7 shows what Southpro predicts the stand table will look like 60 years after planting bare land. Predicted harvest in year 62 comes from the largest diameter classes. There are no extra trees in the small diameter classes to be harvested.
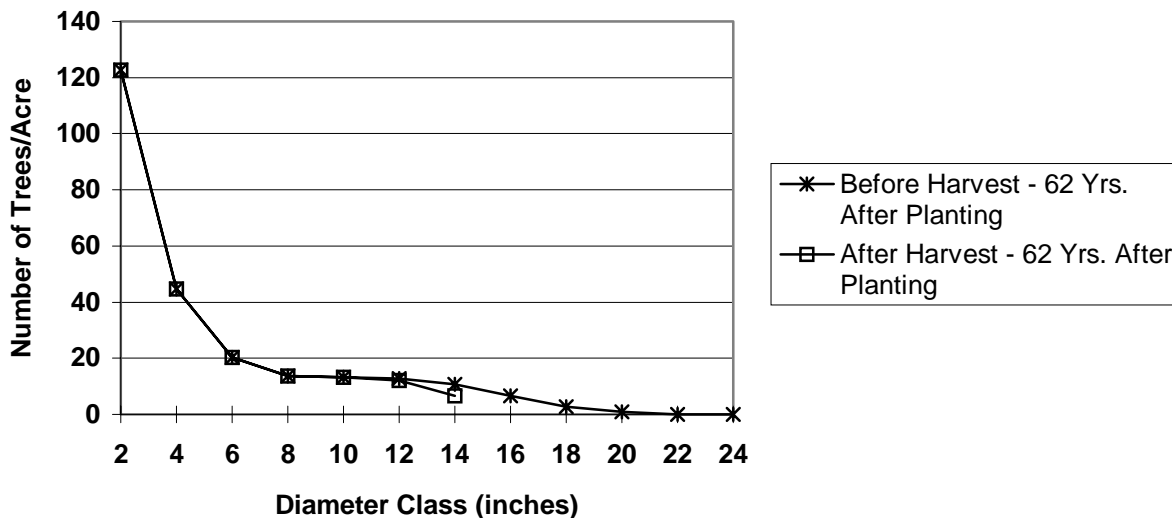
FIGURE 4-7. Diameter Distribution of Uneven-Aged Stand 60 Years After Planting Bare Land.

Converting from a Fully Stocked Even-Aged Stand to an Uneven-Aged Stand. Baker et al. (1996) outlines a conversion strategy from a 50 year old even-aged stand to a balanced uneven-aged stand. This strategy recommends entering the stand at regular cutting cycle entries to maintain the basal area between 45 and 75 ft^2/acre while establishing regeneration. Depending on the state of the beginning stand, one or two cuts are recommended to reduce the basal area to these levels.

We model the conversion from a fully stocked 30 year old even-aged stand in the way recommended by Baker et al. (1996). The beginning inventory has 100+ ft^2 of basal area. To prevent excessive mortality from a single, heavy thinning, Baker et al. (1996) recommends reducing the basal area in two cuts 5 years apart. Our first harvest reduces the basal area to 80 ft^2/acre, the second to 45 ft^2/acre. The stand is then entered every 11 years, maintaining the basal area at acceptable limits and favoring reproduction.

The initial stand is modeled in Tauyield for the two basal area reduction cuts, then entered into Southpro for the final transition to a balanced uneven-aged stand. After the two basal area reduction cuts and 10 years growth, Tauyield predicts the overstory stand has a diameter distribution pictured in Figure 4-8. Underneath this stand is natural reproduction up to 14 years old (Figure 4-9). The combination of these two stands is entered into Southpro and modeled as an uneven-aged stand as it gradually moves towards a balanced uneven-aged condition.

The stand diameter distribution has two classes, the overstory and natural regeneration in the understory. The stand is entered into Southpro growth model with the diameter distribution shown in Figure 4-10
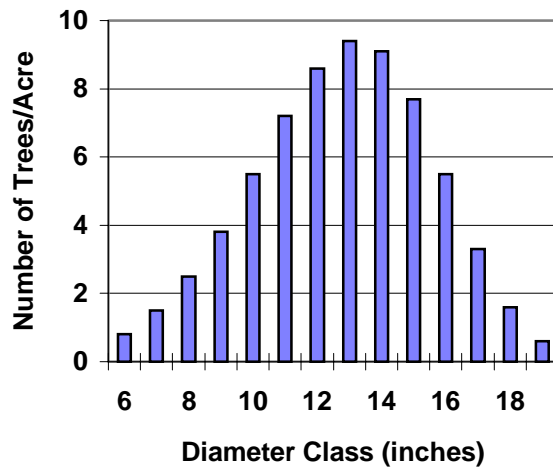
FIGURE 4-8.   Diameter Distribution of a 45 Year Old Stand Thinned at Age 30 and 35.
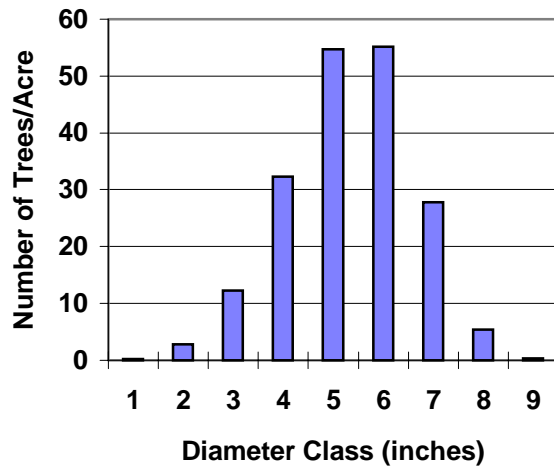
FIGURE 4-9. Predicted Natural Regeneration 14 Years After First Basal Area Reduction Harvest. Stand has had Understory Vegetation Control and a Crop Tree Release Thinning Operation.
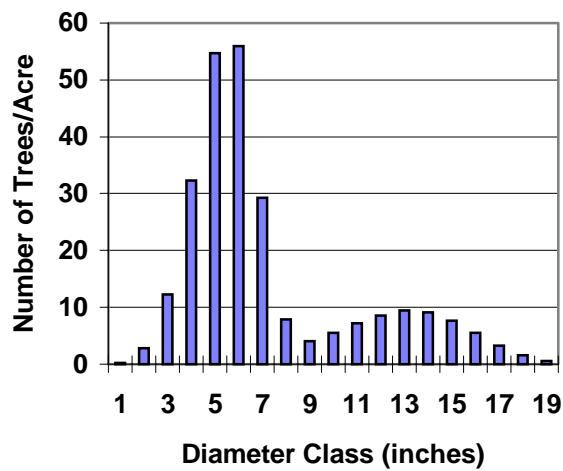
FIGURE 4-10. Diameter Distribution When the Overstory is 45 Years Old.

Converting from an Uneven-Aged Stand to an Even-Aged Stand. To convert from an uneven-aged stand to an even-aged stand, the stand is clearcut and the optimal even-aged regime initiated. This conversion allows a direct comparisons of silvicultural systems. Another alternative would be to allow the stand to grow, possibly much beyond the 80 ft^2/acre of basal area limit of uneven-aged silviculture, and then clearcut and initiate even-aged silviculture.

Silviculture Costs

Uneven-aged Silviculture Costs. Uneven-aged silviculture requires periodic control of competing vegetation to promote the establishment of pine reproduction and to aide the survival and growth of seedlings and saplings. (Williston 1978, Baker et al. 1996, Farrar 1996). Herbicides are the most common control method, although fire may be able to be used in certain situations. (Baker et al 1996, Baker 1986, Farrar 1996). Baker et al. (1996) recommends vegetation control every 10 to 20 years depending on site productivity and vigor of competing vegetation. Redmond and Greenhalg (1990) model a chemical treatment every harvest when the cutting cycle was greater than 7 years and at every other entry when cutting cycle was less than 7 years. They estimate costs of this treatment to be $50/acre. Baker (1986) estimates the cost of herbicide treatment to be $45/acre.

Dubois et al. (1995) report the cost of herbaceous weed control to average $29.05/acre and injection timber stand improvement was $41.03/acre. These are for even-aged treatments For this study, we use a cost of $45/acre every 10 years. This is consistent with the application recommendations of Baker (1996) and the costs estimated by Baker (1986) and Redmond and Greenhalg (1990) and the costs reported by Dubois et al. (1995).

Single-tree selection regeneration harvests from uneven-aged stands require careful marking. Dubois et al (1995) report that the costs of marking natural stands for thinnings costs are $12.95/acre. Baker (1986) used $13/acre for marking costs at each harvest. Redmond and Greenhalg (1990), used $7.20/acre. We use $15/acre at each selection harvest as our marking cost. This is slightly higher than the costs reported by Dubois for marking even-aged thinnings of natural stands and slightly higher than the figure used by Baker (1986) to allow for implementing BDQ regulation.

It is often suggested that annual management costs vary with silvicultural system. Other comparisons have not used this as an assumption. Redmond and Greenhalg (1990) used $4/acre for both silvicultural systems. Baker et al. (1986) used $2.00/acre for both systems. For this comparison of even-aged to uneven-aged silviculture, we use the same annual management cost of $4.00/acre for each silvicultural system. This is because additional costs caused by implementing uneven-aged silviculture over even-aged silviculture, such as harvesting and marking costs, are included as activity specific costs.

Fire suppression costs, reported in Dubois et al. (1995), average $0.68/acre. This figure is used for both systems.

Even-aged Silvicultural Costs.

Costs from Dubois et al. (1995) are used for even-aged silviculture. These are summarized in Table 4-5.

TABLE 4-5. Costs for Forest Practices in the South.

Treatment	Acres	$/Acre	$/Seedling
Site Preparation - Mechanical	267,963	100.74	
Site Preparation - Burning	422,582	11.20	
Site Preparation - Chemical	204,600	87.58	
Planting	613,635		0.09272
Chemical Release	75,400	59.82	

Not every acre received each treatment. Only about 1/2 of the acres planted had mechanical site preparation. Total site preparation costs averaged $80.91/acre. For calculating NPV of even-aged regimes, the average site preparation cost of $80.91/acre is used, although no acres received this exact cost. Planting costs are modeled as $0.093/seedling as reported. Release herbicide treatment cost $59.82/acre for treated acres, however only 75,400 were treated. If 12 percent of the acres planted get a release treatment, the average cost is $7.35/acre. This is assigned for release treatment for NPV calculations. Silvicultural costs used for NPV calculation of even-aged silvicultural regimes are presented in Table 4-6.

TABLE 4-6. Per Acre Silviculture Costs for NPV Calculation.

Treatment	$/Acre	$/Seedling
Site Preparation	80.91	
Planting		0.09272
Chemical Release	7.35	

Summary of Variable Values for NPV Optimization and Silvicultural Comparisons.

Benchmark Variable Values. Initial optimization and comparisons are made with the variables set at the benchmark values in Table 4-7. Through sensitivity analysis each one is varied to show the effect on optimal regimes and on NPV.

TABLE 4-7. Benchmark Variable Values for NPV Calculation.

Variable	Benchmark Value
Interest Rate	4 percent
Harvesting Costs	Benchmark Harvesting Cost Scenario See Figure A-1
Stumpage Prices	222.00 $/mbf Scriber sawtimber (14"+) 155.82 $/mbf chip-n-saw (10, 12") 22.26 $/cord pulp
Site Index	Loblolly Pine Site 90 (base age 50)

Variable Values for Sensitivity Analysis

A summary of the variable values used for sensitivity analysis is in Table 4-8.

TABLE 4-8. Sensitivity Analysis Variable Values for NPV Optimization and Silvicultural System Comparisons.

Variable	Value For Sensitivity Analysis
Interest Rate	8 percent
Harvesting Costs	Low Harvesting Cost Scenario II
Prices Low Sawtimber to Pulp Price Ratio.	145.00 $/mbf Scriber sawtimber (14"+) 126.00 $/mbf chip-n-saw (10, 12") 24.07 $/cord pulp
Prices High Sawtimber to Pulp Price Ratio.	183.00 $/mbf Scriber sawtimber (14"+) 119.70 $/mbf chip-n-saw (10, 12") 12.72 $/cord pulp
Site Index	Loblolly Pine Site 110 (base age 50)

Chapter V. Silvicultural Regimes that Maximize Net Present Value.

Optimization of silvicultural systems has commonly been done using mathematical programming. The "black box" effect of doing this prohibits looking at the response surface to the variables. All calculations for our analysis are done using spreadsheets to facilitate examining the sensitivity of net present value (NPV) to each variable.

Optimal Silvicultural Regimes for Existing Uneven-aged Stands to Maximize NPV.

Optimization of uneven-aged stands involves choosing the Q factor, cutting cycle, maximum tree diameter, and residual basal area which maximize NPV. Using the Growth and Yield model Southpro, we quantify the relationship between NPV and Q factor, cutting cycle, maximum tree diameter, and residual basal area.

For these analyses, all management variables are held constant at the benchmark levels in Table 4-7 unless otherwise noted. The starting inventory for examining different uneven-aged loblolly pine regimes is a loblolly pine stand with the diameter distribution in Figure 5-1.

Analysis across a range of starting inventories and economic conditions shows that Q factors of 1.2 (1 inch diameter classes) maximize NPV. Little research has been done modeling growth as Q factors vary. Figure 5-2 shows the effect of Q on NPV for one representative uneven-aged silvicultural regime. This shows that NPV is not very sensitive to Q factor across the range recommended by Baker et al. (1996) for uneven-aged loblolly pine silviculture. For all further optimization analysis, Q factor of 1.2 (one inch diameter classes) is used as the optimum Q factor.
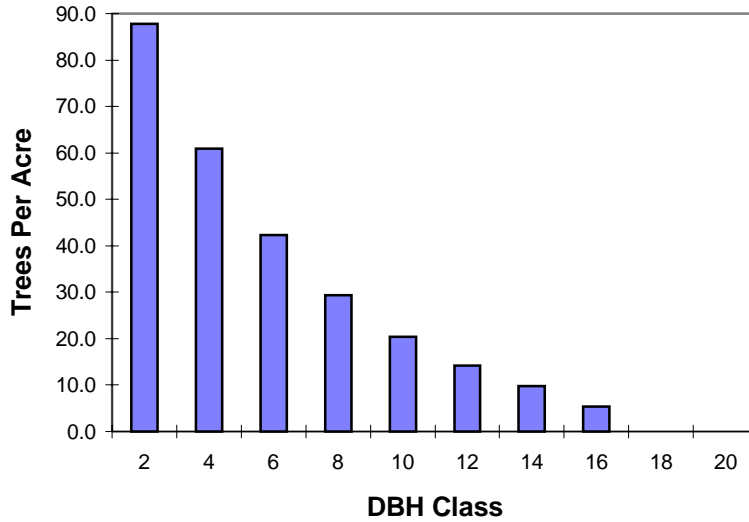
FIGURE 5-1. **Inventory from which NPV-Maximizing Uneven-Aged Silvicultural Regimes are Analyzed.**
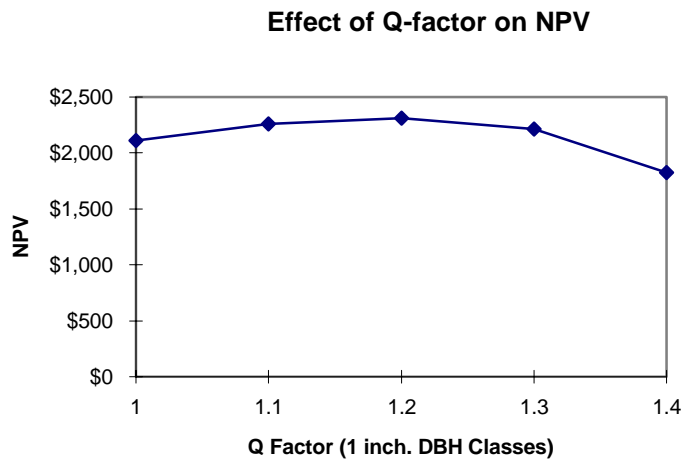
FIGURE 5-2. **Effect of Q Factor on NPV for an Uneven-Aged Silvicultural Regime with 45 ft^2/acre Basal Area, 14 inch Maximum Diameter, and Cutting Cycle of 9 Years. Table 4-7 Benchmark Inputs.**

Benchmark Variable Case. Figure 5-3 and Figure 5-4 show the effect of changes in cutting cycle, maximum diameter, and residual basal area on NPV for the benchmark variable levels. In Figure 5-3, residual basal area is held to 45 ft^2/acre while maximum diameter and cutting cycle are varied across their possible ranges. Maximum diameter, the size above which all trees are harvested at the end of the cutting cycle, must be large enough so that the remaining trees can provide seed for regeneration. In loblolly pine, trees of at least 12 inches must be left in the stand to provide this seed source (Pomeroy 1949, Baker 1996). Larger trees produce more seed. (Wenger 1954). This may be important to consider in areas where regeneration is difficult to establish.
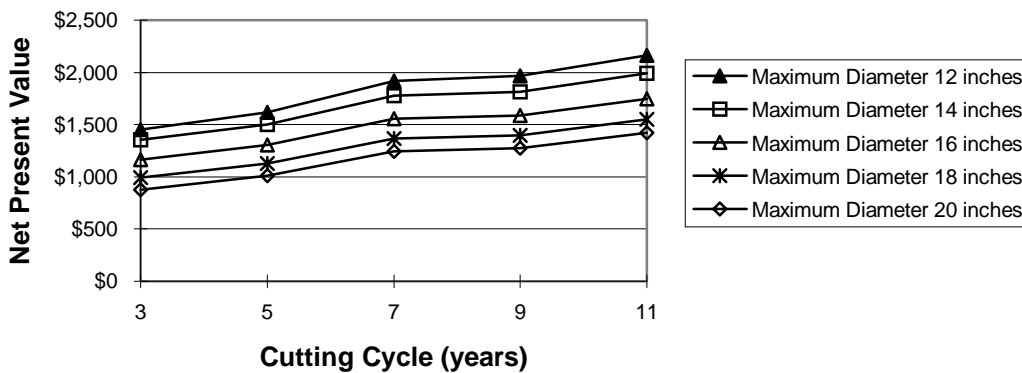
FIGURE 5-3. Effect of Cutting Cycle and Maximum Diameter on Net Present Values while Residual Basal Area is 45 Ft^2/acre. Benchmark Inputs from Table 4-7.

