United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

General Technical
Report NE-148

PROCEEDINGS

8th Central Hardwood Forest Conference

University Park, Pennsylvania
March 4-6, 1991

For attending this conference, each registrant was eligible for 12 hours of Continuing Forestry Education (CFE) credit offered by the Society of American Foresters.

ACKNOWLEDGEMENTS

The editors would like to acknowledge and thank all of the people who served as manuscript reviewers for the Proceedings. The quality of the Proceedings has been improved due to you efforts. We would also like to thank Dr. Mark J. Twery, David E. Fosbroke, Shirley I. Smitl and Mark A. Mitchell for their assistance in converting wordprocessing documents, proofreading, preparation of the table of contents, and layout assistance and Arlyn W. Perkey for providing the cover photograph.

Northeastern Forest Experiment Station
5 Radnor Corporate Center
100 Matsonford Road, Suite 200
P.O. Box 6775
Radnor, Pennsylvania 19087

March 1991

8TH CENTRAL HARDWOOD FOREST CONFERENCE

Proceedings of a Meeting

Held at

The Pennsylvania State University

University Park, PA

March 3-6, 1991

Edited by

Larry H. McCormick and Kurt W. Gottschalk

SPONSORED BY:

School of Forest Resources, Pennsylvania State University

Northeastern Forest Experiment Station, USDA Forest Service

Bureau of Forestry, Pennsylvania Department of Environmental Resources

in cooperation with the Office of Conferences and Short Courses, College of Agriculture, Pennsylvania State University.

PROGRAM COMMITTEE

Co-chairs:

Kim C. Steiner (program), Larry H. McCormick (proceedings), Todd W. Bowersox (arrangements), School of Forest Resources, Pennsylvania State University.

Committee Members:

Kurt W. Gottschalk and Stephen B. Horsley, Northeastern Forest Experiment Station, USDA Forest Service, and Glen R. Stanosz, Bureau of Forestry, Pennsylvania Department of Environmental Resources.

FOREWORD

This conference is the eighth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, and University of Tennessee. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the central hardwoods and to engender coordination among forest scientists in the central hardwood region. This purpose is evidently well-served: the last several conferences have each attracted some 45 to 65 program contributions, and the audiences have been correspondingly large.

Previous organizers have refrained from drawing precise boundaries around the "central hardwood region." We prefer to continue that policy on the grounds that to do otherwise might preclude some very worthwhile participation. Thus, while the principal focus has remained on the oak resource for reasons that are obvious, the ecological scope has broadened from oak-hickory (in the early meetings) to Appalachian oak (Knoxville and State College) and mesophytic forests. With a few exceptions, the commercially significant species are similar for all these forest types, and advancements in knowledge are of general interest.

But the central hardwood region is not merely a collection of similar forest types. It also has historical, demographic, political, and economic characteristics that tend to distinguish it from other forest regions of the United States. For example, the population is heavily rural and agricultural, primary wood markets tend to be diffuse and unorganized, wilderness values and endangered species have generally not been overriding issues, and a relatively minor proportion of the forest land is controlled by public agencies or corporate ownerships. These and related conditions play critical roles in the practice of forestry in this region, and in the aggregate they emphasize its distinction from other regions; but no single one is necessarily unique to the central hardwoods. For these reasons, the characteristics of nonindustrial private forest land owners in Massachusetts might be just as relevant to the central hardwood region as regeneration methods for white oak in Indiana.

Since these proceedings are being published in advance, we have no way of judging the ultimate success of the upcoming Eighth Conference. Of course, our earnest hope is that this meeting shall sustain the excellent reputation of the series. We believe this hope is encouraged by the quality of the papers in these proceedings.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and style of their papers.

TABLE OF CONTENTS

POSTER SESSION

SHIPPING COAL TO NEW CASTLE: ARE SRIC *POPULUS* PLANTATIONS A VIABLE FIBER PRODUCTION OPTION FOR THE CENTRAL HARDWOODS REGION?

Charles H. Strauss[1]

Abstract: Production costs for short rotation, intensive culture (SRIC) *Populus* biomass were developed from commercial-sized plantations under investigation throughout the eastern U.S. *Populus* hybrid planted on good quality agricultural sites at a density of 850 cuttings/acre was projected to yield an average of 7 ovendry (OD) tons/acre/year. Discounted cash-flow analysis of multiple rotations showed pre-harvest production costs of $15/ton (OD). Harvesting and transportation expenses would increase the delivered cost to $36/ton (OD). Although this total cost compared favorably with the regional market price for aspen (*Populus tremuloides*), future investments in SRIC systems will require the development of markets specific to this biomass output.

INTRODUCTION

Foreign restrictions of oil imports to the U.S. during the 1970s resulted in a review of energy-use policies and an allied search for alternate energy sources. The perceived energy crisis brought about an accelerated exploration for domestic sources of fossil fuels and an investigation into the use of solar energy and allied forms of renewable energy (OTA 1980).

Woody biomass was evaluated as a supplemental fuel source, both in terms of expanded supplies from domestic forests and from short rotation, intensive culture (SRIC) energy plantations. During the 1970s wood provided a small portion of U.S. energy supplies, amounting to 2% of annual energy needs (OTA 1980). Most of this biomass was used for residential heating. In terms of the future, an expanded use of forest growth, mortality, and urban wood waste, above current forest industry usage, could provide about 8% of U.S. energy needs (Peterson 1983). An additional 6% of our energy needs could be developed by converting one-tenth of the nation's private forest, range, and pasture lands to SRIC plantations (OTA 1980). However, one of the unresolved questions is whether woody biomass could compete, cost-wise, with other fuel sources.

Most of the early proposals regarding the expanded use of wood energy were tied to the direct combustion of biomass for electric generation (Skelton et al. 1982). However, under current and near-future world prices for coal and petroleum, biomass-dedicated conversion

[1]Professor of Forest Economics, School of Forest Resources, The Pennsylvania State University, University Park, Pennsylvania 16802.

systems cannot compete with large scale, coal- and oil-fired systems (Strauss et al. 1988). Woody biomass would have a better option as a feedstock for ethanol production. Liquid fuels are in strategic short supply within the U.S., making this country vulnerable to supply and/or price disruptions (Wright 1988). The production of ethanol from woody biomass has been proposed under several processes, with the final product considered to be cost competitive under open-market situations (Wright and d'Agincourt 1984, Bergeron et al. 1988). Biomass from SRIC *Populus* plantations would be particularly well suited to these conversion processes on the basis of material characteristics and supply capabilities (Ranney et al. 1987, Strauss et al. 1988).

SRIC production is designed to promote high biomass yields at a young stand age. The most cost-effective cultural approaches have included the use of improved clonal material, intensive site preparation and weed control, planting densities of 600 to 1600 trees/acre, fertilization, coppice regeneration, and two to three harvest cycles of five to eight years each (Ranney et al. 1987). In order to facilitate these cultural designs and secure a maximum output, most of the SRIC plantations have been placed on good agricultural lands. Hardwoods have been preferred due to their rapid early growth, good stress tolerance, and strong coppicing ability. Major attention has been directed to the poplars (*Populus* spp. and hybrids), eucalypts (*Eucalyptus* spp.), silver maple (*Acer saccharinum*), sweetgum (*Liquidambar styraciflua*), sycamore (*Platanus occidentalis*) and black locust (*Robinia pseudoacacia*). Willows (*Salix* spp.) have been investigated in Canada and northern U.S., involving "wood grass" strategies with over 10,000 stems/acre and ultra-short rotations of one to three years (Wright et al. 1988).

Research on SRIC technology in the U.S. was initiated in the mid-1960s, with major improvements secured through numerous experimental trials. Much of this work was funded or co-funded by the U.S. Department of Energy and coordinated through its Short Rotation Woody Crops Program (SRWCP) (Wright et al. 1989).

In order to encourage the commercialization of SRIC programs, the economics of plantation systems are being evaluated under two general stages of research. These include feasibility studies of proposed commercial-sized systems (Perlack et al. 1986, Strauss et al. 1988) and, more recently, the scale-up analysis of actual commercial plantations (Wright, in press). This latter effort includes economic and viability trials of 50-acre or larger monoculture plantations established by several research institutions and private companies through cost-sharing programs. Much of the work in both stages was completed in the northcentral and northeastern regions of the U.S. and has focused on various *Populus* hybrids (Wright, in press).

This paper develops a general production model from these combined research efforts; focusing on the establishment and maintenance of commercial-sized *Populus* plantations. Unit costs for biomass are developed and compared to the current market price of similar wood supplies from domestic forests.

PROCEDURES

Research sponsored by SRWCP over the past decade provided a nation-wide appraisal of various silvicultural designs for SRIC biomass plantations. In an effort to summarize the central findings of these investigations, a woody biomass production model was developed and evaluated under a discounted cash-flow design.

Plantation Design and Operations

The design for the SRIC system uses *Populus* hybrid planted on good agricultural sites at a density of 850 trees/acre. Rotation length was expected to fall in the range of five to eight years, with two to three rotations anticipated from the initial planting. Selection of the optimum-length rotation was dependent on a discounted cash-flow analysis of production costs.

The establishment of SRIC plantations is similar to the procedures used for agricultural row crops, involving a fall preparation of the site and spring planting of the poplar cuttings (Perlack et al. 1986, Grado et al. 1988). During the fall period, the site receives a total- kill herbicide and mowing operation to remove old field vegetation, followed by offset disking to prepare the soil for planting. Lime may be added at this time, depending on soil acidity. In the spring, the soil is disk harrowed, with a pre-emergent herbicide applied to counter residual weed sources. In order to insure an adequate nutrient base for tree growth, a complete nitrogen-phosphorus-potassium fertilizer prescription is applied prior to planting, with additional nitrogen supplemented throughout the rotation (Table 1). Machine planting was assumed within the cost structure of the model, with the poplar cuttings produced at a self-owned nursery (Grado et al. 1988).