The cutting cycle must not be so long that the residual trees grow to a density which prohibits regeneration. This is a function of cutting cycle length and residual basal area. Generally, basal areas above about 75 ft^2/acre or 80 ft^2/acre kill the regeneration (Baker et al. 1996, Farrar 1996). The Southpro Growth Model, as it is used in this study, predicts that after 10 years, an uneven-aged stand starting with 45 ft^2/acre of basal area will have 75 ft^2/acre of basal area and after 11 years will have 78 ft^2/acre, right at the silvicultural maximum acceptable limit. For a residual basal area of 45 ft^2/acre, an 11 year cutting cycle is considered the longest feasible cutting cycle while still maintaining an uneven-aged stand structure. Silvicultural experience is necessary here. It may be that cutting cycles a little shorter or a little longer are the silvicultural maximum. The Southpro Model does not show the regeneration-excluding effects of basal areas in the 75 ft^2 to 80 ft^2/acre range. These limits have been found though experience and specific studies of uneven-aged loblolly pine silviculture.
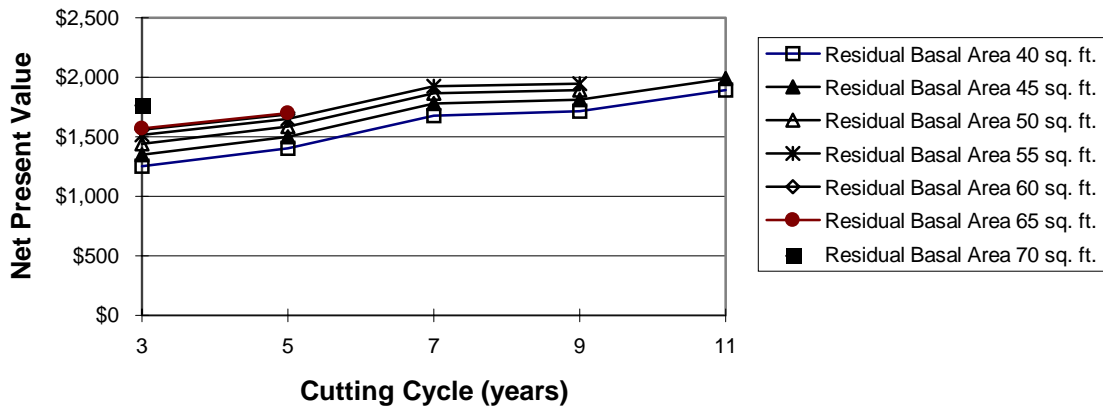
FIGURE 5-4. **Effect of Cutting Cycle and Residual Basal Area on Net Present Values while Maximum Diameter is 14 inches. Benchmark Inputs from Table 4-7.**

In Figure 5-4 maximum diameter is held to 14 inches, while residual basal area and cutting cycle are varied. As residual basal area increases above 45 ft^2/acre, the maximum cutting cycle length is necessarily shorter to maintain basal area below 80 ft^2/acre. 14 inches is chosen as the maximum diameter because it is not on the biologic edge of feasibility as 12 inches is. In areas where regeneration is difficult to establish a 14 inch maximum diameter would provide more seed. The shape of these curves does not change and the conclusions about residual basal area and cutting cycle are the same with 12 or 14 inch maximum diameters.

Figures 5-3 and 5-4 show, for the benchmark inputs, low maximum diameters, long cutting cycles, and high residual basal areas maximize NPV within the limits of biological feasibility. With residual basal area held constant, the lowest possible maximum diameter maximizes NPV. For each cutting cycle, with maximum diameter held constant, higher residual basal areas yield higher NPVs. The longest possible cutting cycle maximizes NPV in all cases. For the benchmark inputs, the regime yielding the highest NPV has a maximum diameter of 12 inches, residual basal area of 45 ft^2/acre and a cutting cycle of 11 years.

Sensitivity Analysis

Figures 5-3 and 5-4 show which management regimes maximize NPV while the variables in Table 4-7 are at their benchmark levels. For sensitivity analysis, each of these variables is changed, and new Figures 5.2 and 5.3, analogous to 5-3 and 5-4, are generated to analyze the effects on NPV.

8 Percent Interest Rate. Figure 5-3a and 5-4a show the effect of changes in cutting cycle, maximum diameter, and residual basal area on NPV when the interest rate is changed to 8 percent. All the other Table 4-7 variables are at their benchmark levels. Figure 5.3a shows that with 8 percent interest, low maximum diameters and long cutting cycles still maximize NPV.

FIGURE 5-3a. **Effect of Cutting Cycle and Maximum Diameter on Net Present Values while Residual Basal Area is 45 Ft^2/acre. Interest Rate = 8 Percent. Benchmark Inputs from Table 4-7.**
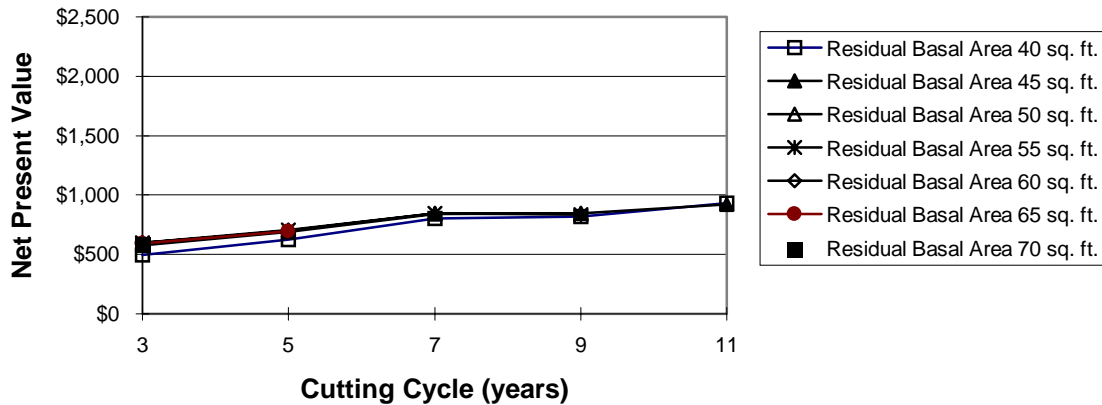
FIGURE 5-4a. **Effect of Cutting Cycle and Residual Basal Area on Net Present Values while Maximum Diameter is 14 inches. Interest Rate is 8 Percent. Benchmark Inputs from Table 4-7.**

Figure 5-4a shows that while maximum diameter is held constant, longer cutting cycles and higher residual basal areas maximize NPV. The optimum regime does not change from the optimum regime found under the benchmark conditions. At the variable levels tested, NPV is insensitive to residual basal area. Higher residual basal areas reduce the year 0 harvest, but result in higher periodic harvest levels. Lower residual basal areas mean more of the initial stand can be harvested in year 0, but there is less growing stock and periodic volumes will be lower.

Low Harvesting Cost Scenario II. Figure 5-3b and 5-4b show the effect of changes in cutting cycle, maximum diameter, and residual basal area on NPV under low harvesting cost scenario II (where harvesting costs are projected to be only slightly higher in selective harvesting of uneven-aged stands than when clearcutting). All the other Table 4-7 variables are at their benchmark levels.

Figure 5-3b shows that under the lower harvesting cost scenario II, with residual basal area held constant, NPV is still maximized at low maximum diameters and long cutting cycles

FIGURE 5-3b. Effect of Cutting Cycle and Maximum Diameter on Net Present Values while Residual Basal Area is 45 ft^2/acre. Harvesting Cost Scenario II. Benchmark Inputs from Table 4-7.
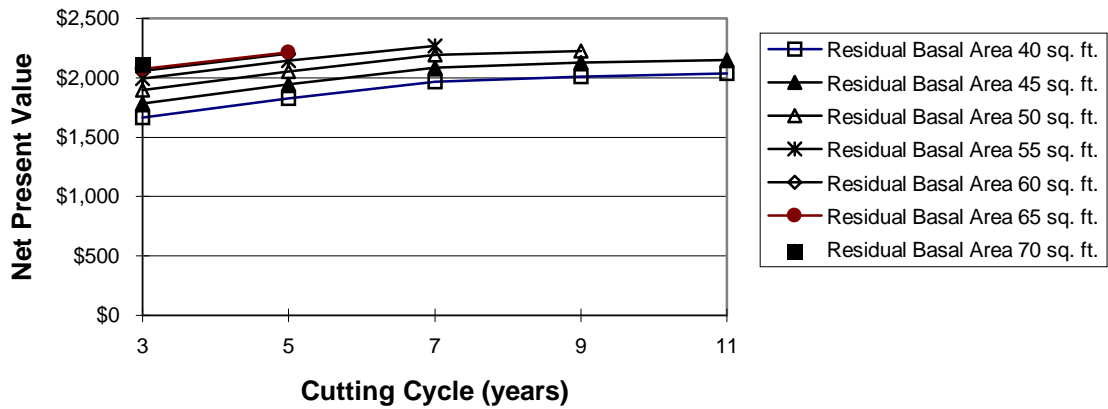
FIGURE 5-4b. Effect of Cutting Cycle and Residual Basal Area on Net Present Values while Maximum Diameter is 14 inches. Harvesting Cost Scenario II. Benchmark Inputs from Table 4-7.

Given lower logging costs (scenario II), Figure 5-4b shows that long cutting cycles maximize NPV with residual basal area held constant. As residual basal area increases above 45 ft^2/acre, the maximum allowable cutting cycle drops below 11 years to maintain end of cutting cycle basal area below 80 ft^2/acre. The regime yielding the highest NPV has a shorter cutting cycle (7 years) than the benchmark optimum, and a higher residual basal area of 55 ft^2/acre. This optimum, under low harvesting cost scenario II, is 10 ft^2/acre higher than the benchmark optimum in Figure 5-4, and the cutting cycle is 4 years shorter. The optimum maximum diameter is still 12 inches. This regime yields a NPV of $123/acre more than the regime found optimal for the benchmark case.

Sawtimber Price to Pulp Price Ratio. Figure 5-3c, 5-4c, 5-3d, and 5-4d show the effect of changes in cutting cycle, maximum diameter, and residual basal area when there is a low or high sawtimber to pulp price ratio. These figures should be compared with Figures 5-3 and 5-4.
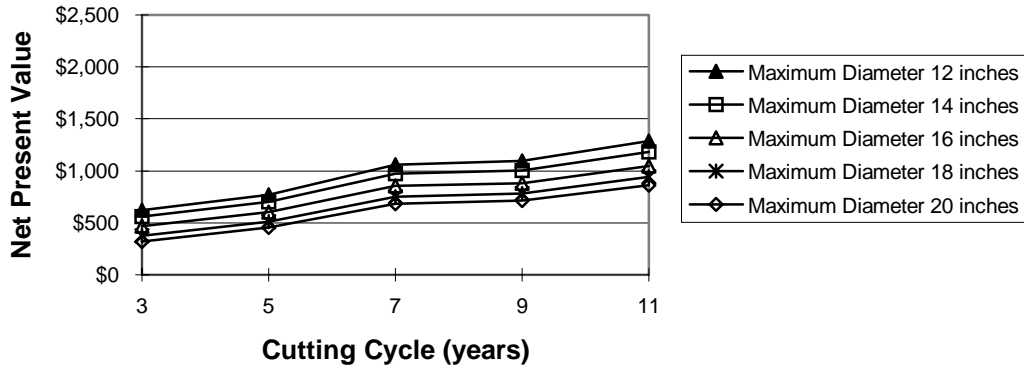
FIGURE 5-3c. **Effect of Cutting Cycle and Maximum Diameter on Net Present Values while Residual Basal Area is 45 ft^2/acre. Low Sawtimber to Pulp Price Ratio. Benchmark Inputs from Table 4-7.**
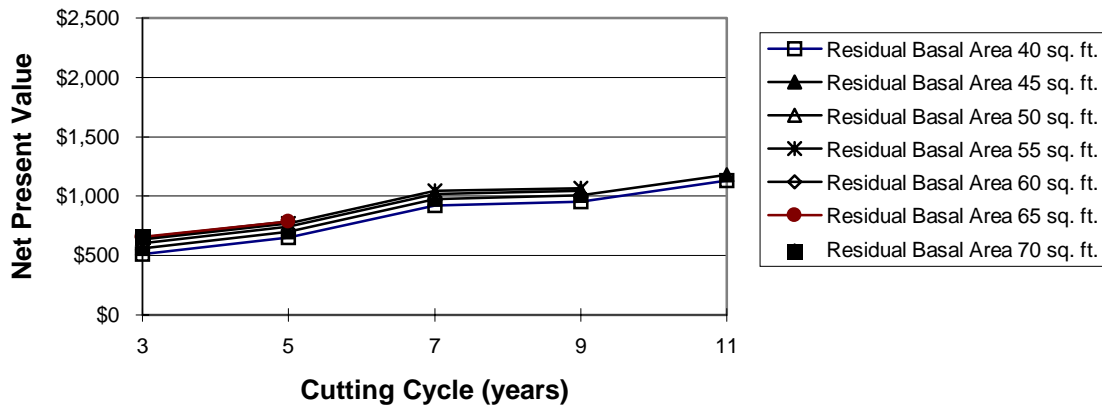
FIGURE 5-4c. **Effect of Cutting Cycle and Residual Basal Area on Net Present Values while Maximum Diameter is 14 inches. Low Sawtimber Price to Pulp Price Ratio. Benchmark Inputs from Table 4-7.**
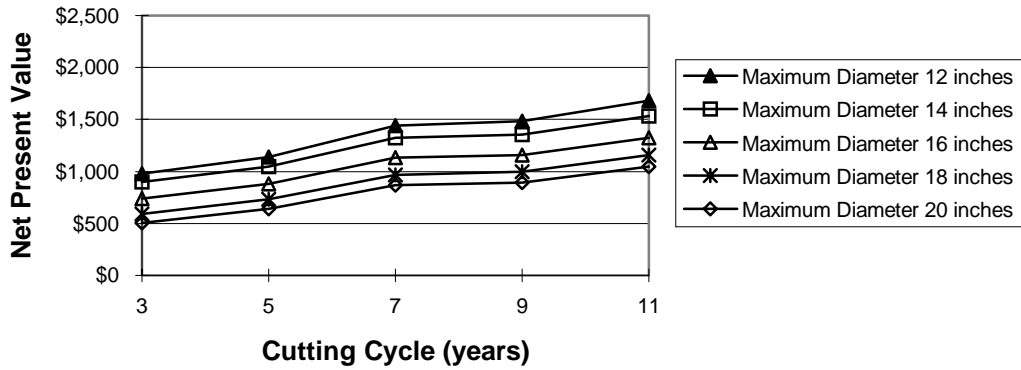
FIGURE 5-3d. Effect of Cutting Cycle and Maximum Diameter on Net Present Values while Residual Basal Area is 45 ft^2/acre. High Sawtimber to Pulp Price Ratio. Benchmark Inputs from Table 4-7.
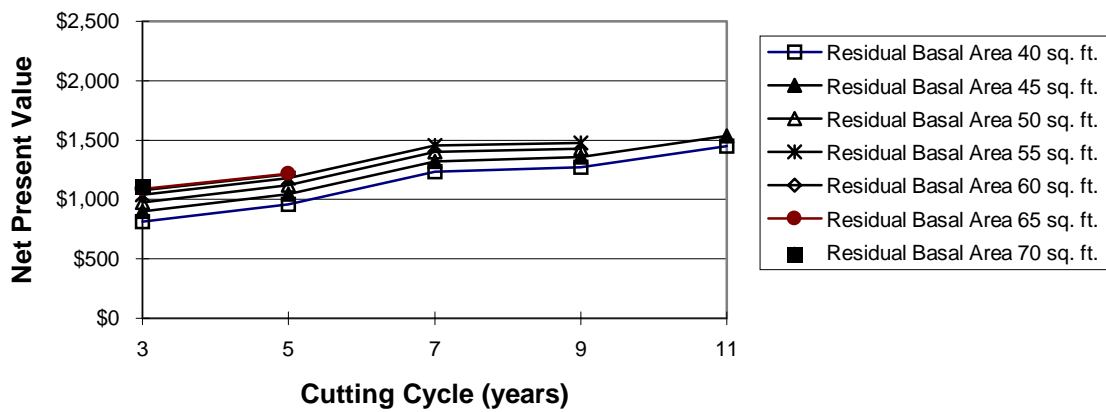
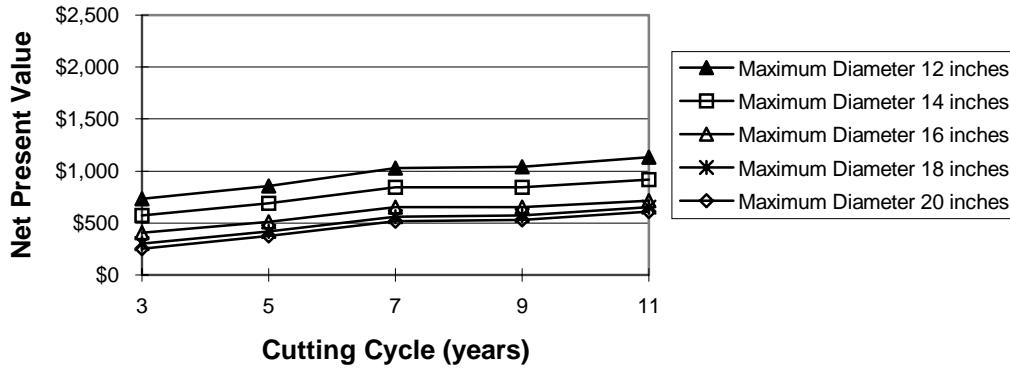**FIGURE 5-4d. Effect of Cutting Cycle and Residual Basal Area on Net Present Values while Maximum Diameter is 14 inches. High Sawtimber Price to Pulp Price Ratio. Benchmark Inputs from Table 4-7.**

These graphs show that the optimal management regime is not sensitive to the range of price ratios examined. This is because uneven-aged silviculture does not produce much pulpwood. Most trees of pulpwood size are allowed to grow to sawtimber size. The optimum regime under these different price scenarios is the same as under the Table 4-7 benchmark scenario.

High Site Class. Figure 5-3e and 5-4e show the effect of changes in cutting cycle, maximum diameter, and residual basal area on NPV for loblolly pine site 110 (base age 50). All variables are at their benchmark levels. These graphs show results similar to Figures 5-3 and 5-4 (site index 90). As before, within the range of biologic feasibility in uneven-aged silviculture of loblolly pine, the optimum uneven-aged silvicultural regimes have low maximum diameters, high residual basal areas, and long cutting cycles. However, we project that on these high sites, 9 years will be the longest possible cutting cycle while still maintaining an uneven-aged stand. After 9 years, basal area will be high enough to restrict regeneration and damage the stands ability to regenerate itself. Again, individual sites will differ and the actual longest possible cutting cycle may differ from the 9 years projected here. The optimum regime for the higher site quality has a cutting cycle of 9 years, residual basal area of 45 ft^2/acre and maximum diameter of 12 inches.

NPV-Maximizing Uneven-Aged Regimes. These simulations show that with variables at their Table 4-7 benchmark values, an 11 year cutting cycle, a 12" maximum diameter, and residual basal area of about 45 ft^2/acre maximizes NPV. Sensitivity analysis shows that this does not vary much as the Table 4-7 variables vary. Optimum regimes for the Table 4-7 benchmark case and the sensitivity analysis are summarized in Table 5-1.
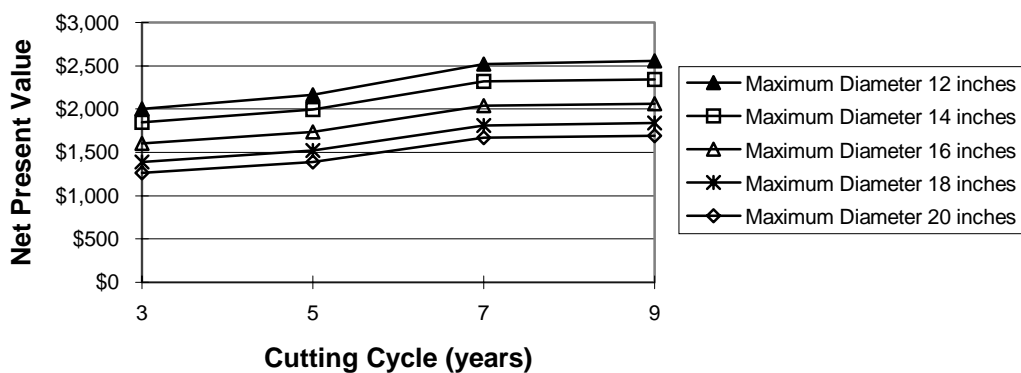
FIGURE 5-3e.   Effect of Cutting Cycle and Maximum Diameter on Net Present Values while Residual Basal Area is 45 ft^2/acre. Loblolly Pine Site 110 (Base Age 50). Benchmark Inputs from Table 4-7.
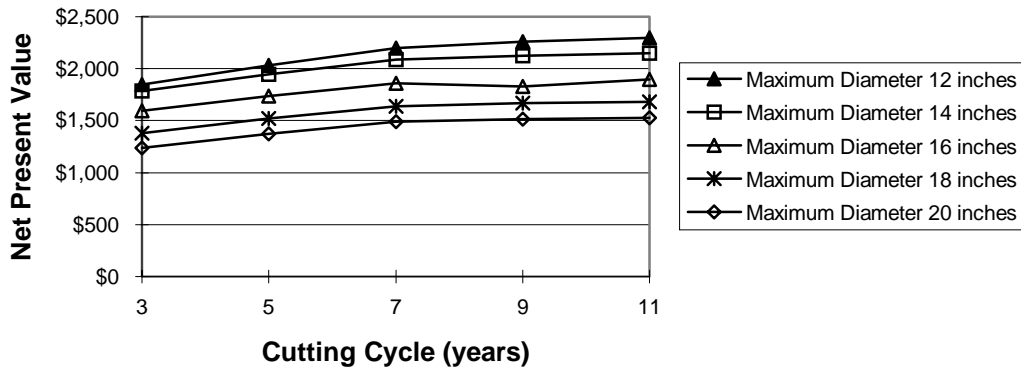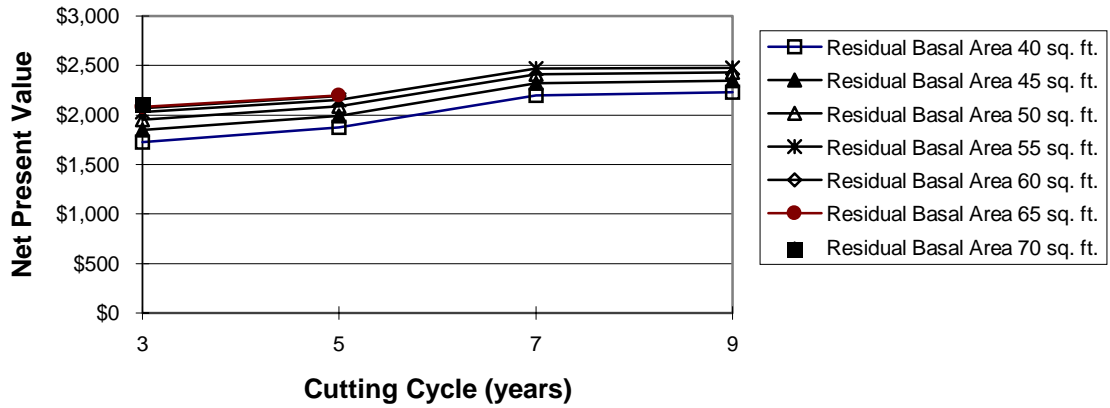
FIGURE 5-4e. **Effect of Cutting Cycle and Residual Basal Area on Net Present Values while Maximum Diameter is 14 inches. Loblolly Pine Site 110 (Base Age 50). Benchmark Inputs from Table 4-7.**

TABLE 5-1. Optimal Uneven-aged Regimes for the Benchmark Values and Sensitivity Analysis.

Variable Values	Cutting Cycle (years)	Maximum Diameter (inches)	Residual Basal Area (ft^2/acre)
Benchmark	11	12	45
Interest Rate 8%	11	12	45
Low Harvesting Cost Scenario II	7	12	55
Low Sawtimber to Pulp Price Ratio	11	12	45
High Sawtimber to Pulp Price Ratio	11	12	45
High Site	9	12	45

Table 5-1 shows that NPV is maximized at longer cutting cycles and lower residual basal areas than those found by Farrar et al. (1989) and Hotvedt and Ward (1990). This is attributable to the higher harvesting costs of both the benchmark harvesting cost scenario and low harvesting cost scenario II. This analysis also shows that Q of 1.2 and the smallest biologically feasible maximum diameters maximize NPV. Because of growth model limitations, these were not examined in previous studies. Figures 5-3 and 5-4 show the sensitivity of NPV to cutting cycle length, maximum diameter, and residual basal area.

Optimal Management of Even-aged Stands for NPV Maximization.

Benchmark Variables. Previous loblolly pine sawtimber stand-level optimization studies with variables near our benchmark levels show that regimes which maximize NPV have one thinning around age 15 leaving 70 to 80 ft^2/acre of basal area and a final harvest around age 30. This is close to the optimum solution for the even-aged stand optimization problem found by Broderick et al (1982), Hotvedt and Straka (1987), and Arthaud (1996). Studies differ about which planting density maximizes NPV. Hotvedt and Straka (1987) did not use planting density as a variable, Arthaud mostly confined optimization to planting densities of 750 trees per acre (tpa) and, when released, planting densities went to 200 tpa. Broderick's optimum 436 trees per acre was found by testing a range of densities within the growth model capabilities. Here 436 trees per acre (10X10 ft. spacing) is used for optimum even-aged regimes. More detailed summaries of these studies follow.

Hotvedt and Straka (1987) found that at 4 percent interest, loblolly pine site 60 (base age 25), planting density at 750 tpa, and a similar price ratio to our benchmark prices, the optimal even-aged regime has one thinning at age 15 leaving 80 ft^2 of basal area and final harvest at age 30. On loblolly pine site 70 (base age 25), with the planting density fixed at 750 trees per acre, and interest rate set at 4 percent, the optimal regime had two thinnings, however the regime yielding the second highest NPV had one thinning at age 15, residual basal area of 90 ft^2, and final harvest at age 25. The optimum set of regimes was consistent for different planting densities and price ratios. The results of this study showed that optimal management regimes tended to have at least one thinning and a final harvest age around 30 years. Also, NPV differences in the top management regimes were slight, indicating thinnings and final harvest ages could be planned to suit other strategic management plans.

Broderick et al. (1982) found on loblolly pine site 70 (base age 25), with a sawtimber to pulp price ratio similar to our benchmark price scenario, and with an interest rate of 6 percent, that the optimal even-aged regime has a planting density of 436 tpa, one thinning at age 15 leaving 80 ft^2 of basal area, and final harvest at age 25. On site 60, with a sawtimber to pulp price ratio similar to our benchmark price scenario, and with 6 percent interest, the optimal even-aged regime had a planting density of 436 trees per acre, one thinning at age 15 leaving 60 ft^2 of basal area, and final harvest at age 30. Optimal rotations lengthened as real interest rate declined. None of the work by Broderick et al (1982) exactly matched the input variables of this study; however, their study finds that one thinning at age 15 and final harvest around age 30 yields optimum NPV.

Arthaud (1996) used dynamic programming to analyze the impact of relative prices on optimal stand management decisions. On loblolly pine site 60 (base age 25), 4 percent interest rate, and sawtimber to pulp price ratio similar to our benchmark price scenario, the optimal even-aged management regime had a planting density of 200 trees per acre and final harvest at age 28. With planting density fixed at 700 tpa, the optimum regime had one thinning at age 22 and final harvest at age 34. For loblolly pine site 70 (base age 25) the optimal regime with fixed planting density of 700 had one thinning at age 18 and final harvest at age 30. The study by Arthaud had the only analysis which included chip-n-saw grade and sawtimber grade and the effect of these on optimal management regimes. On loblolly pine site 60 (base age 25), with planting density fixed at 700 trees per acre, and a chip-n-saw price ratio equal to our benchmark price scenario, the optimal regime has one thinning at age 24 and final harvest at age 33.

8 Percent Interest Rate. As the variables in Table 4-7 change, the optimal even-aged regime could also change. Hotvedt and Straka (1987) found that, generally, the optimum management regime was similar under interest rates from 4 to 10 percent, although final harvest age tended to decrease as interest rate rose. Broderick et al. (1982) had similar conclusions. At 8 percent, NPV was maximized at a rotation age of 25. For our analysis, we use the same even-aged regime for interest rates of 4 and 8 percent, except that final harvest age will be 28 years with the 8 percent interest rate.

Harvesting Costs. Broderick et al. (1982), found that optimal even-aged regimes were insensitive to increased thinning costs, reflected in thinning stumpage prices, when stumpage

prices were varied from 80 percent of clearcut stumpage prices to thinning stumpage price of 0. Thinning became economically infeasible when thinning costs were sufficiently high. For our comparisons, the optimum even-aged regime does not vary from the optimum benchmark level under low harvesting cost scenario II.

Prices. Hotvedt and Straka (1987), analyzed different relative sawtimber prices, where high relative prices represented scenarios where large trees would be valued as sawtimber or peelers, and where low relative sawtimber ratios represented areas where large trees might be valued at pulp or chip-n-saw prices. The optimum regime of 750 tpa planting density, 1 thinning at age 15 to 80 ft^2/acre, and rotation age of 30, did not change as relative sawtimber price changed. Arthaud (1996), found that as the sawtimber to pulpwood price ratio decreased, thinning ages increased and final harvest ages decreased. At ratios below 2.2 for loblolly pine site 60 (base age 25), no thinning was optimal. Our low sawtimber to pulp price ratio, representing the lowest ratio of all the state averages in Timber Mart South (1996), was 2.25. At this level, on site 60, Arthaud found thinning at age 24 and final harvest at age 31 optimal. On site 70, thinning age was 20 and final harvest was 28. As the sawtimber to pulp price ratio increased, thinning ages declined and final harvest ages increased. On site 60, for a sawtimber to pulp price ratio of 5.4, our high sawtimber to pulpwood price ratio scenario, Arthaud found thinning age of 21 and final rotation age 35 to be optimal. On site 70, thinning at age 17 and final harvest at age 32 were optimal. For our sensitivity analysis, the even-aged regime for the low sawtimber to pulp price ratio and the for the high sawtimber to pulp price ratio follow the conclusions of Arthaud's analysis. For the low sawtimber to pulp price ratio, optimal even-aged regime has one thinning at age 20 and final harvest at age 28. For the high sawtimber to pulp price ratio, the optimal even-aged regime has one thinning at age 17 and final harvest at age 32.