Additional herbicide applications were scheduled at the beginning of the first and second summer periods to limit weed growth. Protection from insect and canker attack was provided through a biennial insecticide/fungicide spray program. This represented an insurance cost in reducing the susceptibility of monoculture systems to infestations, such as cottonwood leaf beetle (*Chrysomela scripta*) and *Septoria* canker (Ostry et al. 1988).

Annual charges were also assessed for land rent, property taxes, and the managerial supervision of the entire production effort. In this manner, land and management were identified as specific inputs to the production system.

Table 1.--Establishment and maintenance costs for SRIC plantations, 1987-88.

Operations	Cost Components	$ /acre
FALL ESTABLISHMENT:		
Total kill herbicide	machine and labor	2.
	materials (1.3 lb/a)*	30.
Mowing/brushing	machine and labor	8.
Plowing	machine and labor	14.
Liming	machine and labor	3.
	materials (1 ton/a)	28.
Total		85.
SPRING ESTABLISHMENT:		
Disking	machine and labor	5.
Pre-emerg. herbicide	machine and labor	2.
	materials (1.6 lb/a)*	36.
Fertilization	machine and labor	6.
	materials (50 lb/a each N,P,K)	18.
Planting	planter and labor	9.
	materials (850 cuttings/a)	42.
Total		118.
SUMMER ESTABLISHMENT:		
Herbicide-year 1	machine and labor	2.
	materials (1.0 lb/a)*	22.
Herbicide-year 2	machine and labor	2.
	materials (1.0 lb/a)*	22.
Total		48.
MAINTENANCE:		
Insecticide/fung.	machine and labor	1.
(years 2,4,6)	materials (1.4 lb/a/appl.)**	9.
Fertilization	machine and labor	3.
(years 3,5,7)	materials (110 lb/a/appl. of N)	11.
Land rent	(5.0% of $690/a)	35.
Land taxes	(0.75% of $690/a)	5.
Managerial	labor and facilities	14.
	av. annual	66.

* combination of linuron/glyphosate.

** combination of Sevin/Dylox.

Plantation Yields

Growth and yield functions were developed from SRWCP data sets. These included yield information from partial and first rotations of several *Populus* systems planted at 700-1400 trees/acre and one double rotation system planted at 8500 trees/acre.

An estimated growth curve was developed for an 850 trees/acre plantation, having, as a targeted yield, 7 ovendry (OD) tons/acre/year. This production level was consistent with current research results and was considered a conservative estimate of future SRIC yields (Ranney et al. 1987). Recent summaries of record SRIC small-plot yields for *Populus* hybrid have shown production levels in the range of 6-9 tons (OD)/acre/year (Hansen 1988).

Biomass Costs

The unit cost of biomass was developed from a least-cost model for SRIC plantations (Strauss et al. 1990):

$$C=\frac{\left(\frac{R}{i}+\frac{T}{i}\right)+\left(\frac{E(1+i)^n}{(1+i)^n-1}\right)}{\frac{Y_t}{(1+i)^t-1}} \qquad (1)$$

where,

C = biomass cost, per unit of yield
R = annual land rent and taxes, per unit area
T = annual maintenance costs, per unit area
E = establishment costs, per unit area
Y_t = yield, per unit area
t = rotation age in years
n = plantation life expectancy in years
and i = real interest rate.

Under this formula, unit costs are a function of the discounted cash flows originating from the establishment and annual operations of the SRIC system and the discounted yields of the plantation. Annual costs, including land rent, taxes, and maintenance, were discounted as annual perpetual series. Established costs were compounded to end of the plantation's life expectancy and then discounted as periodic perpetual series. It was assumed that the requirements and costs of reestablishing a new plantation would approximate those followed in the original establishment phase. Yields were discounted as perpetual periodic series specific to their individual rotation lengths. The plantation's life expectancy was based on the number and length of rotations in any given analysis.

A 5% real rate of return was used throughout the analysis. This represented a compromise between the 6% historic real rate identified for corporate capital (Klemperer 1979) and the 4% real rate expected on new long-term investments (Row et al. 1981).

Establishment and Annual Operating Costs

Estimated costs for the individual operations were developed from the SRWCP data base and are reported in U.S. dollars for the 1987-1988 period (Table 1). Contract charges for the establishment and annual operations of commercial-sized plantations compared well to previous models of SRIC systems (Lothner et al. 1985, Perlack et al. 1986, Grado et al. 1988). Variations in costs were largely attributed to the differences in equipment and prescribed materials used on alternate sites. The final budget reflected the establishment and annual operations of a site having good aspect and soil quality.

Establishment costs totaled $250/acre, including the discounted cost of the second-year herbicide operation (Table 1). Herbicide operations were 47% of establishment costs, with materials constituting over 90% of this expense. Land preparation and planting were 31% of establishment costs, with 54% of this expense tied to the poplar cuttings (Grado et al. 1988). First-year liming and fertilization constituted the final 21% of establishment costs.

Annual maintenance included additional fertilization on an alternate year basis ($14/acre/application) and the application of insecticides/fungicides on an alternate year schedule ($10/acre/application). In addition, an annual managerial cost of $14/acre was assessed for administrative and personnel requirements (Strauss et al. 1988).

Annual rent was assessed at 5% of the land value, with annual property taxes estimated at 0.75% of land value. Land was valued at $690/acre, representing the capitalized net return of a good corn production site (110 bu corn/acre/year). This was representative of the land values from several SRIC projects and was 20% above the 1988 U.S. average for farm real estate (USDA ERS 1988).

Growth and Yield

The projected growth of *Populus* hybrid represented an average function for first and second rotations (Table 2). Typically, the above-ground growth secured during the initial portion of the first rotation will be 20-40% lower than for comparable points in the second rotation due to the concurrent development of root systems in the first rotation.

Current annual increment (CAI) was projected to accelerate during the first five years, reaching a maximum of 10.5 tons (OD)/acre in the 5th growing season. As expected, mean annual increment (MAI) increased at a more gradual rate, attaining the targeted maximum of

7.0 tons (OD)/acre/year after the 6th growing season. The narrow range of MAI values in the 5th to 8th years reflected the high CAIs in the 3rd to 6th growing seasons.

Table 2.--Yields and cost of biomass for SRIC plantations.

Year	Yields (ton(OD)/acre)	Cost* - 2 Rotations ($/ton(OD))	Cost* - 3 Rotations ($/ton(OD))
3	13.4	27.11	23.80
4	23.4	19.28	17.35
5	33.9	16.03	14.68
6	42.4	15.11	14.02
7	48.9	15.19	14.23
8	53.3	15.95	15.07

* Discounted cash flow analysis at 5%.

RESULTS

Unit Costs of Biomass

The discounted cash-flow analysis of pre-harvest production costs under a two rotation system placed the least-cost solution in the 6th year at $15.11/ton (Table 2). Optimum rotation coincided with maximum MAI due to the compression of the plantation's growth function into a relatively short period. During this period, annual growth changes were more volatile than the respective increases in cost, with the short time span also reducing the effects of discounting. Of further interest, extending the plantations into the 7th growing season increased the output cost by less than 1%. This reflected the modest decline of CAI in the 7th year.

The principal cost in the SRIC model was land rent and taxes, amounting to 42% of the total. Managerial costs, fertilizer and lime, and herbicides each represented about 14-15% of the total. The composite of land preparation, planting, and insecticide/fungicides was the final 15% of expenses.

If the plantations could support a third rotation under the same yield pattern, the least-cost solution would also occur in the 6th year, with the unit cost reduced to $14.02/ton (Table 2). The 7% cost reduction resulted from the extended prorate of the establishment costs over the additional rotation.

Harvesting costs were based on a feller/buncher unit designed for closely-spaced, small-diameter trees (Stokes et al. 1986, Woodfin et al. 1988, Strauss et al. 1988). The harvested material would be chipped in the field, and transported 25 miles with tractor-trailer units. Under this design, harvesting and transportation costs were estimated at $18/ton (OD). A final delivered cost of $36/ton (OD) was established for the two rotation system on the basis of an 85% net delivery of plantation yields.

DISCUSSION

Marketing and Pricing Considerations

Given the financial profile for SRIC wood production, some question remains as to whether this venture represents a viable option for northeastern U.S. In terms of fiber production, our hardwood forests are typically overstocked with respect to available markets. Softwoods are the principle force in pulpwood markets, with the short-fibered hardwoods representing a certain drudge on the market. On the basis of stumpage prices, softwoods typically carry two to three times the value of hardwoods (Peterson 1990).

An exception to this hardwood situation is provided by aspen (Populus tremuloides) in the Lake States. This lighter weight and faster growing species has generated a major roundwood market among the particleboard and paper industries. Current prices for delivered, unpeeled aspen in the Lake States are $38-40/ton (OD) (Peterson 1990). Of interest, aspen shares many of the mechanical and chemical properties of the hybrid poplars, with both species groups adaptable to the production of ethanol. Several ethanol-conversion studies have established feedstock prices in the range of $38-42/ton (OD) (Wright 1989, Bergeron et al. 1989). As such, SRIC biomass at $36/ton (OD), delivered, would be competitive with domestic aspen and also meet the expected feedstock prices for ethanol production.

In many respects, *Populus* biomass is a unique product. It is homogeneous in terms of either physical or chemical properties and can be genetically engineered for sensitive chemical processes (Blankenhorn et al. 1984). Furthermore, SRIC designs would permit a constant and sustained rate of production. Probably the best example of commercial SRIC *Populus* production in the U.S. is the 7000 acres of plantations developed by the James River Corporation along the Columbia River in Oregon. These plantations were initiated in 1984 in response to hardwood shortages among Pacific Northwest paper mills (Stanton 1987). Their general design and estimated output levels parallel the SRIC model presented in this paper.

Plantation and Allied Production Costs

Sensitivity analysis was used to evaluate the parameters having the greatest impact on pre-harvest and delivered costs. The pre-harvest cost was most sensitive to land costs and biomass yields, with harvesting and transportation having the greatest effect on total delivered cost. A further address of these factors was considered.

The general SRIC model included land rent and taxes as specific cost requirements. These charges, representing 42% of pre-harvest costs, were a direct reflection of land's value in other agricultural pursuits. In order for the SRIC proposal to compete for this resource, comparable or higher net returns will be required from the biomass enterprise. The option of using lower priced, marginal lands for SRIC plantations would reduce this cost impact but, in all probability, would also lower yield potentials. Further investigations of the economic niche of SRIC production within the various gradients of land may be required.

Plantation yields had the greatest impact on pre-harvest unit costs. If, for example, yields were reduced by 25%, plantation costs would increase by 32%. In contrast, a 25% increase in output would decrease pre-harvest costs by over 20%. A comparison of record experimental yields to actual field yields among agricultural crops and for SRIC Populus plantations (Hansen 1988) suggested that the immediate field potential for commercial SRIC plantations may only be within the range of 4.5 - 5.5 ton/acre/year. Further increases were considered possible, with the realization of future gains dependent on cultural and breeding research. More recent estimates of growth in commercial-sized *Populus* plantations by Wright (in press) point to the 7 - 9 ton/acre/year range as an attainable objective. This range has also been verified by results from commercial-sized field trials in northcentral U.S.

The particular design of a SRIC plantation is paramount in determining production success. This involves a careful matching of clonal hybrids to the particular growing site and a successful implementation of the prescribed cultural strategy. Attention to these design prerequisites will, in large measure, enhance the degree of success in SRIC ventures.

In order to move SRIC biomass to the market, major harvesting and transportation costs have to be met. These costs, plus those associated with material loss, more than doubled the final delivered cost of biomass in the SRIC model. Currently, most SRIC harvesting systems represent either developing technologies or adaptations of existing systems used in native forests. Cost reductions can be anticipated, as harvesting equipment is better designed for the needs of biomass plantations (Stokes et al. 1986, Woodfin et al. 1988). However, a current stalemate exists in the development process owing to the lack of investments in SRIC plantations and allied conversion technologies. In all likelihood, the feasibility of energy and fiber technologies need to be first resolved before further attention is placed on SRIC harvesting equipment.

SUMMARY AND CONCLUSIONS

A general model of a commercial-sized SRIC biomass plantation was developed from a series of research programs coordinated by the U.S. Department of Energy's Short Rotation Woody Crops Program. The model centered on the use of *Populus* hybrid, planted on good quality agricultural sites at a density of 850 cuttings/acre. Establishment costs amounted to $250/acre, with weed control and planting representing 47% and 21%, respectively, of this total expense. Average annual maintenance, including the prorated cost of land, amounted to $66/acre/year.

Plantation yields were projected to reach a maximum MAI of 7 tons (OD)/acre/year by the sixth year. Discounted cash-flow analysis of cost and growth parameters indicated that two 6-year rotations would achieve a pre-harvest unit cost of $15/ton. Land was the dominant cost factor, representing 42% of the unit cost. Managerial costs, fertilizer and lime, and herbicides each contributed about 15% to the unit cost. Additional harvest and transportation requirements placed the delivered cost of *Populus* biomass at $36/ton.

In its proposed operational form, SRIC biomass would be competitive with aspen from domestic forests and also fulfill the cost requirements of a feedstock for ethanol production. The major cost of land within the financial model suggests the need for evaluating less expensive and lower quality land resources. However, the linkage between site quality and yields represents a critical balance in the cost equation. Although improvements in harvesting and transportation technologies could provide major cost reductions, further developments will probably depend on some form of industrial commitment to biomass production.

ACKNOWLEDGEMENTS

This research was supported by funding from the U.S. Department of Energy Subcontract No. 19X-07928 with Martin Marietta Energy Systems, Inc., Environmental Sciences Division, Oak Ridge National Laboratory.

LITERATURE CITED

Bergeron, P. W., J. D. Wright, and C. E. Wyman. 1988. Dilute acid hydrolysis of biomass for ethanol production. In: Energy from Biomass and Wastes XII. Institute of Gas Technology. Chicago, IL pp. 1277-1297.

Blankenhorn, P. R., T. W. Bowersox, C. H. Strauss, G. L. Stimely, C. A. Hornicsar, and M. L. DiCola. 1984. The characteristics of hybrid poplar as a potential feedstock for fermentation to ethanol. In: Proceedings of TAPPI 1984 Research and Development Conference. Appleton, WI pp. 43-44.

Grado, S. C., C. H. Strauss, P. R. Blankenhorn, and T. W. Bowersox. 1988. Short rotation woody biomass plantations: Technical requirements and costs for establishment. Biomass 17(4):277-289.

Hansen, E. A. 1988. SRIC yields: A look to the future. In: Economic Evaluations of Short-Rotation Biomass Energy Systems. International Energy Agency. Duluth, MN pp. 197-207.

Klemperer, W. D. 1979. Inflation and present value of timber income after taxes. J. For. 77:94-96.

Lothner, D. C., H. M. Hoganson, and P. A. Rubin. 1985. Examining Short-Rotation Hybrid Investments using Stochastic Simulation. USDA For. Serv. N. Cent. For. Exper. Sta. Duluth, MN 31 p.

Office of Technical Assessment. 1980. Energy from Biological Processes. U.S. Congress Off. of Tech. Assess. OTA-E-124. Washington, DC 195 p.

Ostry, M. E., L. F. Wilson, H. S. McNabb, and L. M. Moore. 1988. A Guide to Insect, Disease, and Animal Pests of Poplars. Ag. Hdbk. 677. U.S. Dept. Ag. Washington, DC 118 p.

Perlack, R. D., J. W. Ranney, W. F. Barron, J. H. Cushman, and J. L. Trimble. 1986. Short-rotation intensive culture for the production of energy feedstocks in the US: A review of experimental results and remaining obstacles to commercialization. Biomass (9):145-159.

Peterson, R. M. 1983. Managing wood for energy within the multiple use concept. In: The Sixth International Forest Products Research Society Industrial Wood Energy Forum '82. Proc. 7334, Vol. 1:2-5. Madison, WI.

Peterson, T. A. 1990. Wisconsin Forest Product Price Review, Boltwood Edition. April 1990. University of Wisconsin-Extension. Madison, WI 4 p.

Ranney, J. W., L. L. Wright, and P. A. Layton. 1987. Hardwood energy crops: The technology of intensive culture. J. For. 85(9):17-28.

Row, C., F. Kaiser, and J. Sessions. 1981. Discount rate for long-term Forest Service investments. J. For. 79:369-376.

Skelton, J. C., E. S. Lipinsky, W. J. Sheppard, C. K. Badger, E. H. Hall, D. E. Lenerz, M. P. Pease, K. A. St. John, and C. K. Wagner. 1982. The Role of Biomass in Electric Utilities. Battelle, Columbus, OH 184 pp.

Stanton, B. J. 1987. Establishing and maintaining short-rotation, intensively cultured plantations of hybrid cottonwood in the Pacific Northwest. James River Corp. Unpublished paper from DOE SRWCP Contractor's Meeting. Tacoma, WA 29 pp.

Stokes, B. J., D. J. Frederick, and D. T. Curtin. 1986. Field trials of a short-rotation biomass feller buncher and selected harvesting systems. Biomass 11:185-204.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1988. Economic evaluations of multiple rotation SRIC biomass plantations. Solar Energy 41(2):207-214.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1990. Financial selection of rotation age for SRIC plantations. Biomass 23(1):55-69.

USDA Economic Research Service. 1988. Agricultural Land Values and Markets: Situation and Outlook Report. AR-10. USDA ERS. Washington, DC 30 p.

Wright, J. D. 1988. Evaluation of enzymatic hydrolysis processes. In: Energy from Biomass and Wastes XII. Institute of Gas Technology, Chicago, IL pp. 1247-1277.

Wright, J. D., and C. G. d'Agincourt. 1984. Evaluation of Sulfuric Acid Hydrolysis Processes for Alcohol Fuel Production. SERI/TR-231-2074. Solar Energy Research Institute. Golden, CO 111 p.

Wright, L. L., D. R. DeBell, C. H. Strauss, W. A. Geyer, L. Sennerby-Forsse, and L. Zsuffa. 1988. Panel discussion on the relative merits of woodgrass and SRIC. In: Energy from Biomass and Waste XII. Institute of Gas Technology. Chicago, IL pp. 261-274.

Wright, L. L., J. H. Cushman, and P. A. Layton. 1989. Dedicated energy crops: Expanding the market by improving the resource. Biologue 6(3):12-19.

Wright, L. L. (in press). Commercialization of short-rotation intensive culture tree production in North America. In: Energy from Biomass and Waste XIII. Institute of Gas Technology, Chicago, IL.

Woodfin, S. L., L. L. Wright, and D. T. Curtin. 1988. SRIC: Integration of production and harvesting system costs. In: Economic Evaluations of Short-Rotation Biomass Energy Systems. International Energy Agency. Duluth, MN pp. 115-150.

HARVESTING IMPACTS ON STEEP SLOPES IN VIRGINIA

William B. Stuart and Jeffrey L. Carr[1]

Abstract: Ten tracts in the mountains of western Virginia were intensively sampled to determine the type and extent of soil disturbance from ground-based logging and the attendant erosion risk. Average slopes for the tracts ranged from 21 to 43 percent. Logged slopes exceeded 50 percent. All tracts surveyed were logged prior to the push for voluntary Best Management Practices and had been completed at least three months before the survey was conducted. Two logging methods were observed: skidding overland directly from stump to roadside, and the use of bladed skid trails. Overland skidding, when topography permits, was found to cause less disturbance and soil compaction. High risk of soil movement and erosion was associated with a relatively few, high-risk, spots left after harvesting, rather than the general application of the system.

INTRODUCTION

The increasing demand for Appalachian forest products, both lumber and pulpwood, coupled with increased environmental awareness, has renewed interest in the impacts of ground-based logging systems on steep slopes. Alternative systems such as helicopter, balloon and cable ways may find limited application on sites were the combination of volume, value, and ecological sensitivity can justify the additional expense required. Rubber-tired skidders with their advantages of cost, flexibility, modest skill requirements, and reduced weather sensitivity are the most economical means of removing timber from moderately steep (30-40% slopes) sites and will likely remain the method of choice from an operational standpoint.