High Site. At loblolly pine site 80 and interest rate 4%, Haight and Smith (1991) found that rotation age was 30 years, but that thinning should occur at age 10, leaving 136 tpa. Teeter and Caufield (1991) found that NPV was maximized by planting 400 tpa, thinning at age 21, and final harvest at age 26. Under our benchmark values with site 83 (base age 25), the regime with thinning at year 10 and final harvest at age 30 yields higher NPV than the thinning at age 21 and final harvest at age 26.

Table 5-2 summarizes optimal even-aged regimes for the benchmark case and sensitivity analysis.

TABLE 5-2.   Optimal Even-Aged Regimes For The Table 4-7 Benchmark Values and Sensitivity Analysis.

Variable Values	Planting Density(tpa)	Thinning Age (yrs), Residual Basal Area ft^2/acre	Final Harvest Age
Benchmark	436	15, 70	30
Interest Rate 8%	436	15,70	28
Low Harvesting Cost Scenario II	436	15,70	30
Low Sawtimber to Pulp Price Ratio	436	20,70	28
High Sawtimber to Pulp Price Ratio	436	17,70	32
High Site	436	10,40	30

Chapter 6 . Comparisons of NPV Between Uneven-aged and Even-aged Silvicultural Systems

Considering 3 different starting inventories, we compare the NPVs of implementing either uneven-aged or even-aged silviculture. Starting from bare land, an uneven-aged stand, and an even-aged stand, the NPV of adopting both systems is calculated using equations 3-2 and 3-4. The mean annual increment (MAI) of sawtimber (ft^3) and total volume (ft^3) are calculated from the yields over the first 200 years. Equivalent annual annuity is calculated using equation 3-5.

Starting with Bare Land

TABLE 6-1.   Comparison of Net Present Values and Volume Yields Between Uneven-Aged Silviculture and Even-Aged Silviculture Starting from Bare Land.

Table 4-7 Variables	Uneven-aged Silviculture		Even-Aged Silviculture		Uneven-Aged NPV / Even-Aged NPV	Equivalent Annual Annuity Difference $/Acre
	NPV $/Acre	MAI Ft^3/Acre Sawtimber, Total Fiber	NPV $/Acre	MAI Ft^3/Acre Sawtimber, Total Fiber		
Bench-mark	654	70, 73	877	127, 155	0.75	9
Interest Rate 8%	33	70, 73	110	124, 155	0.31	3
Harvesting Cost II	680	69, 76	877	127, 155	0.78	8
Low Price Ratio	392	70, 73	521	98, 144	0.77	5
High Price Ratio	426	70, 73	565	125, 150	0.75	6
High Site	1,017	91, 93	1,570	154, 180	0.65	22

Table 6-1 shows the NPVs of implementing uneven-aged silviculture and even-aged silviculture. The first row shows the NPV comparison under the benchmark conditions from Table 4-7. This analysis shows that uneven-aged silviculture yields a NPV of $654/acre. This is 75 percent of the optimal even-aged silvicultural regime NPV of $877/acre. The uneven-aged silvicultural regime yields a mean annual increment (MAI) of 73 ft^3/acre of which 70 ft^3/acre is

predicted to be sawtimber. The even-aged silviculture is projected to yield a MAI of 155 ft^3 total and 127 ft^3 sawtimber. If uneven-aged silviculture is to be chosen over even-aged silviculture, this analysis shows that the annual non-timber benefits of uneven-aged silviculture must be worth at least $9/acre more than the annual non-timber benefits of even-aged silviculture. This 9 $ is the annualized difference in NPV of the two silvicultural systems. Rows 2 - 6 of Table 6-1 show the comparison between the optimal regimes of each silvicultural system when Table 4-7 values are changed. In none of the cases does uneven-aged silviculture yield a higher NPV than even-aged silviculture. The closest is under the low harvesting cost scenario II when uneven-aged silviculture yields 78 percent of the NPV that even-aged silviculture yields.

Under the bare land conversion strategy, the land has an even-aged structure for the first 40 years. The landowner does not give up revenue for going to uneven-aged for the first 30 years, but also does not get any potential added benefits of uneven-aged silviculture for this time period.

Starting with an Uneven-Aged Stand.

TABLE 6-2. Comparison of Net Present Values and Volume Yields Between Uneven-Aged Silviculture and Even-Aged Silviculture Starting from an Uneven-Aged Stand.

Table 4-7 Variables	Uneven-aged Silviculture		Even-Aged Silviculture		Uneven-Aged NPV/Even-Aged NPV	Equivalent Annual Annuity of NPV Difference $/Acre
	NPV $/Acre	MAI Ft^3/Acre Sawtimber, Total Fiber	NPV $/Acre	MAI Ft^3/Acre Sawtimber, Total Fiber		
Bench-mark	2,084	75, 78	2,152	133, 163	0.97	3
Interest Rate 8%	1,207	75, 78	1,413	129, 162	0.85	8
Harvesting Cost II	2,143	76, 79	2,152	133, 163	1.00	0
Low Price Ratio	1,207	75, 78	1,328	104, 151	0.91	5
High Price Ratio	1,604	75, 78	1,505	131, 158	1.07	-4
High Site	2,713	95, 98	2,661	160, 188	1.02	-2

If a stand is already in an uneven-aged condition a manager could continue uneven-aged silviculture or convert to even-aged silviculture. Table 6-2 compares these two alternatives when the starting stand has a balanced uneven-aged diameter distribution as shown in Table 5-1. The first row of Table 6-2 shows the NPV comparison for the Table 4-7 benchmark conditions. This analysis shows that uneven-aged silviculture yields a NPV of $2,084/acre. Even-aged silviculture yields $2,152/acre. The uneven-aged alternative NPV is 97 percent of the even-aged silvicultural regime NPV. The uneven-aged silvicultural regime yields MAI of 78 ft^3/acre of which 75 ft^3/acre is sawtimber. The even-aged silviculture is projected to yield a MAI of 163 ft^3/acre total of which 133 ft^3/acre is sawtimber. If uneven-aged silviculture is to be chosen over even-aged silviculture, this analysis shows that the annual non-timber benefits of uneven-aged silviculture must be worth at least $3/acre more than the annual non-timber benefits of even-aged silviculture. Rows 2 - 6 of Table 6-2 show the comparison between the optimal regimes of each silvicultural system when Table 4-7 values are changed. When starting with an uneven-aged stand, this analysis shows even-aged and uneven-aged silviculture are financially very competitive. Under certain conditions, uneven-aged silviculture yields higher NPVs than even-aged silviculture. Equivalent annual annuity needed to justify one system over the other on non-timber values is not more than $8/acre for the selected variable levels when starting with an uneven-aged stand.

Starting with an Even-aged Stand.

From a well stocked, even-aged stand, a manager could continue even-aged silviculture or convert the stand to uneven-aged silviculture. Table 6-3 show the NPV and volume yield differences starting with a well stocked 30 year old stand. If this stand were maintained in an even-aged condition, with the Table 4-7 benchmark variable values, the NPV is $3,400/acre. If this stand is converted to uneven-aged silviculture following the conversion strategy in Chapter 4, the NPV is $2,569/acre. This is 76 percent of the optimal even-aged silvicultural regime NPV. If uneven-aged silviculture is to be chosen over even-aged silviculture, this analysis shows that the annual non-timber benefits of the uneven-aged stand must be worth at least $33/acre more than the annual non-timber benefits of even-aged silviculture. The even-aged system yields a MAI of 163 ft^3/acre total volume of which 132 ft^3/acre is sawtimber, while the uneven-aged system yields a MAI of 85 ft^3 total and 82 ft^3 sawtimber over the 200 year volume projection period. Sensitivity analysis are presented in rows 2-6 of Table 6-3.

Table 6-3 shows that under none of the variables and combinations tested does uneven-aged silviculture yield higher NPVs than even-aged silviculture when starting from a well stocked even-aged stand. Uneven-aged silviculture yields between 60 and 78 percent of the NPV that even-aged silviculture yields.

TABLE 6-3. **Comparison of Net Present Values and Volume Yields Between Even-Aged Silviculture and Uneven-Aged Silviculture Starting from an Even-Aged Stand.**

| Table 4-7 Variables | Uneven-aged Silviculture | | Even-Aged Silviculture | | Uneven-aged NPV/Even-aged NPV | Equivalent Annual Annuity Difference $/Acre |
	NPV $/Acre	MAI Ft^3/Acre Sawtimber, Total Fiber	NPV $/Acre	MAI Ft^3/Acre Sawtimber, Total Fiber		
Bench-mark	2,569	82, 85	3,400	136, 163	0.76	33
Interest Rate 8%	1,581	82, 85	2,633	132, 163	0.60	42
Harvesting Cost II	2,661	83, 86	3,400	135, 163	0.78	30
Low Price Ratio	1,674	82, 85	2,434	103, 143	0.69	30
High Price Ratio	1,933	82, 85	2,705	133, 159	0.71	31
High Site	2,994	101, 104	3,909	161, 187	0.77	37

NPV Analysis Conclusions

The analysis of uneven-aged silvicultural regimes shows optimal regimes are relatively insensitive to the tested changes in the Table 4-7 values. The comparative analysis between uneven-aged and even-aged silviculture shows that even-aged silviculture is economically preferable to uneven-aged silviculture for the tested variable levels when starting from a bare land or a mature even-aged stand. When starting from a balanced uneven-aged stand this analysis shows that even-aged and uneven-aged silviculture are financially very competitive. At some variable levels uneven-aged silviculture yields higher NPVs than even-aged silviculture.

Analysis of annualized difference in NPV shows that, when starting from bare land or a mature even-aged stand, for uneven-aged silviculture to be preferred, its associated non-timber benefits must be between $3 and $44 per acre greater than non-timber benefits of even-aged silviculture. A discussion of many non-timber values follows in Chapter 7.

Redmond and Greenhalg (1990) found uneven-aged silviculture preferable to even-aged silviculture when considering certain understocked stands and high interest rates. Between clearing the understocked stand at a cost to the landowner and establishing even-aged silviculture, and developing and continuing uneven-aged silviculture, they found that the uneven-aged silviculture was sometimes preferable. Uneven-aged silviculture yielded higher NPVs at interest rates above 7.25 percent. Table 6-2 shows that starting with an uneven-aged stand with our benchmark variable values and 8 percent interest rate, that harvesting the uneven-aged and starting even-aged silviculture in some cases yields a higher NPV than continuing uneven-aged silviculture. This indicates that landowners with understocked stands, such as those modeled by Redmond and Greenhalg, may get higher NPV by developing the understocked for a period of years and then clearcutting, rather than developing the understocked stand and continuing uneven-aged silviculture.

NPV differences between silvicultural systems should be considered preliminary because of the nature of the growth and yield model used for uneven-aged silviculture, the uncertainty of future prices by log size, and the practicality of implementing these optimum regimes. The optimal uneven-aged regimes simulated for comparisons with the even-aged regimes are at the edge of the biologic limits at which an uneven-aged stands can be maintained. More silvicultural experience and practice will show if these limits can be extended or limited. In areas where regeneration is difficult to establish, higher maximum diameters and shorter cutting cycles may be necessary to successfully carry out this silvicultural system. As Figures 5-3 and 5-4 show, this has some negative impact on NPV of uneven-aged silviculture.

Chapter 7. Non-Timber Considerations

Not every difference in silvicultural systems can be captured in a NPV comparison. Some differences are difficult to include because their effects on NPV are not well know or the economic losses are not quantifiable. Some differences have effects on NPV only for landowners with particular goals and objectives. Other differences might have effects on NPV, but the level of impact is highly variable, so the risk of economic loss does not transfer well to an individual stand level analysis. This section outlines differences between even-aged and uneven-aged silviculture that are not included in the NPV analysis. Aesthetics, harvesting differences, silvicultural differences, modeling differences, and components of ecosystem management are addressed.

Most issues addressed in this section do not have definitive data quantifying differences between silvicultural systems. During my research, many professionals have shared their opinions about differences in silvicultural systems. Some of these opinions are in direct conflict with each other. This section outlines the different points of view associated with each issue. Published literature is drawn upon when possible.

Some of these issues are probabilities of economic loss due to predictable events, uncertainty due to poor data, or uncertainty of future market conditions. Often in economic analysis, these risks are addressed through higher discount rates. Management regimes with different levels of risk could be discounted at different rates to account for the different levels of risk. The large number of uncertainties, the uncertainty with which each issue applies to each silvicultural system, and the different opinions and values of landowners make these issues difficult to quantify into different discount levels for each silvicultural system. Instead, each landowner can consider potential risks by silvicultural system, and take these into account while considering NPV differences.

Aesthetic Differences.

While discussing uneven-aged silviculture and even-aged silviculture many people bring up the aesthetic qualities of both. visual quality may be a more descriptive term than aesthetics. Studies of visual quality show that, in general, there are certain desirable and undesirable characteristics of forests. People prefer vistas, but often rebel against clearcutting. They also prefer large trees and open, park-like stands much like many urban parks. Rows of trees are a detriment to visual quality. Roads are considered bad if they clash with the surrounding environment, such as new roads do, but old roads which do not contrast with the environment, can be good if they give the impression of accessibility and mystery. Stumps, downed wood, and slash lower visual quality. (Hull 1997)

Beyond these generalities, visual quality and aesthetic preferences are difficult to define and compare. Hull (1988) lists nine products of visual quality. To judge the visual quality of uneven-aged silviculture to even-aged silviculture, the desired product from visual quality must be agreed upon. Also, the impacts of silvicultural system must be considered over the planning horizon, not immediately before or after a management activity such as clearcutting. Visual quality is at least partly due to the accumulations of scenes as one moves through the landscape, so evaluation should not be from single, static landscape scenes.

Proponents of uneven-aged silviculture point out that the entire stand is never removed, there is never bare ground and dead tops to look at, and there are no sharp edges and unnatural patterns which are often created by clearcutting. Uneven-aged silviculture may be especially aesthetically pleasing when viewed from a long distance or from the air, where the forest canopy appears continuous. These arguments point out the natural appearance of uneven-aged silviculture which lacks clearcuts and defined edges.

Proponents of even-aged silviculture point out that the foliage of developing regeneration prohibits seeing for great distances in an uneven-aged forest. They claim that these forests lack places where one can see beyond the road edges, and that road edges in an uneven-aged forest would be very monotonous, lacking variety and contrast which help drivers stay alert. In defense of even-aged silviculture, proponents offer that clearcutting does not have to create sharp edges, that buffer strips can hide bare soil and dead tops until regeneration develops, and that even-aged silviculture looks similar to many other agricultural crops grown in the South. These arguments appeal to the preferences for vistas, which even-aged silviculture provides across over clearcuts and young plantations.

Both arguments point out strengths of each silvicultural system which appeal to the aesthetic, or visual qualities of each silvicultural system. Which silvicultural system yields more visual quality depends on the relative values attached to the visual products each provides.

To help illustrate different visual qualities of each silviculture system, a series of photos gives examples of from each silvicultural system.

PICTURES 7-1 - 7-3. Examples of Uneven-aged Silviculture.

Picture 7-1 (jpeg. 56 k)
Picture 7-2 (jpeg 57 k)
Picture 7-3 (jpeg 60 k.)

PICTURES 7-4 - 7-8. Examples of Even-aged Silviculture.

Clearcut - Picture 7-4 (jpeg 68 k)
Young Plantation Picture 7-5 (jpeg 38 k)
Older Plantation - Picture 7-6 (jpeg 49 k)
Age 16 - Picture 7-7 (jpeg. 89 k)
Mature Stand - Picture 7-8 (jpeg 85 k)

PICTURE 7-9. Even-aged Plantation in Front of a Mature Stand

Picture 7-9 (jpeg 55 k)

Harvesting Differences.