The harvesting impacts of ground systems on these sites fall into three broad categories: those which increase erosion risk, those which reduce site productivity, and those which alter the aesthetics of the tract. Erosion risk increases as a result of removing the forest cover (a largely unavoidable consequence of timber harvesting), removing the litter layer, opening of drainage channels up and down the slope, and altering soil structure to the extent that infiltration rate is reduced. Soil compaction is perhaps the greatest threat to site productivity, especially if root penetration is inhibited and soil porosity is lost. Logging alters the canopy profile, but the most objectionable impacts are the exposure of mineral soil, imposing straight lines of haul roads and skid trails on the natural topography and leaving broken stems and piles of debris.

---

[1]Associate Professor, Department of Forestry, Virginia Tech, Blacksburg, VA 24061-0324 and Lumber Sales Representative, Procter & Gamble Cellulose, Memphis, TN 38108-0407, respectively.

The literature is replete with articles describing the impacts of harvesting on various soil types (Dickerson 1968, Dryness 1965, Froelich et al. 1981, Krag and Webb 1987, Mace 1970, Reinhart et al. 1963, Reisinger et al. 1988, Willis 1971). The diverse nature of forests, forest soils, past land management practices, and research objectives make it nearly impossible to draw broad generalizations from this research base. Harvesting technology has changed rapidly over the period of this research as well. Direct-drive machines of the early 70's have been supplanted by power-shift transmissions. Hydrostatic drive machines are becoming more common. Each advancement in drive trains alters the manner of soil machine interaction.

Major changes have occurred in tire and track design as well. Tire widths have increased, carcass construction has improved, and tread designs have been adapted to specific applications. Undercarriage design, balance, and drives for crawler tractors have improved over the same period. Soil effects have often driven these design changes. Lumping a new power-shift machine mounted on wide tires into the same category as a pre-1970's, direct-drive machine on modified agricultural tires negates much of this effort.

The change in technology has expanded the range of harvesting options. Wood form may range from log length to full tree. The ability to skid along the contour on steep slopes has increased, landing size and location can be better adapted to the terrain, and forest road designs altered to take advantage of more powerful and maneuverable trucks.

The fundamental divisions of the forestry profession often insulate those concerned with the effects of operations on the forests from those concerned with reducing those effects. The silviculturist is measuring the impacts of a technology that is at best current, more likely already superseded, on stand development. The harvesting specialist--whether forester, engineer or other professional--is concerned with the impacts of current and future technology and practices. The two can normally exist in blissful isolation until an external disturbance focus an interaction.

The recent move to Best Management Practices has been such a destabilizing influence. The various states have been involved in developing guidelines for forestry operations either voluntarily or at the direction of their legislatures. The basis for these guidelines has been a mix of published research findings, experience, and what the state next door is doing. The fit with the current activities and local conditions is seldom tested except by empirical methods based on improvement in the environmental variable of interest.

This study was structured to assess the harvesting impacts from current ground-based operations on slopes greater than 30 percent in the mountains of central Virginia. The objectives of the study were:

a. to document the form and extent of soil disturbance and compaction associated with conventional operations.

b. to identify this disturbance with specific forms of causality in planning, operation and closure, and;

c. to make recommendations for reducing these impacts in future operations.

METHODS AND PROCEDURES

The cooperators in the project--Georgia Pacific, Nekoosa Packaging, the U.S. Forest Service, and Westvaco--were asked to submit a list of tracts from the central Virginia region which had been or would be clearcut between September 1988 and September 1989 by ground-based systems, and which had average slopes in excess of 30 percent. The tracts were to be "forwarded" without consideration of the apparent "quality" of the logging job. Twenty-nine tracts were identified, of which 10 were selected for detailed study. The final selection attempted to assure a diversity of ownership, soil type, season of harvest, equipment, harvesting strategy, and skidding practices (Tables 1 and 2). None of the tracts was visited prior to selection. The contractors performing the harvest did not know the tracts were to be included in a study of this type. Virginia was updating its Best Management Practices activity at the time the tracts were cut, but compliance was still voluntary and inspections had not begun. Consequently, there was no indication that "special" precautions were taken by the contractor or crew during the harvest.

Designated skid trails are commonly recommended for steep terrain (Froelich et al., 1981). The research basis for much of this has come from the Pacific Northwest or Scandinavia (Wasterland 1987). The alternatives had not been fully tested on Appalachian forests. The 29 tracts provided were roughly evenly split between those harvested using designated bladed trails and those skidded overland. The split was maintained as an important variable in the study.

Tract orientation relative to the contour appears to be a major factor in determining which method will be used. Two of the tracts were harvested by the same contractor, using different skidding methods. Tracts laid out with the long axis running perpendicular to the contour were skidded using overland methods; tracts with the long axis parallel to the contours required bladed skid trails.

The cooperators provided maps and description of each tract. Additional information pertaining to soils, weather conditions during and following the harvest and other descriptive material was collected. A two-person study team visited each tract during the summer of 1989. The general characteristics of the tract were documented: the location of roads, landings, skid trails, rock outcrops, streams, and drainages, along with other gross tract features. This was supplemented by circular plots, 20 feet in diameter installed at 50-foot intervals along contours. The area encompassed by these plots ranged between 5 and 8 percent of the tract surface area, depending upon the amount of land area reserved for wildlife plots, streamside management zones, or deemed unloggable because of rock outcrops, bluffs, or low timber quality.

Table 1.--Summary of physical study-tract characteristics.

Tract	Soil Type	Ownership	Rainfall During Harvest	Average % Slope	Size (acres)	Aspect
A	silt loam and stoney loam[1]	industry	13.59 in. 3 months	43	11.0	west
B	shaly silt loam[2]	industry	11.53 in. 4 months	33	15.7	north
C	sandy loam to loamy sand[3]	public	14.12 in. 4 months	35	16.1	northwest
D	stoney, fine sandy loam[4]	private	12.02 in. 3 months	21	*20.8	northwest
E	sandy loam to loamy sand [3]	public	13.45 in. 4 months	27	40.4	southwest
F	sandy clay loam silt loam [5]	public	6.84 in. 3 months	29	18.0	southeast
G	shaly silt loam[2]	industry	22.65 in. 4 months	37	19.8	east
H	stoney, fine sandy loam[6]	public	17.12 in. 3 months	25	23.5	northwest
I	stoney, fine sandy loam[4]	private	22.70 in. 4 months	28	39.0	northwest
J	shaly silt loam[7]	public	13.46 in. 3 months	31	19.9	east

[1]Sequoia and Dekalb.
[2]Berks-Weikert.
[3]Leetonia.
[4]Edneytown.
[5]Landig-Berks.
[6]Edneytown-Peaks-Thurmond.
[7]Berks-Weikert-Rushtown.

Table 2.--Summary of study-tract harvest characteristics.

Tract	Season of Harvest	Skid Trail Type	Equip. (make/ model/tire size)	Skid Direction	Cubic Feet Harvested (per acre)
A	summer	overland	Timberjack 240E 23.1x26	15% uphill 85% down	2332
B	fall	overland	Timberjack 240E 23.1x26	96% uphill 4% down	3421
C	winter	overland	CAT 518 23.1x26	1% uphill 99% down	1509
D	spring	overland	Timberjack 230D 23.1x26	80% uphill 20% down	1734
E	summer	overland	John Deere 640 23.1x26	65% uphill 35% down	602
F	winter	bladed/ overland	CAT 518 18.4x34	35% uphill 65% down	1702
G	summer	bladed	Timberjack 450 23.1x26	95% uphill 5% down	2266
H	spring	bladed/ overland	Timberjack 230/ 450 18.4x34	94% uphill 6% down	2293
I	summer	bladed	Cat 518 23.1x26	2% uphill 98% down	2301
J	spring	bladed	John Deere 18.4x34	92% uphill 8% down	1072

The soil surface characteristics within each plot were mapped and classified using a descriptive system adapted from Miller and Sirois (1986):

1. Undisturbed: Litter in place and undisturbed; no evidence of machine traffic or compaction.
   Subclasses: Non-soil (rock outcrops, stumps, etc.)
   Debris piles (slash over 30 cm deep)

2. Slightly disturbed -- any of the following three conditions:

   a. Litter removed and mineral soil exposed
   b. Mineral soil and litter mixed
   c. Mineral soil deposited on top of litter to a depth of 5 cm
      Subclasses: Compacted -- obvious depression caused by passage of log or machine
      Debris piles

3. Severely disturbed: Surface soil removed and the subsoil exposed.

   a. Cut or rutted soil remaining in its original location
   b. Pushed or filled soil from harvesting or earthwork activities
      Subclasses: Compaction -- obvious depression caused by passage of log or machine
      Debris piles

4. Depression deposits: Sedimentation of soil in holes, troughs, or behind debris dams.

In addition, a cone penetrometer was used to measure differences in soil mechanical strength between the above categories and subcategories measured in each plot. If the entire plot was disturbed, an unimpacted measurement was taken from the nearest undisturbed area. (Penetrometer readings were not recorded for depression deposits because of the small area and major shift in soil structure with depth.) Slope was recorded at each plot center, and skid direction (uphill/downhill or along contour) was noted. Measurements of the depth of organic layer, soil texture, and other characteristics for each disturbance class were taken. Live brush density and the parameters required for the universal soil loss equation adapted to forested sites were recorded. Plots were installed in skid trails, landings and roads as well as the forest floor to assure all disturbance classes were documented.

A total of 1120 plots was established on the 10 tracts. These were further supplemented by measuring and documenting engineered earthworks, such as roads and landings, and non-engineered earthworks such as skidder blade work on skid trails or water bar construction. These on-the-ground measurements were supplemented by scaled measurements from aerial photographs taken of each tract.

RESULTS AND DISCUSSION

The Universal Soil Loss Equation was used to estimate potential soil movement, in terms of tons per acre per year, from each plot. Soil movement, estimated in this manner, means the soil is moved from its place of origin and should not be equated with potential stream sedimentation. The forest floors after harvest on most of the plots, had sufficient litter layer and micro topography to slow runoff and force deposition of much of the soil near the place of origin.

Figure 1 from Tract A shows the common pattern. No soil movement was expected for a majority of the plots and moderate movement for most of the others. Each tract contained a few plots with a very high risk. Five hundred fifty of the 1120 plots had an estimated zero risk of soil movement. Soil movements of less than 1 ton per acre per year were estimated for an additional 173 plots. Each tract contained a few "hot spots" with very high erosion risks. Maximum individual plot measurements for the 10 tracts ranged from a low of 6 tons per acre per year to a high of 158. These "hot spots," without exception, occurred on a road, landing, or skid trail. The values also reflect the risk during the first year after harvest and would decline rapidly as the tract revegetates, and exposed soil on roads, tracts, and landings are covered with grass.

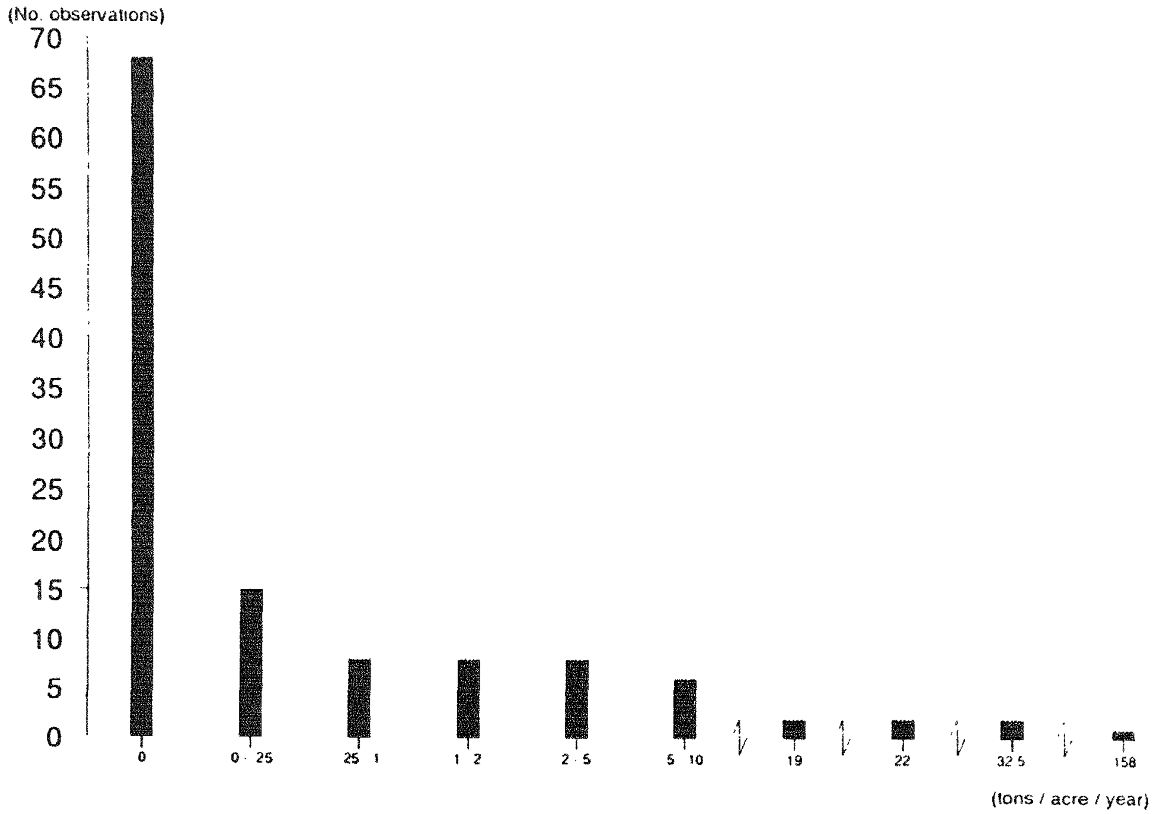

Figure 1. Frequency of potential soil movement estimates from the Universal Soil Loss Equation, based on estimates from 121 plots on Tract A.

Potential net soil loss (off-site sedimentation) was estimated for the entire tract using average values from plot data and a total tract parameter to estimate on-site storage. The results, shown in Figure 2, indicate that half of the tracts would lose less than 0.25 tons per acre during the first year after harvest. Only one of the tracts had an estimated loss of greater than 1 ton per acre per year. Tracts A through E were harvested using overland skidding methods, while F through J had systems of designated and bladed skid trail.

Figure 2. Potential soil loss estimates using the Universal Soil Loss Equation modifies for forested land.

Table 3 was developed by averaging the soil loss estimates for each of the sample plots to develop a tract average rate of soil movement. To demonstrate the importance of tract closure, the average was recalculated assuming the two and five highest risk plots were treated, reducing the movement risk to another zero. In most cases, treating the two highest risk sites reduced the average by 30 to 50 percent. Treating the five worst sites results in virtual elimination of soil movement on many of the tracts.

Table 3.--Potential soil movement estimates in terms of median, arithmetic average, and treated averages using field plot data.

Tract	Median	Arithmetic Average	*Added Closure Average	**Intensive Closure Average
A	0	3.37	2.10	1.49
B	0.04	2.86	2.21	1.90
C	0	0.41	0.27	0.14
D	0	0.37	0.27	0.12
E	0	0.21	0.12	0.05
F	O	1.08	0.83	0.58
G	O	2.94	2.01	1.06
H	O.01	1.17	0.60	0.42
I	O	1.01	0.66	0.45
J	O	1.17	0.26	0.04

* Arithmetic average assuming the two highest soil movement estimates equal zero.
** Arithmetic average assuming the five highest soil movement estimates equal zero.

SUBSOIL DISTURBANCE

Harvesting activities disturbed less than 30 percent of the tract area on all of the 10 tracts (Table 4). No differences could be found when overland skidding was compared with designated trails.

Table 4.--Comparison of undisturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent Undisturbed Area Using Overland Skid Trails	Tract	Percent Undisturbed Area Using Bladed Skid Trails	Rank
D	71			1.0
		G	74	2.5
		H	74	2.5
		F	75	4.5
		J	75	4.5
B	79			6.5
C	79			6.5
		I	81	9.0
A	81			9.0
E	81			9.0
Total Ranks:	32		23	

Areas characterized by slight disturbance ranged from 11 to 15 percent on nine of the tracts (Table 5). One tract had a low of zero percent resulting from an extensive bladed trail system which reduced machine travel over the site. These values correspond with the findings of Miller and Sirois (1986), who estimated that 13% of the area of tracts they studied were left in this condition.

Six to 14 percent of the tracts' areas were left in a severely disturbed condition. Severe disturbance was most commonly associated with the construction of skid trails rather than skidder damage. Water-bars, haul roads, and landings were major contributors as well. A significant difference (alpha < 0.008) between skidding methods was found using the Wilcoxon Rank Sum Test (Table 6). Overland skidding resulted in less severe disturbance. The values shown for overload skidding include the disturbance associated with water bar construction. Excessive use of waterbars on overland trails (following BMP formulas) often resulted in greater risk of soil movement than if they had been omitted.

No significant differences were found in the percentage of the areas in the non-soil category, under debris piles or covered with depression deposit between skidding methods.

The percent of the tract area in skid trails did vary between skidding methods (Table 7). Overland skidding resulted in less skid trail area then using bladed trails (alpha = 0.075).

Table 5.--Comparison of slightly disturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent Slightly Disturbed Area Using Overland Skid Trails	Tract	Percent Slightly Disturbed Area Using Bladed Skid Trails	Rank
		I	6	1.0
E	11			3.0
		F	11	3.0
		H	11	3.0
A	12			5.0
B	14			6.5
		G	14	6.5
C	15			9.0
D	15			9.0
		J	15	9.0
Total Ranks:	32.5		22.5	

Table 6.--Comparison of severely disturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent severely disturbed area using overland skid trails	Tract	Percent severely disturbed area using bladed skid trails	Rank
B	6			1.5
C	6			1.5
A	7			3.0
E	8			4.0
D	10			5.5
		J	10	5.5
		G	12	7.0
		I	13	8.0
		F	14	9.5
		H	14	9.5
Total Ranks:	15.5		39.5	

Table 7.--Percent of total study tract surface area in noticeable skid trails.

Tract	Tract Percent in Overland Trails	Rank
A	4	2.5
B	3	1.0
C	9	8.5
D	6	5.5
E	4	2.5
		Total 20

Tract	Tract Percent in Bladed Trails	Rank
F	6	5.5
G	9	8.5
H	7	7.0
I	5	4.0
J	10	10.0
		Total 35

Compaction

The slightly disturbed/compacted class included from 1 to 5 percent of the tract areas. The resulting small sample size made it difficult to assign significances to these data. Values in italics in Table 8 are based on a sample size of less than 10. While no tests of significance were attempted, the absolute values indicate that the field crew's ability to identify compaction was good.

SUMMARY

Using conventional ground skidding systems left between 70 and 80 percent of the surface soil on the 10 tracts in an undisturbed condition. Six to 15 percent of the area had been slightly disturbed, a condition which would increase the risk of soil movement on the tract but not impact tree growth. Some compaction did occur within the slightly disturbed classification, but the amount (1 to 3 percent of the tract area) was too small to develop inferences concerning tree growth or water infiltration. Six to 14 percent of the tracts were left in a severely disturbed condition, usually as the result of construction skid trails, haul roads and landings.

Table 8.--Average change in mechanical strength (psi) between paired data samples of the undisturbed class and listed class.