Timber harvesting is one of the key factors professionals address when considering differences between silvicultural systems. Entry frequency relates to many of the harvesting issues. The optimal uneven-aged cutting cycle under the Table 4-1 benchmark values is 11 years. The optimum even-aged silvicultural regime has one entry at age 15 and final harvest at age 30. There are at least 1.3 entries to the uneven-aged stand for every entry into the even-aged stand. Also, each entry into the uneven-aged stand is a thinning, while only 1 out of 2 into the even-aged stand is a thinning operation. The entry frequency should be kept in mind when considering each component of the harvesting operation.

Soil Disturbance. The link between soil disturbance and compaction, productivity, and sedimentation is dependent on many factors. Kluender et al. (1994) found that percentage of the residual stand area that was undisturbed decreased sharply with harvesting intensity. In that study, between 48.3 percent and 62.2 percent of the land area was undisturbed after the selection harvest while between 9.6 percent and 50.4 percent of the area clearcut was undisturbed. This must be considered in light of the entry frequency. This disturbance will be created more often in uneven-aged silviculture than in even-aged silviculture.

Reducing harvesting intensity will increase the number of acres which need to be entered to supply the same quantity of wood. Kluender et al. (1994) reported that 294 acres of uneven-aged stands would have to be entered to produce the same volume (1000 cf.) as 42.3 clearcut acres. Harvesting low volumes per acre could be a greater problem in areas where seasonally accessible sites are restricted to narrow harvesting windows. Road building is the part of the harvesting process with the greatest potential for causing water quality problems. Entering more acres to supply same quantity of wood will mean more roads and potentially more problems.

The effects of harvesting on soil compaction and sedimentation are very site specific and depend on many factors of the harvesting process. Machinery, soils, weather conditions, and operator care all have effects on compaction and sedimentation in either silvicultural system.

Harvest Damage. In a study of harvesting methods in even-aged and uneven-aged stands, Kluender et al. (1994) report there were 16 trees per acre damaged by the selection harvest. This will vary considerably depending on a wide variety of factors, however the important consideration is the difference between silvicultural systems. For the even-aged system, thinning happens only once every 30 years. If the same level of damage were incurred for each system when doing partial harvests, the even-aged system incurs this only 1/3 as often as the uneven-aged system. The economic losses due to this damage are difficult to quantify. Newbold and Rowell (1990) attempted to evaluate losses from damage from an even-aged thinning operation. Preliminary results indicate trees with greater than 50% bole damage (percentage of circumference at breast height) had considerably higher mortality than undamaged trees. For

those trees that survived, they calculate the discounted value loss due to be $1.80 per tree. They suggest this per tree damage value could be considerably higher for trees in uneven-aged stands. These factors are difficult to put into the NPV analysis because of the high variability in amount of damage and the unknown economic loss caused by that damage, but should be considered when choosing silvicultural systems. Pictures of harvesting damage illustrate damage that could occur in thinning of even-aged stands or in single-tree selection regeneration harvests of uneven-aged stands.

PICTURES 7-10 - 7-11. Harvesting Damage Possible in Partial Harvests.
Picture 7-10 (jpeg 43 k)
Picture 7-11 (jpeg 75 k)

Harvesting Contracts. Newbold and Rowell (1990) outline some of the problems and difficulties of executing contracts which help minimize the damage to the residual stand in partial harvests. They point out that loggers view partial harvests as constraints on productivity from reduced volume per acre harvested and from reduced efficiency from protecting residual trees. Also, landowners may not appreciate the fixed costs of logging operations or the maneuvering requirements of harvesting machinery. In two examples, Newbold and Rowell (1990) describe problems in securing protection for residual trees through written contracts. These examples show the need to communicate what the desired job constitutes, and that these restrictions reduce stumpage values. We make harvesting cost difference estimates in our analysis, but this will likely vary widely based on equipment, loggers, history, and market availability.

Minimum Sale Volumes. The minimum feasible sale volume should be considered when choosing silvicultural systems for small tracts. Loggers prefer jobs be at least large enough to constitute a weeks worth of work. If average daily production is 5 - 6 loads, and if each load is 25 tons, then minimum sale volume to provide a weeks worth of work is 625 - 750 tons. For jobs with lower total sale volumes, clearcut or single-tree regeneration harvests, higher logging costs should be expected.

The Future of Harvesting Costs. The current cost of the harvesting component is $12/ton for clearcutting. This equates to about 100 $/mbf, nearly one-half of the sawtimber stumpage value. For pulpwood, $12/ton is considerably higher than half of the raw material value. The future of harvesting costs is uncertain. Some speculate that technology has reached a plateau, and that labor costs will continue to rise. Others speculate that the trend to bigger, more efficient machines will continue, lowering harvesting costs in even-aged stands, but possibly increasing harvesting costs of partial harvests. Increased harvesting costs could widen the financial gap between uneven-aged and even-aged silviculture. Others speculate that raw material values will rise in response to increasing demand for wood and wood fiber. In this case, rising harvesting costs may be offset by increases in raw material value. When considering future expectations, consider the difference in volume yields and harvesting conditions between silvicultural systems.

Non-Quantifiable Silvicultural Differences.

Catastrophic Loss. Professionals point out that ice and wind can each catastrophically damage southern forests, and that the risks of each differ with silvicultural systems. Some point out that uneven-aged stands, with periodic thinnings, may be always be prone to extensive damage due to ice or wind. Also, the stand always has a high capital value on the stump. There is always the potential for loss due to ice or wind. These professionals suggest that even-aged stands may be more resistant, except for years immediately following thinnings. Also, when a stand is in a clearcut state, or in years immediately following, the value of the capital at risk is much smaller. The counter to this view is that uneven-aged stands are open-grown stands which are more resistant to ice and wind, even after periodic thinnings. More research in this area could help identify comparative risks.

If stands are damaged from ice or wind, and many surrounding stands are also damaged, harvesting equipment may be scarce. Denser even-aged stands may be more attractive for salvage operations, leaving less dense uneven-aged stands to be salvaged at a later date. If the damaged stand has a high component of large, high value trees, these may have higher salvage value than even-aged stands.

Chemicals Applications. Application of herbicides will vary greatly depending on the specific site and species conditions. Herbicides are a common component of both silvicultural systems. It is beyond the scope of this research to outline specific treatment recommendations, however potential differences in silvicultural systems can be identified.

Uneven-aged silviculture, especially on good sites, usually depends heavily on chemical control of hardwoods. Fire is being explored as a viable option, especially when long cutting cycles are used (Farrar 1996), but is not yet recommended way of controlling vegetation in uneven-aged forests. Usually herbicides are used, sometimes as frequently as every 7 years, but often in conjunction with harvest activities, 11 years in the recommended cutting cycle under the Table 4-1 benchmark values. Picture 7-12 shows vines constricting a loblolly pine sapling, a possibility when herbicide applications are not used to control competing vegetation.

PICTURE 7-12. Vines Constricting a Loblolly Pine Sapling.
Picture 7-12 (jpeg 56 k.)

In even-aged silviculture, herbicides are applied in stand establishment, possibly once for site preparation and once for release of established regeneration. Once the stand is free to grow, herbicides are not usually applied for the rest of the rotation. In even-aged silviculture, fire is a viable alternative to herbicides in stand establishment.

Two herbicide applications per 30 year rotation for even-aged silviculture is at least a third fewer applications than for uneven-aged silviculture. Also, in even-aged silviculture fire and site preparation activities can ameliorate the need for herbicide applications. Thus, an environmental concern in uneven-aged silviculture is the likelihood of heavier herbicide use than in traditional

even-aged silviculture. An added difficulty in uneven-aged silviculture is that herbicides must be applied with mature trees present on the stand. This can make aerial applications more difficult and possibly more costly than applications in even-aged silviculture.

Genetic Gains. Genetic improvement of planting stock has greatly improved yields of loblolly pine plantations. These gains may continue to improve volume and value yields from even-aged silviculture. Uneven-aged silviculture benefits from improved natural regeneration because deformed and slow trees are either out-competed for growing space, or are removed before they are of seed-bearing age through selective removals in harvesting. The gains from this built-in tree improvement program are difficult to quantify, although some professionals believe it at least equals those from genetic tree improvement programs. More research in this area would also improve the comparative analysis between silvicultural systems.

Wood Quality. Guldin and Fitzpatrick (1991) compared log quality from even-aged and uneven-aged silvicultural systems in South Arkansas. They found that trees from uneven-aged stands produced better sawlogs than trees from even-aged plantations. The authors state that the results should be considered indicative of quality differences expected from different silvicultural systems. Wood quality is highly related to thinning regimes, planting density, hardwood control, and genetics.

Price increases from value attributed to sawlogs grown in uneven-aged conditions over even-aged conditions may exist, but were not included in this analysis. If higher prices are available for trees with particular growth rates or stem quality, both silvicultural systems could be modified to change the characteristics of the harvested trees. If sawlogs from one silvicultural system are expected to bring significantly higher prices than sawlogs from the other, managers can look at the NPV levels between systems and the different price scenarios presented and consider how different prices might influence comparative analysis.

Non-Quantifiable Modeling Differences.

Growth and Yield. The data used for uneven-aged growth and yield are the best available. Comparisons between the three available growth models show that each predicts similar yields. Uneven-aged silviculture has not been practiced under BDQ regulation, the recommended regulation technique, long enough to validate growth and yield estimates. Actual yields may differ from the predicted yields. The even-aged data from Tauyield should be much more reliable. Even-aged silviculture has a much stronger growth and yield history than uneven-aged silviculture. Forest managers should keep in mind that growth estimates used in this study are preliminary. More research work, especially surrounding the Q factor, maximum diameter, and different site indexes, will strengthen this analysis.

Market Risk. We analyze different price ratios between sawtimber and pulp prices; however, some professionals predict that manufactured wood products may replace solid wood products and existing price differentials may lessen. This may make even-aged silviculture even more attractive compared to uneven-aged silviculture. Conversely, a premium for large diameter

sawtimber trees may continue, in small areas, or widely, and make growing high quality sawlogs more profitable. Opinions about where prices are heading, especially by product class, vary greatly.

Price Variability. As price levels in individual markets levels fluctuate, managers may want the flexibility to wait for timber markets to improve before selling timber. Uneven-aged silviculture has the benefit of smaller, more frequent, harvests. A dollar cost averaging effect results, reducing the variability of value yields. Figure 5-3 and 5-4 show that length of cutting cycle between 7 and 11 years does not have a great effect on NPV. However, waiting too long and developing too much basal area will kill the regeneration and reduce future harvest yields. Studies of even-aged silviculture also show that NPV is not highly sensitive to rotation ages within 2 or 3 years of the optimal age. Both silvicultural systems have some capacity to wait for acceptable prices.

Components of Ecosystem Management

Hardwood Retention. Uneven-aged silviculture often involves keeping the forest free of hardwoods. This is necessary for recruitment and retention of seedlings and saplings. Baker et al. (1996) suggests two options for maintaining hardwoods in uneven-aged stands when managers want greater species diversity. The first is to allow the desired level of hardwoods in the stand through single tree selection. Up to about 10 ft^2/acre of hardwoods might be able to replace pine in an uneven-aged stand without severely restricting pine regeneration establishment and growth. This hardwood component would likely not support an operational hardwood harvest, but could be a source of firewood. It would cause a corresponding reduction in pine volume. The second option is to maintain hardwoods in certain portions of the stand. This option makes it easier to protect the hardwoods during vegetation management applications in the rest of the stand, allows optimal species-site relationships, concentrates mast-producing trees in specific areas, can protect ecologically sensitive areas, simplifies silvicultural practices for the rest of the stand, and creates diverse wildlife habitat. The rest of the stand could be maintained in pure or mostly pure pine. Either of these options would reduce pine volume and value.

Even-aged stands managed to maximize NPV also have a very small or non-existent hardwood component. A few hardwoods may survive in the understory, however they are removed during harvesting and site preparation activities prior to establishing regeneration. Similar options for hardwood retention could be employed in even-aged silviculture as were suggested for uneven-aged silviculture.

Diversity. Neither system, optimized for NPV, is great for plant diversity. Each has pine as its major component, and excludes other species from reaching maturity. Uneven-aged silviculture maintains stands in one successional stage, so may have less diversity than even-aged silviculture.

Wildlife Habitat. Even-aged and Uneven-aged silviculture provide different wildlife habitat types. Even-aged has definitive edge effects, clearcuts, and even-aged stands from plantations through to mature timber. Uneven-aged silviculture has continuous forest cover in a

mosaic of stand conditions. Small patches and individual mature trees are surrounded by regeneration in various stages of development. Each silvicultural system provides different habitat types. Individual wildlife species needs should be considered when addressing impacts of silvicultural systems on wildlife habitat. However, no published information outlines quantifiable differences in wildlife populations which could be expected under even-aged versus uneven-aged silviculture in loblolly pine.

The potential for uneven-aged silviculture to be habitat for the red-cockaded woodpecker (RCW) is being evaluated. Rudolph and Conner (1996) claim that even-aged and uneven-aged silvicultural systems, properly implemented, are both compatible with recovery of the RCW. The silvicultural regimes they discus vary considerably from the regimes which maximize NPV discussed here. Modification to retain necessary conditions for the RCW would result in lower NPV for both systems.

White-tailed deer (Odocoileus virginianus) is one of the premier big game animals in North America. Even-aged silviculture provides excellent habitat for these animals, especially when units are less than 60 acres and age classes are well dispersed throughout the forest (Halls 1984). Uneven-aged silviculture, with the frequent entries and relatively low basal areas should also provide the food supply and cover these animals need. The impact of more uneven-aged silviculture on deer populations is not known, however this system can be expected to maintain healthy populations of these animals.

Ecosystem Context. Uneven-aged silviculture mimics the scattered overstory mortality of late successional stages (Baker et al. 1996, Guldin 1996). Like late successional stages of natural stands of loblolly pine, a stand managed with uneven-aged silviculture maintains continuous forest cover. Unlike late successional stages, uneven-aged stands do not have high levels of downed woody debris and very low net growth. Naturally occurring forests in late successional stages also had high hardwood components in the understory, and, following single tree disturbance events, in the overstory. Uneven-aged stands, managed for maximization of NPV, would be hardwood free.

Guldin (1996) suggests that for ecosystem management, a forest should have a variety of disturbance sizes, disturbance intensities, and successional stages. If ecosystem management is a goal of forest managers, the options for hardwood retention should be considered along with silvicultural system selection and appropriate adjustments in projected NPVs made.

Chapter 8. Future Research

Future research would strengthen this analysis of uneven-aged silviculture and the comparison between silvicultural systems. This section outlines areas where future research would help comparative analysis.

Growth and Yield

Plots are installed (Murphy and Shelton 1994) in Arkansas and Louisiana to strengthen the growth and yield work from uneven-aged stands under BDQ regulation. Continued support of these studies will provide long term growth and yield data which can be used to develop better growth and yield models for uneven-aged stands and BDQ regulation.

The transition of these stands from even-aged stands or understocked stands should also be measured. Converting stands between silvicultural systems is a time consuming and costly operation. Developing efficient ways to make this conversion would provide more accurate comparisons between silvicultural alternatives. For understocked stands the question should be addressed of which silvicultural system to adopt and also when to adopt it. An initial stand could be clearcut, developed into an uneven-aged stand, or developed into a mixed age stand which is later clearcut.

This study and other studies address stands of pure loblolly pine. For landowners with goals other than NPV maximization, mixed species stands should be addressed. An alternative to clearcutting might involve mixed species stands and longer rotations with multiple thinnings, that is even-aged, but never clearcut.

Two-Story Stands.

Another alternative to silvicultural systems with clearcuts are two-story stands. There are multiple ways a two-story stand could be perpetuated. Growth and yield data is not available to model these stands. For those interested in this alternative to clearcutting, equations 3-1 and 3-2 can be adapted to costs and revenues of two story stands.

Keys to considering two-story stands are stocking control and regeneration. Research shows that basal areas above 80 ft^2/acre kill understory loblolly pine regeneration. The basal area must be kept below this limit while loblolly pine is in the understory. A similar tradeoff between cutting cycle length and basal area occurs as in the BDQ regulation. Long cutting cycles must have low residual basal areas in order to develop and maintain the understory throughout the cutting cycle length. Many of the same non-timber issues apply to two-story stands as were discussed in Chapter 7.