Slightly disturbed class

(Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class:									
	12	14	15	15	11	11	11	6	15
(Depth inches):									
1	-4	0	5	*13	-2	0	*30	_20_	6
2	11	1	1	*29	-2	-3	*33	_34_	7
3	14	4	-7	*39	4	2	*50	_39_	9
4	*24	11	-26	*40	12	-11	3	_67_	-5
5	*40	5	-28	*27	6	-11	25	_76_	-25
6	*59	2	-31	*26	-8	-7	28	_71_	-24

Slightly disturbed/compacted class

(Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class:									
	2	2	2	5	2	1	1	1	3
(Depth inches):									
1	_35_	_13_	_104_	*63	15	_25_	_33_	_139_	_106_
2	_90_	_26_	_132_	*70	28	_48_	_54_	_146_	_131_
3	_138_	_47_	_145_	*84	18	_110_	_56_	_191_	_119_
4	_137_	_57_	_98_	*79	42	_52_	_15_	_173_	_99_
5	_135_	_63_	_89_	37	23	_68_	_3_	_169_	_71_
6	_140_	_70_	_68_	*57	16	_63_	_14_	_169_	_91_

* represents values significantly different at the 95% confidence level.
_(00)_ had less than ten observations within the sample.

Skidding method had an effect on both the extent of severe disturbance and the potential off-site sedimentation. Overland skidding resulted in significantly less severe disturbance and generally less risk of off-site sedimentation.

Most of the risk of soil movements was associated with a relatively few, very vulnerable spots on each tract. Additional closure effort to reduce this vulnerability would have cut the average soil movement risk nearly in half.

CONCLUSIONS AND RECOMMENDATIONS

Conventional, ground-based harvesting systems can be used on slopes greater than 30 percent in the central Virginia highlands without significant risk to water quality or subsequent stand development. A reasonable degree of care and management is assumed.

High-risk areas -- those with fine-textured soils, poor drainage, and low rock content should be avoided during wet weather. Harvesting contractors should be allowed some flexibility in scheduling or contract life to reduce the urgency of cutting these tracts when the risk of damage to both the site and the equipment is greatest.

Tract boundaries should be laid out to favor overland skidding on slopes of less than 45 percent. On slopes greater than 45 percent, safety and common sense dictate the use of blade skid trails.

Tract closure is an especially important means of reducing erosion and sedimentation risk. A few very vulnerable spots accounted for a large share of the estimated soil movement and soil loss. Waterbars, if properly installed can be quite effective in reducing these risks; overuse can increase soil loss. Other techniques of slowing water flow rates on roads and trails which require less soil disturbance should be investigated. Alternatives include using logging debris, siltation barriers, paper machine felts, or other products entering the market.

Vegetation is the ultimate protector of the site. Leaving the site in a condition such that trees, grasses, shrubs and forbs can quickly reoccupy the tract is the best solution to minimizing runoff and sedimentation.

LITERATURE CITED

Dickerson, B. P. 1968. Logging disturbance on erosive sites in northern Mississippi. USDA For. Serv. Res. Note SO-72.

Dyrness, C. T. 1965. Soil surface conditions following tractor and high-lead logging in the Oregon Cascades. J. For. 63:272-275.

Froelich, H. A., D. E. Aulerich, and R. Curtis. 1981. Designing skid trail systems to reduce soil impacts from tractive logging machines. For. Res. Lab., Oregon State Univ., Res. Pap. 44.

Krag, R. K., and S. R. Webb. 1987. Caribou Lake logging trails: a study of three harvesting systems on steep slopes in the central interior of British Columbia. For. g. Res. Inst. Can., Tech. Rep. No. 76.

Mace, A. C., Jr. 1970. Soil compaction due to tree-length and full-tree skidding with rubber-tired skidder. Sci. Jour. Ser. Pap. No. 7226, Univ. of Minnesota Agric. Exp. Stn., St. Paul, MN.

Miller, J. H., and D. L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in a loamy hill forest. Soil Sci. Soc. of Am. J. 50(6):1579-1583.

Reinhart, K. R., A. R. Eschner, and G. R. Trimble, Jr. 1963. Effect on stream flow of four forest practices in the mountains of West Virginia. USDA For. Serv. Res. Pap. NE-1.

Reisinger, T. W., G. L. Simmons, and P. E. Pope. 1988. The impact of timber harvesting on soil properties and seedling growth in the South. Sou. J. Appl. For. 12(1):58-67.

Wasterland, I. 1987. Machine forces that damage trees and ground in thinning operations. Proc. Harvesting Machines and Systems Evaluation Workshop. Research Notes 108, pp. 187-197. Swedish Univ. Agric. Sci.

Willis, J. R. 1971. A case study of the effects of articulated rubber-tired skidders on soil physical conditions in Greene County, Georgia. M.S. Thesis, Univ. of Georgia.

IMPACT OF TIMBER HARVESTING ON RESIDUAL TREES IN A CENTRAL HARDWOOD FOREST IN INDIANA

Thomas W. Reisinger and Phillip E. Pope[1]

Abstract: Residual stand damage resulting from conventional ground-based logging operations was assessed on six oak-hickory, upland hardwood timber sales in south central Indiana. Two areas were harvested each year--1984, 1986 and 1988--using a combination of individual-tree and group selection methods. An average of 2.6 trees per acre was damaged, and 70% of the exposed sapwood wounds were larger than 100 in.^{2} in size. Skidding caused 71% and felling 29% of these injuries. Study results indicate that the size of the wounds and the percent damage to the larger diameter classes and to higher value species is greater than reported in previous studies. The data suggest that much of the skidding damage was caused by carelessness, and could have been avoided. Damage to residual stands can be kept to a minimum by closer supervision during logging, greater operator care when skidding, and better pre-harvest planning.

INTRODUCTION

Damage to residual trees continues to be a concern of forest managers responsible for implementing individual-tree selection harvests or other types of partial cuts in hardwood forests. Damage may be limited to skinned bark and exposed sapwood, root damage, or broken branches in the crown, any of which can result in decreased vigor and quality. Or the damage may be severe enough to kill the tree. When a tree is wounded, certain physiological changes and cell differentiation occurs in the area surrounding the wound, and the wound usually becomes sealed off from the rest of the tree (Shigo 1966). Most decay and defect problems in trees originate in and spread from some kind of wound, and the impact of these wounds is likely to increase with time (Shigo 1966, Shigo and Larson 1969, Shigo 1984, Carvell 1984). The type and severity of bole damage; the susceptibility of the tree species present; and the rate of wound healing (which may be indirectly related to discoloration or linked to sources of decay) are also important considerations.

Residual tree damage is an inherent aspect of partial cutting, but the level of damage should be minimized to assure future product quality. Recent emphasis on "quality" in the

[1]Assistant Professor, Industrial Forestry Operations, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0324; and Professor, Forest Soils, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907.

manufacturing sector demands that foresters examine the impact of current hardwood logging practices on the production of quality hardwood products. This paper reports on skidding and felling damage to residual trees for six timber sale areas where individual-tree selection and group selection harvesting was conducted over a six-year period. The objectives of the study were to obtain post-harvest data on the impact of harvesting operations on the residual stand; to assess the impact of damage on log quality; and to determine specific guidelines for minimizing stand damage when logging a central hardwood forest (Hammond 1988).

METHODS

Data were collected from six timber sale areas on the Morgan-Monroe State Forest located in the Brown County Hills section of the Highland Rim Natural Region of Indiana (Homoya et al. 1984). This section of Indiana is characterized by deeply dissected, well-drained, uplands underlain by siltstone, shale, and sandstone soils. The topography consists of ridges with moderate to steep slopes ranging from 10 to 70%. The forest type is predominantly oak-hickory with a mixture of other hardwoods such as yellow poplar, white ash, sugar maple, beech, sassafras, and cherry.

General site information for the six study areas is provided in Table 1. Each of the six harvest areas was similar in size, volume of timber that was removed, soil type and terrain. The same type of 4-wheel-drive rubber-tired skidding equipment was used in each. All timber sales were logged during the fall with two areas each harvested during 1984, 1986 and 1988. Sampling design was not replicated; but two similar areas were evaluated every two years over a 6-year period. The areas ranged from 57 to 108 acres in size with the average being 78 acres, and the volume removed averaged 1.41 MBF per acre (1000 board feet). Data on residual basal area prior to harvesting were not available.

Harvest trees on each sale area were marked by Indiana Division of Natural Resources (IDNR) foresters using a combination of individual-tree selection and group selection methods. The group selection method resulted in openings of various sizes; as shown in Table 1, the average number of openings was 2.3 and average size was 5.3 acres. All areas were logged by independent contractors using chainsaws for felling, and cable skidders for moving tree lengths to the landing area. Trees were topped at a merchantable diameter of approximately 8.0 inches and skidded full length (i.e., 18-40 feet). Landing or deck areas were designated by IDNR foresters, but skid trail locations were determined by individual contractors. In all cases, the logging contractors had no prior knowledge that these tracts would be evaluated for residual stand damage.

Residual stand damage data were obtained from 179 permanently marked 0.2 acre plots centered on transect lines uniformly distributed throughout each study area. Transect lines were spaced 5 chains (330 feet) apart and perpendicular to the topography; plot centers were placed 4 chains (264 feet) apart along the transect lines. This sampling design approximated a 20% sampling intensity.

Table 1.--General information for the six study sites located on Morgan-Monroe State Forest, Indiana.

Study Site	Year of Harvest	Tract Size (acres)	Volume Removed (MBF/acre)	Number & Acreage of Openings[1]	Residual Basal Area[2]
A	1988	71	1.43	-- (0.0)	36.9
B	1988	70	2.19	2 (5.0)	58.8
C	1986	57	1.70	2 (6.6)	45.7
D	1986	108	1.37	4 (9.7)	72.7
E	1984	84	2.49	2 (6.0)	48.6
F	1984	76	1.77	8 (15.0)	58.4
Mean		78	1.41	2.3 (5.3)	56.4

[1]Per tract.
[2]Basal area (square feet) per acre with openings.

Damage to residual stems was determined by examining all trees located within the sample plot boundaries (53-foot radius). A harvest-inflicted wound was defined as bark removed accompanied by exposure of cambium or sapwood on stems 6 inches dbh or larger, damage to branches or crown, and/or root damage. Destroyed, bent, or leaning trees less than 6 inch dbh were not recorded. Wound characteristics were recorded by species and dbh; data collected included:

1. Number of wounds per tree;
2. Position of each wound above groundline (to the nearest 1.0 foot);
3. Size of exposed sapwood wound (to nearest square inch);
4. Maximum depth of wound (to nearest 0.1 inch);
5. Percent crown damage (was determined ocularly); and
6. Root damage (was noted, but not measured).