Artificial Regeneration. One possible two-story system could use artificial regeneration. This would allow introducing genetically superior stocking. Genetically improved trees which are

more shade tolerant or have better wood quality could improve yields and value. An intensive two-story stand could be maintained by controlling stocking and regeneration at many different stand ages and densities. One possibility of such a system could have a 15 year cutting cycle. If the starting inventory is an even-aged 15 year old stand, the stand could be heavily thinned and under-planted. At age 30 the overstory could be removed, and the understory would be thinned as necessary and the stand replanted. The thinning would have to be heavy enough so the remaining trees did not shade out regeneration. This system would never be clearcut and could yield a steady supply of wood products. Available even-aged growth and yield models could be used to estimate yields from the overstory. Appropriate adjustments in growth should be made for trees in the understory.

Concerns about this system are that the 15 year old trees will be susceptible to windthrow if they are not prepared through stocking control. Wide planting spacing of 10 X10 or greater might be necessary for these trees to be able to withstand the heavy thinning necessary. Some harvest damage is likely to be sustained at each entry. This damage has all the same problems and connotations as the harvesting of stands under BDQ regulation. Figures 8-1 through 8-5 show how a two-stand, such as the one suggested, might develop.
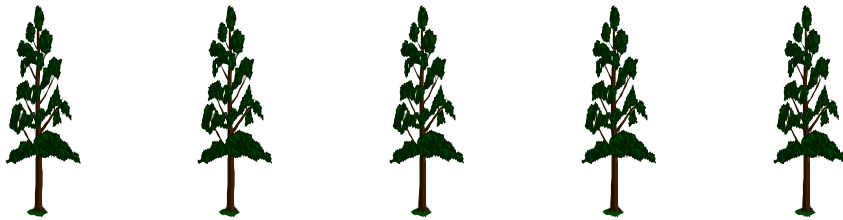
PICTURE 8-1. Year 0. Start from a 15 Year Old Even-Aged Plantation.
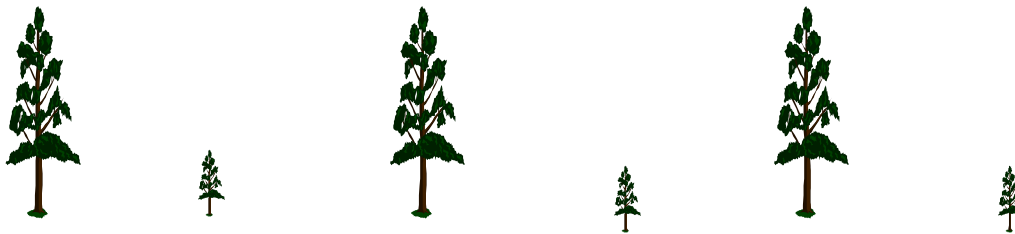
PICTURE 8-2. Year 0 After Harvest. The Plantation is Thinned and Planted.
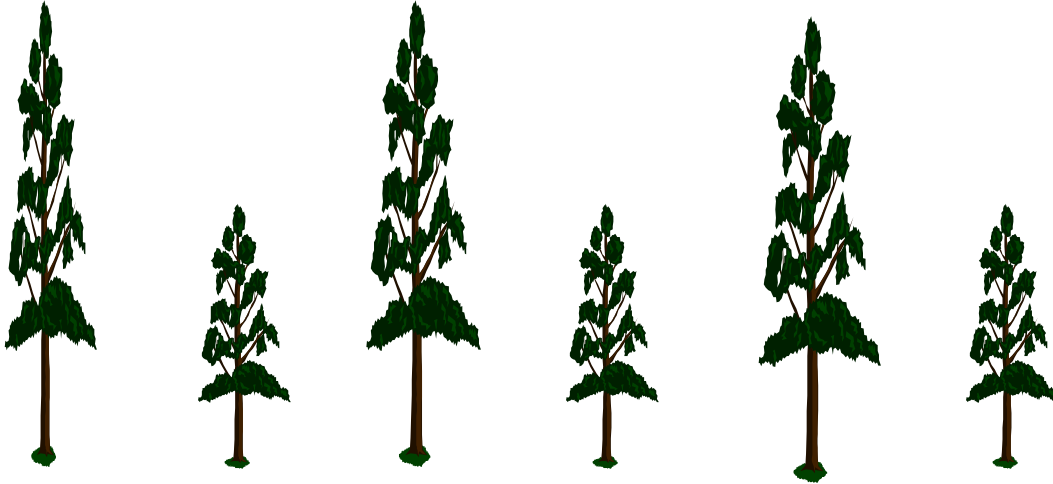
PICTURE 8-3. Year 15. The Stand has Developed into a Two-Aged Stand with Ages 30 and 15.
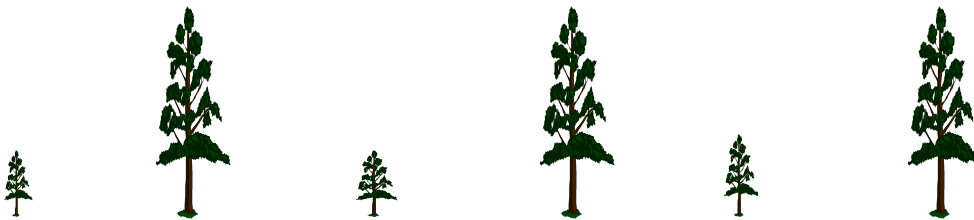
PICTURE 8-4. Year 15 After Harvest. The 30 Year Old Overstory has been Harvested and the Stand is Again Planted.
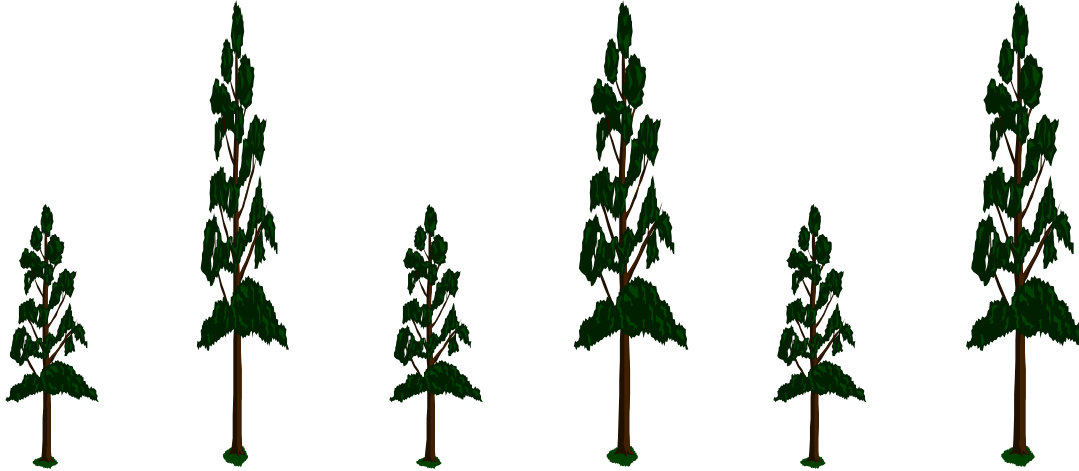
PICTURE 8-5. Year 30. The Two-Aged Stand is Perpetuated. Year 30 Harvest Would Remove the 30 Year Old Trees and Replace them with Seedlings.

Natural Regeneration If natural regeneration is desired, then tree size and viability for seed production must be considered. One possible system would be to start with an even-aged stand. The stand could be periodically thinned to enhance vigor of the residual trees. A regeneration cut would need to open up the stand to allow natural regeneration by at least harvesting to 60 - 70 ft^2/acre of basal area. The stand would then need to be re-entered and the overstory removed before crown closure and loss of regeneration. The overstory could be removed any time after regeneration is established, in a single reentry, as a shelterwood silvicultural system, or in several re-entries. This system could be maintained so that the site never has the negative connotations of clearcutting.

Other Research Opportunities

Harvesting Differences. Much work in the harvesting process could strengthen this analysis. Comparative research using optimal harvesting systems for each silvicultural system would help quantify harvesting cost differences. Measures of site disturbance, both of soil and residual trees could quantify important differences between silvicultural systems. Long term studies of site productivity and soil and water relationships could identify differences between silvicultural systems.

Log Values. Another important area that more research could strengthen are the effects of silvicultural regimes on log values. Silvicultural systems, harvest timing, and harvest intensity may effect log values in ways that cubic foot volume does not show. Some professionals suggest that logs grown in uneven-aged silvicultural regimes are much more valuable than logs grown in plantations. Others suggest that logs of different characteristics can be grown under either silvicultural system through careful control of stocking and through silvicultural investments.

A stronger link between log characteristics and log value would also strengthen the analysis. Final product yield by log diameter class and grade would strengthen analysis of different silvicultural regimes and comparisons between silvicultural systems. Quantifying these difference might change optimal regimes and the comparative analysis of the silvicultural systems.

Catastrophic Losses. Stand susceptibility to ice storms, hurricanes, insects, fire, and diseases would help. Measuring economic losses in uneven stands would include value losses at the time of the event and the impact on future periodic harvests. This could be compared to losses in even-aged stands from similar events. The susceptibility of the different even-aged age classes to these events must be considered.

Chemical Applications. Experimentation with site preparation tools other than herbicides in uneven-aged silviculture is being investigated (Farrar 1996). For those landowners who desire not to use herbicides, this would take away a concern of uneven-aged silviculture.

Genetic Gains. Genetically improved stock has the potential to increase yields in uneven-aged silviculture. These could be introduced through understory planting after periodic harvests. The genetically improved stocking could be specially selected for characteristics that would help in an uneven-aged stand. This could be shade tolerance, better form class, or faster growth under low light conditions. These trees might extend the biological ranges of uneven-aged silviculture.

Wildlife Habitat. There is no quantitative data on how different species would respond to large acreages managed with uneven-aged silviculture. Certainly habitat changes dramatically with silvicultural systems, but the changes in quantity and quality of vegetation necessary for different wildlife species are not clear. More research would yield information on the effect of silvicultural system on different species.

Chapter 9 Summary and Conclusions

Using the uneven-aged growth model Southpro (Buongiorno and Schulte 1997), and the even-aged growth model Tauyield (Amateis et al. 1996), and spreadsheet simulations, this study compares financially optimal uneven-aged and even-aged loblolly pine silvicultural regimes. Uneven-aged regimes which maximize net present value (NPV) are found by quantifying the effects of diameter distribution (Q factor), maximum diameter, cutting cycle, and residual basal area on NPV. Financially optimal even-aged regimes are taken from published literature of even-aged silviculture.

Under the benchmark variable values (See Table 4-7), the optimum uneven-aged regime has a Q factor of 1.2 (1" diameter classes), maximum diameter of 12 inches, residual basal area of 45 ft^2/acre, and a cutting cycle of 11 years. This maintains the basal area within biologically feasible limits, allows for natural regeneration, and provides operable harvest levels. When the real interest rate increases from 4 to 8 percent, the optimum uneven-aged regime does not change. Under the low harvesting cost scenario II, the optimum uneven-aged regime changes to a cutting cycle of 7 years, and a residual basal area of 55 ft^2/acre. The tested range of sawtimber to pulpwood price ratios does not change the optimum uneven-aged regime. On high sites, the optimum cutting cycle length changes to 9 years.

The even-aged silvicultural regime which maximizes NPV for the benchmark variable level is a stand planted at 10 X 10 foot spacing (436 tpa), thinned from below at age 15 to 70 ft^2/acre of basal area, and clearcut at age 30. When the interest rate is 8 percent, the rotation age is shortened to 28 years. The low harvesting cost scenario II does not change the optimum even-aged regime. When there is a low sawtimber to pulpwood price ratio, thinning age is 20 years and rotation age is 28. When there is a high sawtimber to pulpwood price ratio, the even-aged regime which maximizes NPV has one thinning at age 17 and final harvest at age 32. On high sites the optimal regime is thinned at age 10 to 40 ft^2/acre of basal area and the final harvest age is 30 years.

Even-aged and uneven-aged silvicultural regimes are simulated starting from bare land, a mature even-aged loblolly pine stand, and a balanced uneven-aged loblolly pine stand. The conversion strategy from a mature even-aged stand is taken from published literature. The conversion strategy from bare land to an uneven-aged stand is our estimate of an efficient way to do this. Neither of these conversions are optimized.

Starting From Bare Land

Starting from bare land, under benchmark variable values of site index, interest rates, prices, and harvesting costs, simulation of even-aged silviculture yields a NPV of $877/acre. The uneven-aged simulation yields a NPV of $654/acre or 75 percent of the even-aged NPV. Sensitivity analysis shows, for the levels of the variables tested, that even-aged silviculture yields higher NPVs than uneven-aged silviculture when starting from bare land.

High interest rates reduce NPV of uneven-aged silviculture compared to even-aged silviculture. Even-aged silviculture yields higher volumes sooner than uneven-aged silviculture, and, under high interest rates, these volumes are comparatively more valuable. When increasing the interest rate from 4 to 8 percent, the NPV of simulated even-aged silviculture is $110/acre and the NPV from simulated uneven-aged silviculture is $33/acre, or 31 percent of the even-aged silviculture NPV.

The tested harvesting cost scenarios and the different price scenarios have only small impacts on the difference in NPV between systems. Under these variable levels, uneven-aged silviculture yields between 75 and 78 percent of the even-aged NPV. When site index was increased from 90 to 110 (loblolly pine base age 50), with the benchmark variable values, even-aged silviculture has a NPV of $1,570/acre and uneven-aged silviculture has a NPV of $1,017/acre.

The difference in NPV between silvicultural systems was expressed as an equal annual cash flow. Starting from bare land, under the benchmark variable values, uneven-aged silviculture annually yields $9/acre less than the even-aged silviculture. To justify uneven-aged silviculture on a financial basis, the annual non-timber benefits of uneven-aged silviculture must be worth at least $9/acre more than the annual non-timber benefits of even-aged silviculture. The sensitivity analysis shows that for the selected changes in variable values, yearly non-timber benefits of uneven-aged silviculture must be worth between $3 and $22/acre more than the annual non-timber benefits of even-aged silviculture.

Starting from an Uneven-aged Stand.

Starting from an uneven-aged stand with 65 ft^2/acre of basal area, under the benchmark variable values, simulation of even-aged silviculture yields a NPV of $2,152/acre and simulation of uneven-aged silviculture yields a NPV of $2,084/acre. This NPV from uneven-aged silviculture is 97 percent of the even-aged NPV. Sensitivity analysis shows, for all the levels of the variables tested, that even-aged silviculture and uneven-aged silviculture yield very similar NPVs, when starting with an even-aged stand.

When interest rates are raised to 8 percent, simulation of even-aged silviculture yields a NPV of $1,413/acre, and simulation of uneven-aged silviculture yields a NPV of $1,207/acre, or 85 percent of the NPV from even-aged silviculture. The lower uneven-aged NPV reflects the opportunity cost of not clearcutting the initial stand volume and establishing even-aged silviculture.

Compared to the benchmark case, the low harvesting cost scenario II has little effect on the NPV comparison. The NPV from simulated uneven-aged silviculture with the low harvesting cost scenario II is $2,143/acre, and NPV from simulated even-aged silviculture is $2,152/acre.

The two different price scenarios work in opposite directions. When the sawtimber pulpwood price ratio is low, simulation of even-aged silviculture yields a NPV of $1,328/acre and simulation of uneven-aged silviculture yields a NPV of $1,207/acre. The NPV from uneven-aged

silviculture is 91 percent of the NPV from even-aged silviculture. When the sawtimber to pulpwood price ratio is high, simulation of uneven-aged silviculture yields a NPV of $1,604/acre and simulation of even-aged silviculture yields a NPV of $1,505/acre. The uneven-aged silviculture yields 1.07 percent of the even-aged silvicultural value.

When existing stands are understocked (less than 65 ft^2/acre of basal area), Redmond and Greenhalg (1990) found that under certain conditions converting these stands to even-aged silviculture had lower NPV than developing these stands for uneven-aged production. A third option is to develop the understocked stands for a period of years, similar to the development period for uneven-aged silviculture modeled by Redmond and Greenhalg, and later convert to even-aged silviculture. The exact development period and optimal time for conversion to even-aged silviculture would depend on the starting inventory and other factors.

Starting from an uneven-aged stand under the benchmark variable values, the uneven-aged silviculture annually yields $3/acre less than the even-aged silviculture. Sensitivity analysis shows, under the different variable levels tested, that the systems are financially very competitive when starting from an uneven-aged stand. Under certain conditions, simulation shows that uneven-aged silviculture yields higher NPVs than even-aged silviculture. Equivalent annual annuity needed to justify one system over the other on non-timber values is not more than $8/acre for the selected variable levels when starting with an uneven-aged stand.

Starting from a Mature Even-aged Stand

Starting from a mature even-aged stand, under the benchmark variable values, simulation of even-aged silviculture has a NPV of $3,400/acre and simulation of uneven-aged silviculture has a NPV of $2,569/acre. Sensitivity analysis shows, for the levels of the variables tested, that even-aged silviculture yields higher NPVs when starting with a mature even-aged stand.

High interest rates penalize uneven-aged silviculture compared to even-aged silviculture when starting from a mature even-aged stand. Even-aged silviculture yields higher volumes sooner, and, under high interest rates, these volumes are comparatively more valuable. The NPV from simulated uneven-aged silviculture at 8 percent interest rates is $1,581/acre. NPV from simulated even-aged silviculture at 8 percent interest rate is $2,633/acre. The NPV from uneven-aged silviculture is 60 percent of the NPV from even-aged silviculture.

The different harvesting cost scenarios and the different price scenarios have little effect on the difference in NPV between systems when starting from a mature even-aged stand. The uneven-aged silvicultural regimes yield between 69 and 78 percent of the even-aged silvicultural regimes under these levels of harvesting costs and these price differences.

On the high site, loblolly pine site 110 (base age 50), even-aged silviculture yields a NPV of $3,909/acre compared to the uneven-aged silviculture NPV of $2,994/acre. The uneven-aged silviculture yields 77 percent of the even-aged silvicultural value.

Starting from a mature, even-aged stand under the benchmark variable values, the uneven-aged silviculture annually yields $33/acre less than the even-aged silviculture. To justify uneven-aged silviculture from a financial basis, the annual non-timber benefits of uneven-aged silviculture must be worth at least $33/acre more than the non-timber benefits of even-aged silviculture. The sensitivity analysis shows that for the selected changes in variable values, yearly non-timber benefits of uneven-aged silviculture must be worth between $31 and $42/acre more than non-timber benefits from even-aged silviculture.

Summary of Non Timber Conclusions

Non-timber considerations between silvicultural systems are not well documented in literature of loblolly pine. Resource professionals hold opinions often in direct conflict with each other about non-timber costs and benefits. More research would help strengthen comparisons between silvicultural systems.

Scenic values, or aesthetic differences, depend on what product of scenic value is desired. Uneven-aged silviculture may be preferred scenically over even-aged silviculture because it lacks clearcuts. Even-aged silviculture may be preferred over uneven-aged silviculture because it has a diversity of scenes, has a more open understory in mature stands, and has vista-like views which clearcuts and young plantations provide.

There are many differences between silvicultural systems in harvesting processes. The financial analysis incorporates two different estimates of likely differences in harvesting costs between silvicultural systems. More research on harvesting costs in uneven-aged stands is needed. Not included in this financial analysis are the effects on long term soil productivity and water quality of the increased entry frequency in uneven-aged silviculture over even-aged silviculture. The increased entry cycle also has the potential to cause more residual stand damage in uneven-aged harvesting than in even-aged thinnings. Different types of stand damage in each silvicultural system have not been quantified.

Differing views exist on the risk of catastrophic losses in different silvicultural systems. Uneven-aged stands may be less susceptible to some risks because the largely open-grown trees may be more vigorous and able to withstand wind, ice, and disease better than trees in even-aged stands.

Uneven-aged silviculture depends heavily on periodic herbicide applications, which are necessary to control competing species to allow pine regeneration. While herbicide applications are also common in even-aged silviculture, they are likely to be less frequent and alternative site preparation activities, such as fire and mechanical site preparation, can lower herbicide use. Thus, potential negative environmental or social impacts of herbicide use are likely to be less wit even-aged silviculture.

The common practice of artificial regeneration can introduce genetic gains into even-aged silviculture. The value and costs of these gains is difficult to predict. In uneven-aged silviculture the selection process allows for continuous selection of the best trees for reproduction. This

genetic gain is also difficult to measure. Introducing genetic gains through artificial regeneration in uneven-aged stands could be practiced, but has not been done. Genetic gains in more shade tolerant trees could enhance yields from uneven-aged silviculture.

In uneven-aged silviculture, hardwoods can exclude regeneration. In even-aged silviculture, hardwoods can take up growing space or are shaded out by overstory pine. Either system can incorporate hardwoods in patches or throughout the stand. This would reduce NPV, but may provide increases in non-timber forest benefits.

Wildlife habitat changes with silvicultural systems. The effects on different species are not known and difficult to predict. In uneven-aged systems the habitat is consistent, with few changes over the length of the cutting cycle. In even-aged systems, the habitat changes dramatically throughout the rotation. Species specific needs must be addressed when considering differences in silvicultural systems from a wildlife standpoint.

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Appendix A. Harvesting Costs

Studies of thinning costs in even-aged pine stands and from thinnings in other forest types as discussed in the literature review may not be representative of harvesting costs that would be incurred in single-tree selection regeneration harvests from uneven-aged stands. These studies found that volume removed per acre, average diameter of removed stems, total sale volume, and percent of basal area removed each significantly impact total or unit harvesting costs. In single-tree selection regeneration harvests, volume per acre and total sale volume are lower than in clearcutting, raising harvesting costs, not unlike even-aged thinning costs. Unlike thinning from even-aged stands, the average size of the stems removed in selection harvesting of uneven-aged stands is often larger than in clear-cutting or even-aged thinning operations. This lowers logging costs. Percent basal area removed and the difficulty of maneuvering around residual stems will vary depending on the uneven-aged silvicultural regime. Care spent avoiding damage to residual trees, critical for future harvests, has the potential to increase logging costs. Efficiency in single-tree regeneration harvests is less than in even-aged thinnings because trees are marked for removal. The logger has less freedom to choose which trees to take or leave and cannot select these to increase the efficiency of the harvest operation.

We make comparisons using two harvesting cost scenarios. Both predict that costs of selection harvesting in uneven-aged stands are higher than clearcutting even-aged stands. The first scenario, which has a high penalty for harvesting small volumes, is an estimate based on experts' opinions and judgments of how much more selection harvesting of uneven-aged stands might cost than clearcutting. This scenario depends on using the most efficient equipment for each harvest operation. For clearcutting this would be a feller-buncher/grapple skidder operation. For the single-tree regeneration harvesting, this would likely be manual felling and grapple or cable skidders. Single-tree selection harvesting of uneven-aged stands are projected to cost 30% higher than clearcutting even-aged stands, regardless of average stem diameter. The second scenario, based on the study of Kluender and Stokes (1997), projects that selective harvesting of uneven-aged stands costs are from 5 to 13% higher than clearcutting even-aged stands, depending on percent volume cut and average diameter of the removed trees. This study used manual felling and grapple skidders for both the clearcut and the single-tree regeneration harvests. Readers can consider their own areas and stand conditions and evaluate the results accordingly.

Benchmark Harvesting Costs

Because data of selective harvesting of uneven-aged stands are limited, and because professionals harbor strong beliefs about how much selective harvesting might or might not cost more than clearcutting, our benchmark scenario is an estimate. 12 $/ton is used as the clearcut harvesting cost. If taking 100 % of the volume, the harvesting cost would be 12 $/ton. Our estimate suggests that single-tree regeneration harvests removing 25% of the volume incur harvesting costs 30% higher than clearcutting costs. So a selective harvest, removing 25% of average clearcut volumes, would incur harvesting costs of 15.60 $/ton. For more or less volume harvested, costs are estimated to be higher or lower.

Harvesting costs for each entry into uneven-aged stands are based on the periodic volume the uneven-aged regime yields. Cutting cycles between 7 and 9 years yield around 25% of clearcut volumes. These regimes are assigned the 30% higher cost associated with removing 25% of clearcut volumes, 15.60 $/ton. Cutting cycles between 3 and 5 years yield around 10 percent of average clearcut volumes. These regimes are assigned higher harvesting costs of 18 $/ton. Cutting cycles of 11 years yield volumes closer to 50% of the volume expected from clearcutting. These cutting cycles are assigned harvesting costs of 13.80 $/ton. These harvesting costs are presented in Figure A-1.
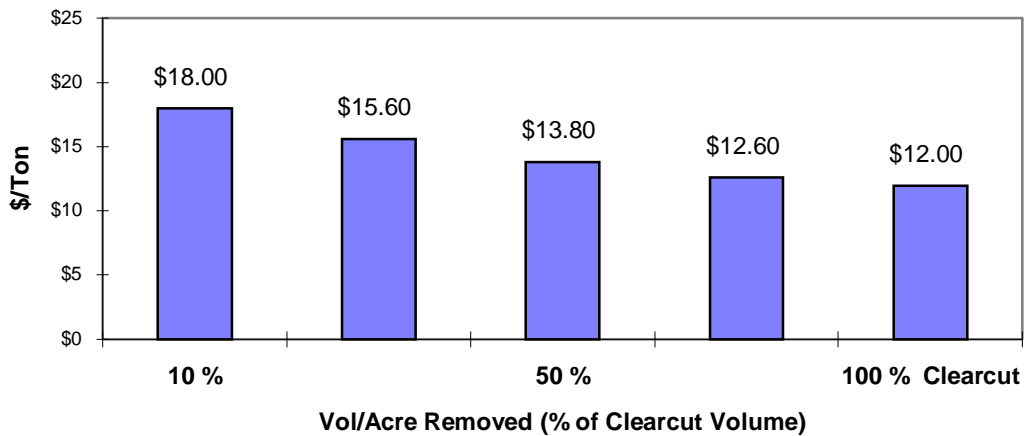
FIGURE A-1.   Benchmark Harvesting Costs ($/Ton) Assigned by Percent Volume Removed.

These harvesting costs are converted $/mbf Scribner and $/cord pulpwood using 7.5 tons/mbf and 2.68 tons/cord. The additional cost of selection harvesting from uneven-aged stands over the clearcut unit costs are deducted from the clearcut stumpage prices. The resulting prices for chip-n-saw and sawtimber yields are in Figure A-2, and for pulpwood in Figure A-3.
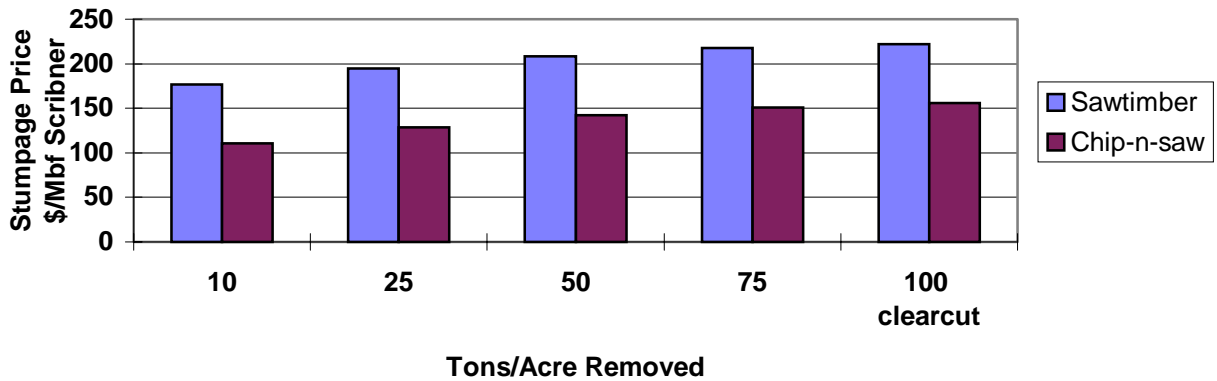
FIGURE A-2. **Benchmark Stumpage Prices for Chip-n-Saw and Sawtimber by Volume per Acre Removed.**
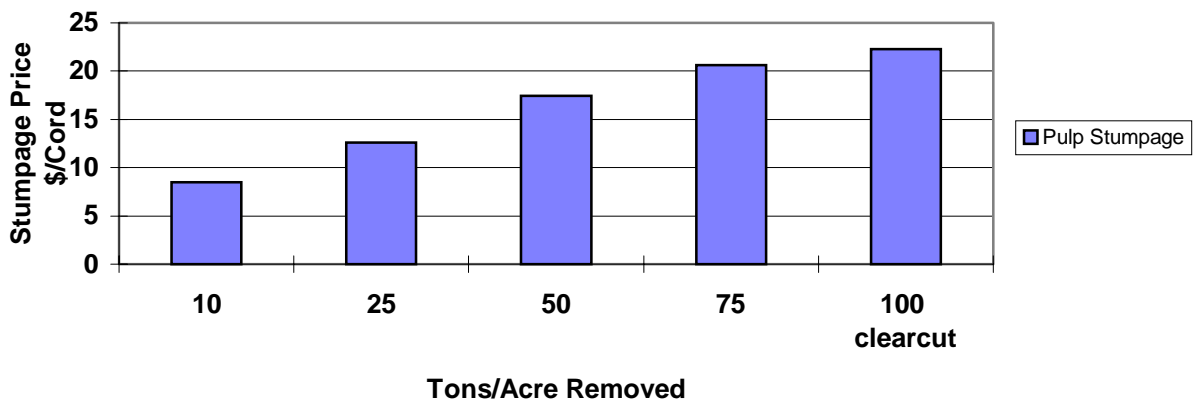
FIGURE A-3. **Benchmark Stumpage Prices for Pulpwood by Percent Volume per Acre Removed.**

An additional charge of $25.00/acre is assigned to cover costs of moving and setup. Table A-1 summarizes stumpage prices based on percent removed for the benchmark harvesting cost scenario.

TABLE A-1.   Stumpage Prices Based on Tons per Acre Removed - With the Benchmark Harvesting Costs Included.

| Product	Tons Removed Per Acre				
	10	**25**	**50**	**75**	**100+ (Clearcut)**
Pulpwood $/cord	$8.48	$12.61	$17.44	$20.65	$22.26
Chip-n-Saw $/mbf Scribner	$110.56	$128.56	$142.06	$151.06	$155.56
Sawtimber $/mbf Scribner	$177.00	$195.00	$208.50	$217.50	$222.00

Harvesting Cost Scenario II .

Harvesting cost scenario II uses the study of Kluender and Stokes (1997). Using manual felling and a 95 horsepower grapple skidder, logging costs were found to be as presented in Figure A-4.