Skid trail patterns and landing locations were mapped for each timber sale area. A hand-held compass and 150-foot steel tape were used to record bearings and distances for mapping primary and secondary skid trails throughout each tract. This information was digitized into a geographic information system (GIS), and the location of skid trails and landing areas were plotted along with study area transect lines, plot centers, contour lines, and haul roads.

RESULTS AND DISCUSSION

Number of Trees Damaged

Bark removals accompanied by sapwood exposure on stems 6 inches dbh or larger were the primary type of logging injury recorded. As indicated in Table 2, the average number of trees with exposed sapwood for all areas was 2.6 per acre, or 198.6 per tract. Area A had the fewest (1.9) injured trees per acre, one of the lowest volumes of timber removed (1.43 MBF/acre), and a low residual basal area (BA) of 36.9 $ft.^2$. In contrast, Area B had the highest number (4.0) of damaged trees per acre with one of the larger volume removals (2.19 MBF/acre) and residual BA (58.8 $ft.^2$). This pattern was not apparent in the results for the remaining study areas. The average BA of all residual stands was 56.4 $ft.^2$ per acre (Table 1). These values include group selection openings which lowered the overall BA; when openings were not included, the average BA was 65.1 $ft.^2$ per acre. Of the injured trees observed, 16 percent received multiple wounds with no particular pattern observed for any individual study area. Nyland and Gabriel (1971) also found that logging damage is often distributed irregularly throughout the stand, and the occurrence of logging wounds seemed independent of the density of the original or residual stand or the intensity of cut.

Size of Exposed Sapwood

The effect of exposed sapwood wounds on future stem quality is well documented, and depends on the severity of the injury. Previous research indicates that individual wounds greater than 100 $in.^2$ are likely to cause decay (Nyland and Gabriel 1971). Exposed cambium wounds will callous and produce some decay in the butt log, but the damaged trees will rarely die because of these wounds. For this study, 70% of the wound sizes were greater than 100 $in.^2$, and the overall average size of tree wounds for all areas was 342.5 $in.^2$ (Table 2). Area A had the smallest average wound size (179 $in.^2$) while D had the largest average wound size (535 $in.^2$). In a study in West Virginia on 50-70% slopes, Lamson et al. (1985) reported that less than 1% of the residual trees (4 trees per acre) had any wounds exceeding 100 $in.^2$ in size. Their study found exposed sapwood wounds averaged 17, 39 and 26 $in.^2$ for sapling, pole-size and sawtimber-size trees, respectively. In contrast to the West Virginia study, over half the wounds in this study were in the 150 $in.^2$ or larger class (Figure 1).

Wound Depth and Position

A deep wound or gouge is of greater concern than bark abrasion or exposed sapwood. Wounds less than 4 inches wide tend to heal in as little as 2 to 4 years; but the longer the wound remains open the more discoloration and rot will result (Carvell 1984). For this study, the average depth of the tree wounds was 1.16 inches (Table 2). Trees on Areas E and F had

Table 2.--Number of trees injured and size, depth, and position of wounds for the six study sites.

Study Area	------Injured Trees------ mean (per acre)	total (per tract)	---------------Wound--------------- Size mean (sq. in.)	Depth mean (inches)	Position[1] mean (feet)
A	1.9	136	178.9	0.78	2.71
B	4.0	280	248.0	0.71	3.53
C	2.3	132	438.5	0.81	0.76
D	2.0	216	535.2	0.96	1.90
E	2.2	181	297.0	2.01	0.47
F	3.2	245	244.3	1.39	0.50
Mean	2.6	198.6	342.5	1.16	1.76

[1]Position above groundline.

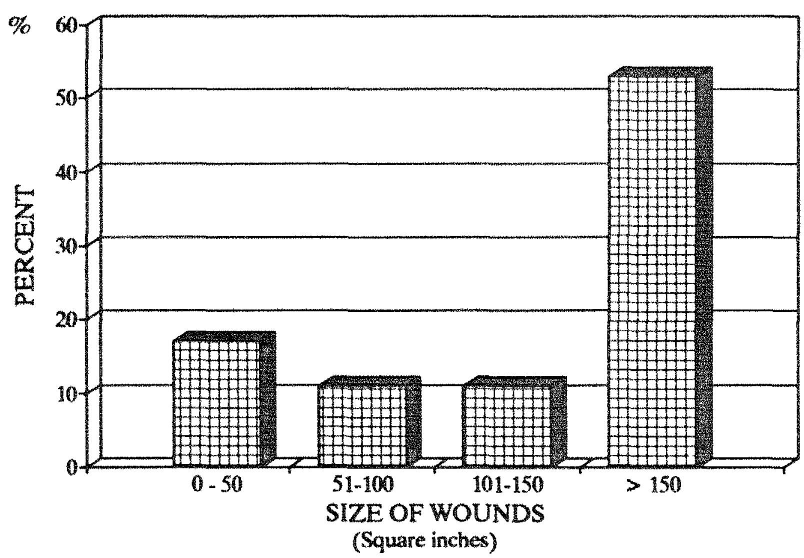

Figure 1. Percent of wounds by 50 in.^{2} size classes for the six study areas.

the deepest wounds at 2.01 and 1.39 inches, respectively. The mean depths for wounds on trees in the other areas were shallower, ranging from 0.71 to 0.96 inches. Residual trees found on the two tracts (Areas E and F) harvested four years ago have developed deep season checks from drying which accounts for the increase in depth. The most common location for wounds on the tree stem was 2.0 feet above groundline (Table 2, Figure 2). For areas A and B, the average wound was higher than 2.0 feet; and the average was below 2 feet for the other four areas. Because the wounds on Areas A and B were fresh, they were more easily detected higher up on the stem than on the areas harvested 2 and 4 years ago. Overall, 73% of the wounds were below 2 feet and 78% were below 4 feet, which agrees with the results reported by Nyland and Gabriel (1971).

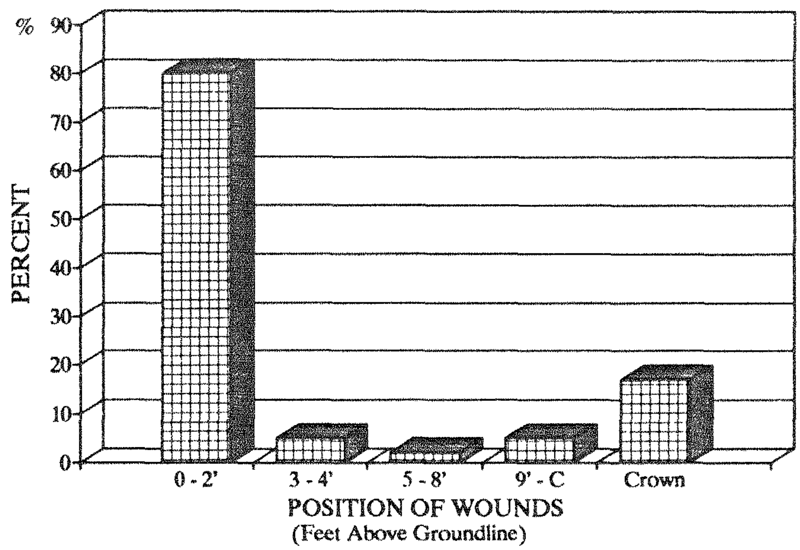

Figure 2. Percent of wounds by position class (above groundline) for the six study sites.

The percentage of wounds over 100 in.^{2} is greater than results found in previous studies (Lamson et al. 1985; Wendel and Kochenderfer 1978; and Biltonen et al. 1978). Such wounds, if they fail to heal quickly, could seriously affect the future quality of those trees injured. The low stem location of the wounds, however, could negate most of the detrimental effects to stem quality. Wounds near the ground are not as detrimental to the tree as wounds higher up on the stem (Shigo 1984). The wounds that cause the most concern are the large wounds located up on the main bole 4-10 feet above ground, and a low percentage of this type of wound was noted (Figure 2). However, a large volume of wood is lost in future harvests if the lower two feet of the butt log is of poor quality.

Tree Diameters and Species Damaged

Injury to stems was most common for trees in the 11- to 14-inch dbh class (Figure 3); 37 trees (34%) in this category and 34 (31%) in the 6-10 inch class were injured. For the 15- to 18-inch and 19- to 22-inch classes, tree damage occurred more frequently than the frequency of that diameter class in the residual stand. The 6- to 10-inch and 11- to 14-inch diameter classes had a lower frequency of damage than their frequency of occurrence in the stand. In contrast to these findings, previous studies have reported that residual stand damage is usually concentrated in the lower diameter classes (Deitschman and Herrick 1957; Nyland and Gabriel 1971; Lamson et al. 1985). The results of this study suggest that the most likely cause of this damage is carelessness -- the skidder operators disregarded or failed to maneuver around the larger residual stems.

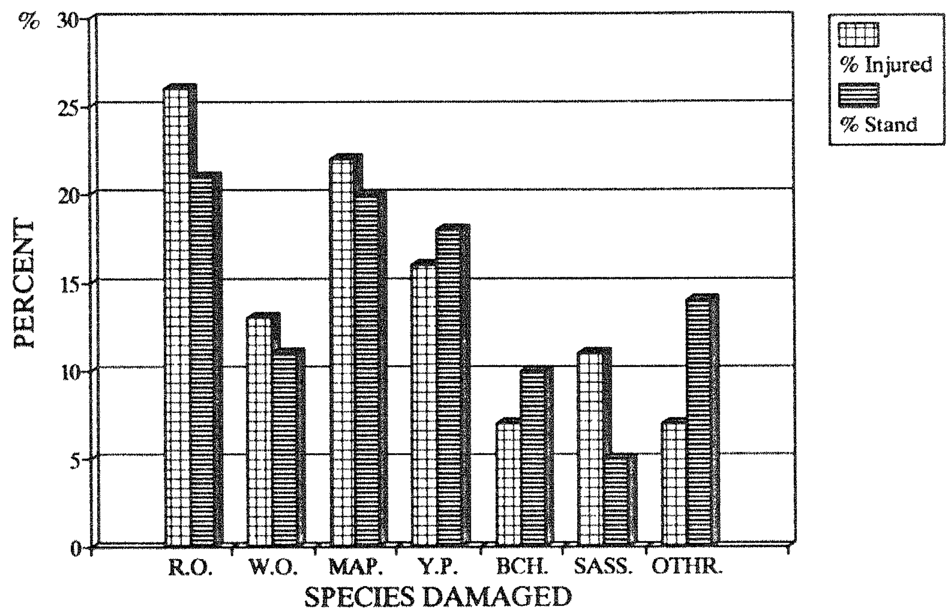

Figure 3. Percent of tree species injured for the six study sites.