For this harvesting cost scenario, $12/ton is still used as the clearcut harvesting cost. Harvesting costs in selective harvests of uneven-aged stands are adjusted by the percentage differences found by Kluender and Stokes (1997). Smaller or larger diameters and less than clearcut volumes are adjusted accordingly. These costs are incorporated into stumpage prices and summarized in Figure A-5 for sawtimber and chip-n-saw and in Figure A-6 for pulpwood.
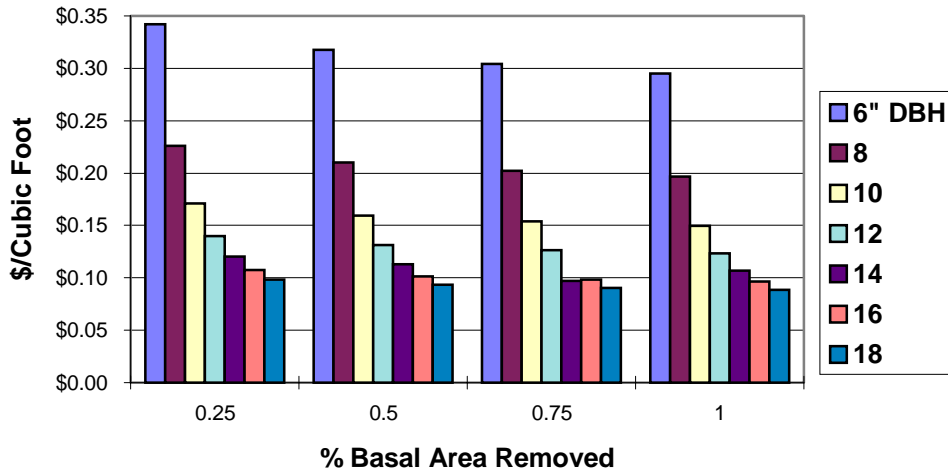
FIGURE A-4. Harvesting Costs Scenario II - Harvesting Cost Per Cubic Foot by Diameter Class of Removed Trees and Percent Basal Area Removed.
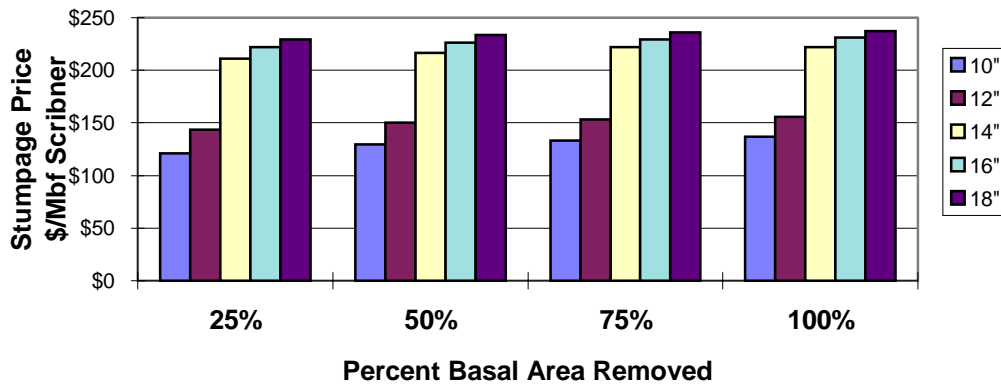
FIGURE A-5. Harvesting Cost Scenario II. - Stumpage Prices for Chip-n-Saw and Sawtimber by Diameter Class and Percent Basal Area Removed for Harvesting Cost Scenario II.
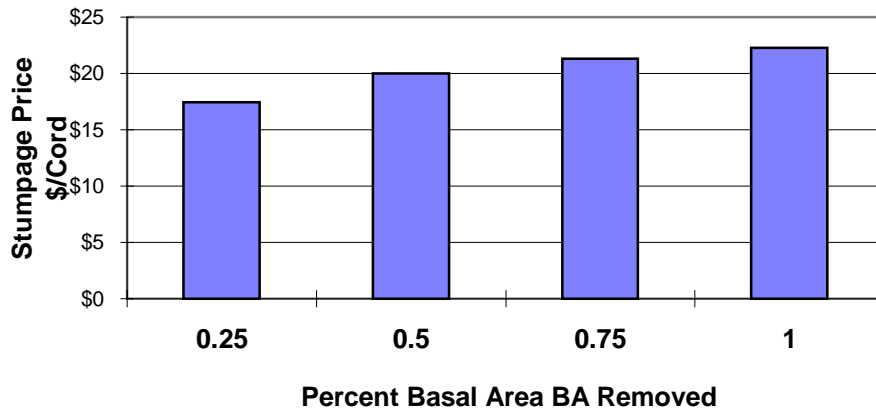
FIGURE A-6. **Harvesting Cost Scenario II. - Stumpage Prices for Pulpwood by Diameter Class and Percent Basal Area Removed for Harvesting Cost Scenario II.**

A summary of the stumpage prices by diameter class and percent basal area removed is in Table A-2. In our analysis, the 25 percent basal area removed corresponds to cutting cycles of 3 and 5 years and the 50 percent basal area removed corresponds to 7, 9 and 11 year cutting cycles.

**TABLE A-2.** **Harvesting Cost Scenario II. - Stumpage Prices by Diameter Class and Percent Volume Removed**

| Product | Percent Basal Area Removed | | | |
	25%	50%	75%	100% (Clearcut)
Pulpwood $/cord	$17.44	$19.99	$21.33	$22.26
Chip-n-Saw 10" $/mbf Scribner	$121.09	$129.34	$133.47	$136.57
Chip-n-Saw 12" $/mbf	$143.79	$149.99	$153.50	$155.56
14" Sawtimber $/mbf	$210.81	$216.76	$222.00	$222.00
16" Sawtimber $/mbf	$221.76	$226.52	$229.14	$231.05
18" Sawtimber $/mbf	$229.38	$233.67	$236.05	$237.48

# Appendix B- Comparison of Uneven-Aged Growth and Yield Models

There are 3 uneven-aged growth models available for modeling development of uneven-aged loblolly pine. Two of these are basal area projectors, which calculate basal area growth and sawtimber volume growth based only on basal area at the beginning of the growth period and time. These were developed from well managed uneven-aged research plots in Southern Arkansas and Northern Louisiana on loblolly site 85 - 90 (base age 50). (Murphy and Shelton 1996, Murphy and Farrar 1982) The third model, Southpro (Buongiorno and Schulte 1997), is a site and density dependent multi-species matrix model for predicting the development of loblolly pine forests. Forest Inventory and Analysis data from the United States Forest Service were used to estimate the ingrowth, upgrowth, and mortality equations. Plots included in the data set had to be classified as within the loblolly pine forest type, be measured at least twice, be classified as "mixed age," and be natural stands. Re-measurement period was between 6 and 11 years and averaged 7.3 years.

This growth and yield model allows modeling of diameter distributions, price/diameter relationships, adjustments in logging costs for diameter class distributions, and models a range of site classes, which the other growth models do not. Fot these reasons, Southpro is the preferred growth and yield model.

Figure B-1 - B-3 show merchantable ft^3 growth projections of the three models for three different stand conditions. In each case, Southpro predicts less growth than the other two models. This should be expected because the data for Southpro comes from a wide range of stand conditions that qualify as uneven-aged, while the data for the other two models come from well managed uneven-aged stands.
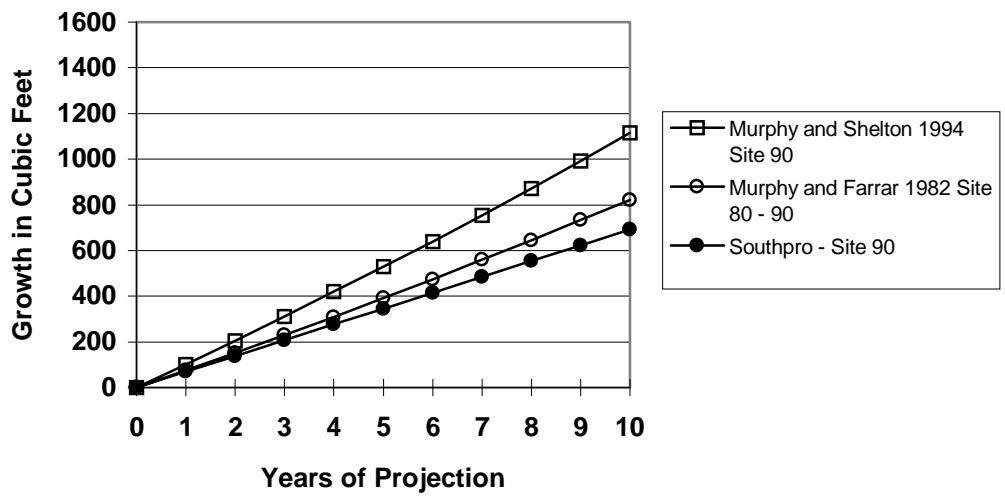
FIGURE B-1. **Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Starting Condition is an Uneven-aged Stand with 45 ft^2 of Basal Area and a Maximum Diameter of 14"**
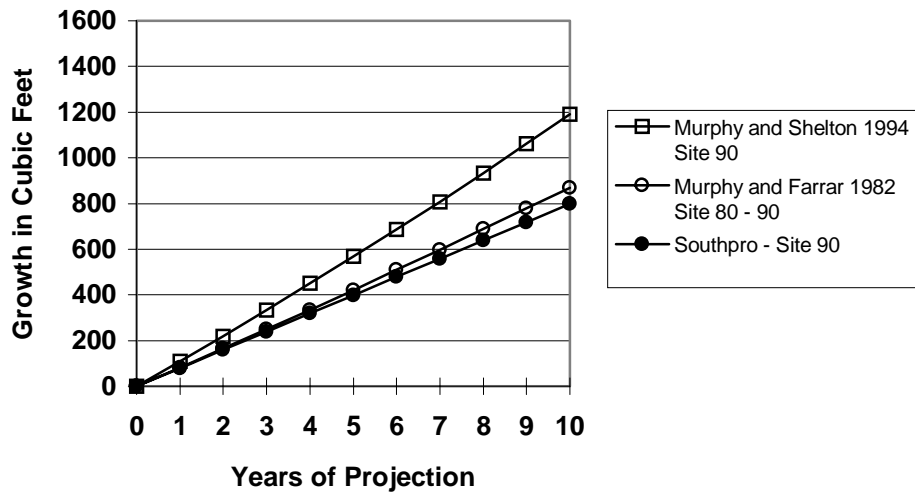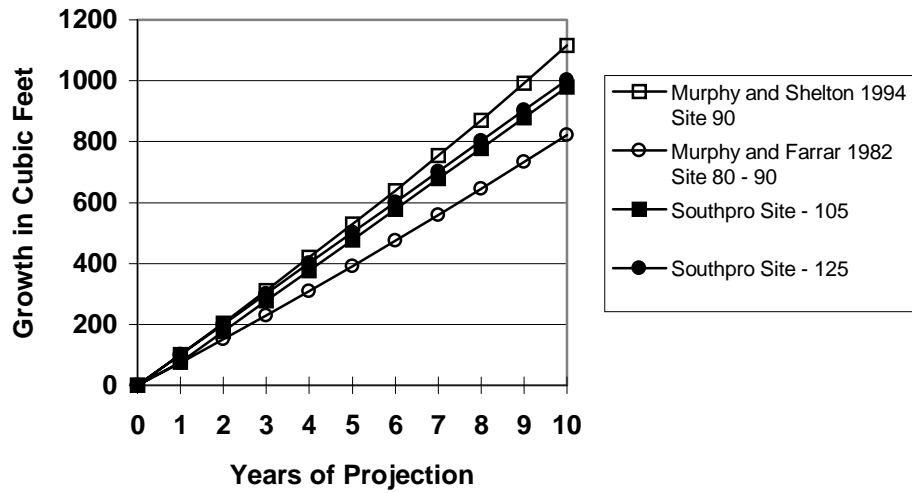
FIGURE B-2.   **Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Starting Condition is an Uneven-aged Stand with 55 ft^2 of Basal Area and a Maximum Diameter of 16"**
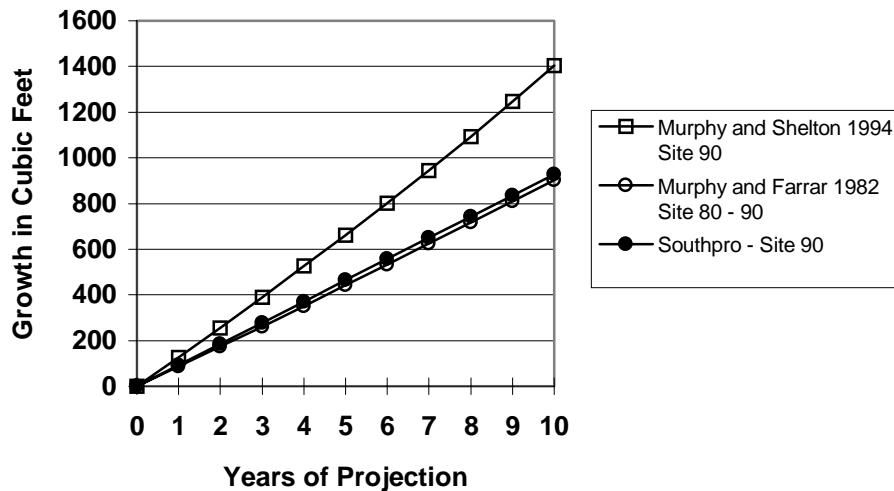
FIGURE B-3.   Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Starting Condition is an Uneven-aged Stand with 65 ft^2 of Basal Area and a Maximum Diameter of 16"

Like the data underlying the growth models of Murphy and Farrar (1982) and Murphy and Shelton (1994), our optimum uneven-aged stand should be well managed and free of hardwood competition. To correct for the under-prediction of growth in Southpro, the site index is increased in the model. Figure B-4 - B-6 compare Southpro, with two higher site indexes, to the other two growth models.

Based on yield differences from these examples, site 105 in Southpro will be used to model loblolly pine site 90. Site 125 is used to model site 110 land. (loblolly pine site. base age 50)
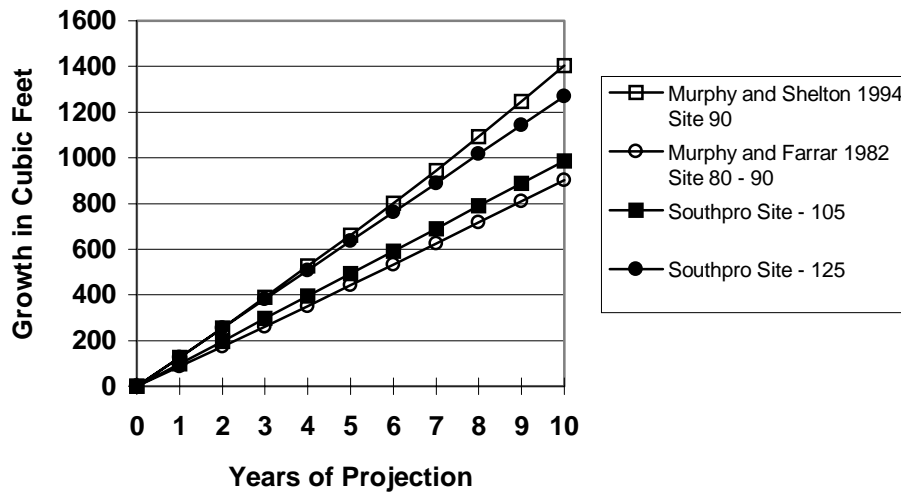
FIGURE B-4. Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Southpro Site Index set at 105 and 125. Starting Condition is an Uneven-aged Stand with 45 ft^2 of Basal Area and a Maximum Diameter of 14".
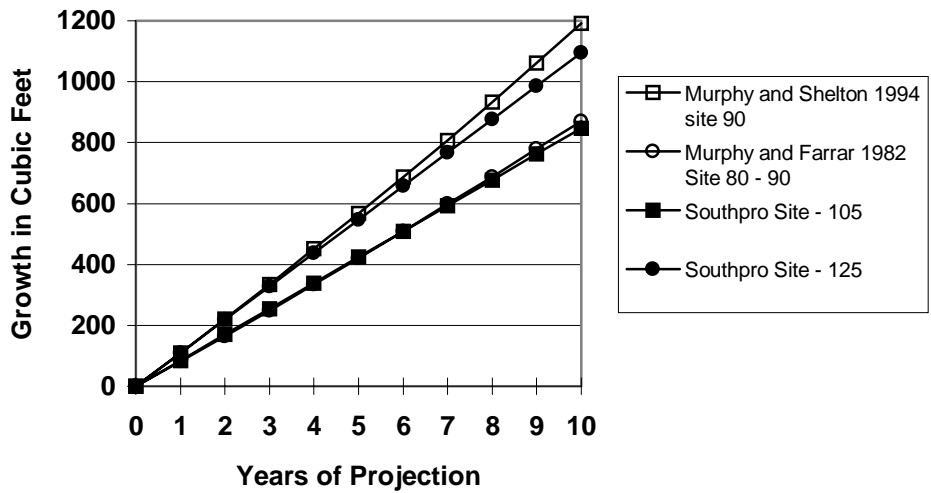
FIGURE B-5. Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Southpro Site Index set at 105 and 125. Starting Condition is an Uneven-aged Stand with 55 ft^2 of Basal Area and a Maximum Diameter of 16".

FIGURE B-6. **Merchantable Cubic Foot Growth Projections for the Three Uneven-aged Growth Models. Southpro Site Index set at 105 and 125. Starting Condition is an Uneven-aged Stand with 65 ft^2 of Basal Area and a Maximum Diameter of 16".**

Vita

Michael J. S. Cafferata was born in Klamath Falls, Oregon on July 30, 1971. He has lived in Oregon most of his life. He graduated from Oregon State University with a B.S. in Forest Management in 1993. Among others, he has worked for Weyerhaeuser Co., Duck Creek Natural Resource Consultants, Mason, Bruce, and Girard Inc., and The Campbell Group. In August of 1995 he moved to Blacksburg, Virginia to attend Virginia Tech.