Red and white oak, sugar maple, and yellow poplar were injured more often than other species found in these stands. As shown in Figure 4, the percentages of red oak, white oak, and sugar maple stems damaged were higher than their overall percentages in the residual stand. All other species had a lower injury percent than the frequency of occurrence in the stand. Red and white oaks combined accounted for 39% of the injured species while the percent of the oaks found in the residual stand was only 32%. One explanation for this could be the skidder operators' failure to recognize the value of future commercially important crop trees. Regardless of the reason, bark scraped from these stems is likely to reduce the future quality and value of these trees.

Operational Considerations

Slope and traffic intensity on the study sites had an effect on the number of trees injured. The highest number of injured trees (per acre) occurred on the flattest sites (Areas F and B), while the smallest number of injured trees occurred on the tract with the steepest terrain (Area A). On steeper slopes, the primary skid trails were located on the ridge tops and secondary

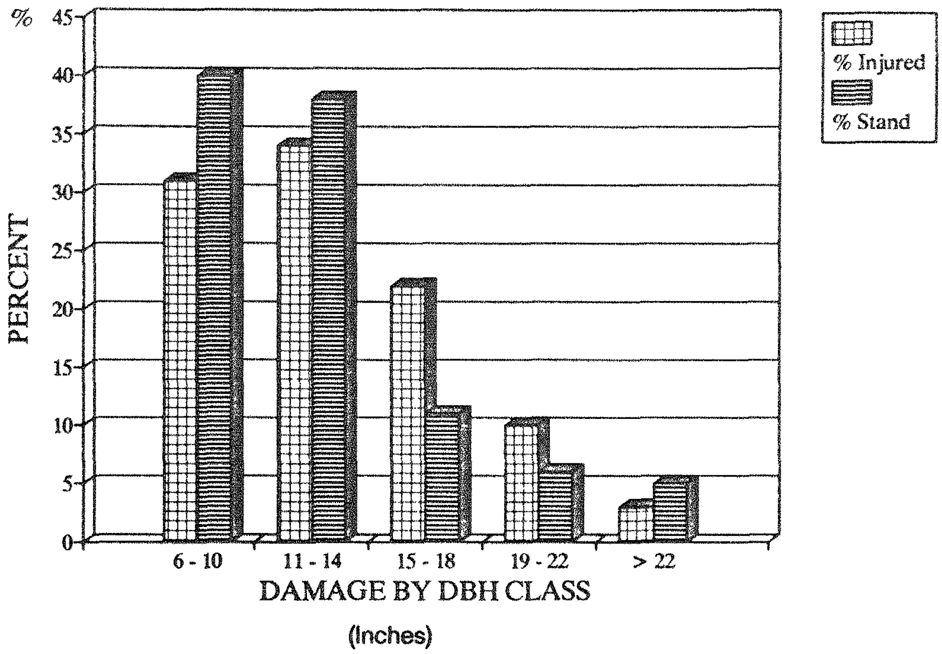

Figure 4. Percent of tree species injured for the six study sites.

skid trails were oriented directly up and down the slopes. Gentle terrain allowed the skidder operators to travel at higher speeds and cover a larger percentage of the total area which, in turn, damaged more residual trees.

As expected, higher rates of stand damage appear to be a function of traffic intensity or number of machine passes. The majority of residual stand damage occurred adjacent to the primary skid trails where the number of machine passes was the highest even though secondary skid trails disturbed 34% more surface area. The average number of trees injured by machine traffic on primary skid trails was 5.8 trees per acre, almost double the number of trees located on secondary skid trails (3.1 trees). Skidding caused 70% of the residual stand damage, felling caused 29%, and 1% of the wounds were caused by landing operations. Ten percent of the wounds were associated with root damage during skidding, and generally were confined to one side of the tree (i.e., adjacent to the skid trail). Other studies involving ground-based skidding report similar results (Nyland and Gabriel 1971; Johnson et al. 1979; Biltonen et al. 1978; and Olsen and Seifert 1984). Nyland and Gabriel (1971) suggest that over half of the skidding injuries might have been avoided by "slightly altering the skid path or using greater caution during skidding."

SUMMARY

The results of this study are similar to those of other studies that have evaluated residual stand damage after conventional ground skidding operations. Past research indicates that it is inevitable that some trees will be injured during partial cutting, but the amount of damage can not be predicted in advance based on stand density or cutting intensity. The average number of trees (> 6" dbh) injured in this study (i.e., 2.6 trees per acre) is fairly typical for partial cuts in hardwood stands. However, the size of the wounds was larger than expected based on previous studies of logging damage, and a majority of these wounds are larger than 100 $in.^2$ size. Wounds this large have a greater potential to cause decay and discoloration, these wounds may not cause defect problems due to their low position on the main bole. The percentage of red and white oaks damaged was also higher than expected. Injury to these and other commercially important species is a concern because it poses a threat to the future merchantability of these hardwood stands. Slower travel speeds and additional care should be exercised by the skidder operators in order to protect future crop trees in the larger diameter classes and those species that have commercial value if product quality is to be maintained in successive harvests.

The majority of the residual stand damage (71%) is caused by skidding along primary skid trails with twice the number of trees damaged on the primary skid trails as on the secondary trails. Terrain seems to influence the position and number of skid trails used, and in turn affect the number of stems injured. Normal levels of residual stand damage associated with individual-tree/group selection cuts can be tolerated and should not cause serious quality problems (Lamson et al. 1985). Because partial cuts require frequent entry to the stand, continued efforts to minimize residual stand damage of each harvest must be encouraged particularly for high quality hardwood stands. The results of this research suggest that greater emphasis be given to the following recommendations.

1. **Operator training.** This research as well as past studies indicate that skidding damage (more than felling injuries) depends upon human factors and can often be avoided. New employees should be trained and experienced machine operators must be made aware of the value of residual crop trees and the importance of minimizing stand damage if uneven-aged stand management practices are to be successful.

2. **Closer supervision.** Many times the machine operators' paycheck is based on production rather than the quality of, or care taken in, carrying out that job. Close supervision of the skidding and felling operations by the logging foreman, management foresters, and/or the landowner is essential if machine operators are to be convinced that care should be exercised to avoid damage to potential crop trees. If that does not work, financial incentives for doing a quality job or penalties for excessive logging damage may need to be specified in the harvesting contract.

3. **Pre-harvest planning.** Preliminary planning done prior to beginning the harvest should consider ways to minimize residual stand damage. The use of pre-planned or designated skid trails offers a solution because pre-planning confines most of the machine traffic within a smaller area, thus reducing the amount of residual stand damage. The practice of leaving designated "rub" trees along main skid trails, where the majority of the trees are damaged, can also greatly decrease the number and severity of damage to residual trees. The "rub" trees receive a larger share of the skidding damage, and are then removed at the end of the harvest.

LITERATURE CITED

Biltonen, F.E., W. A. Hillstrom, H.M. Steinhilb, and R.M. Godman. 1978. Mechanized thinning of northern hardwood pole stands: methods and economics. USDA For. Serv. Research Paper NC-137. 9pp.

Carvell, K. L. 1984. A silvicultural evaluation of cable yarding for partial cuts. In Proc.: Mountain Logging Symposium, Jun. 5-7, Morgantown, West Virginia. pp133-141.

Deitschman, G.H. and D.E. Herrick. 1957. Logging injury in the central states upland hardwood. J. For. 55(4):273-277.

Hammond, S.C. 1989. Impacts of timber harvesting on soils and residual trees in Indiana's Morgan-Monroe State Forest. M.S. Thesis. Purdue University, Dept. of Forestry and Natural Resources. 93pp.

Homoya, M.A. D.B. Abrell, J.R. Aldrich, and T.W. Post. 1984. The natural regions of Indiana. Proc. Indiana Acad. Sci. 94:245-269.

Johnson, J.A., W.A. Hillstrom, E.S. Miyata, and S.G. Shetron. 1979. Strip selection method of mechanized thinning in northern hardwood pole size stands. Michigan Tech. Univ. Res. Notes No. 27. 13pp.

Lamson, N.E., H.C. Smith, and G.W. Miller. 1985. Logging damage using an individual-tree selection practice in Appalachian hardwood stands. No. J. App. For. 2(4):117-120.

Nyland, R.D. and W.J. Gabriel. 1971. Logging damage to partially cut hardwood stands in New York State. State Univ., Coll. of For., Syracuse Univ., AFRI Res. Pap. 5. 38pp.

Olsen, E.D. and J.C.W. Seifert. 1984. Machine performance and site disturbance in skidding on designated trails. J. For. 82(6):366-369.

Shigo, A.L. 1966. Decay and discoloration following logging wounds on northern hardwoods. U.S. Dept. Agric. For. Serv. Res. Pap. NE-47.

Shigo, A.L. 1984. How to assess the defect status of a stand. North. J. App. Forestry 10(9):41-49.

Shigo, A.L. and E.H. Larson. 1969. A photo guide to the pattern of discloration and decay in living northern hardwood trees. USDA, For. Serv. Res. Paper NE-127. 100pp.

Wendel, G.W. and J.N. Kochenderger. 1978. Damage to residual hardwood stands caused by cable yarding with a standing skyline. South. J. Appl. For. 2(4):121-125.

A COMPARISON OF SMALL TRACTORS FOR THINNING CENTRAL HARDWOODS

Neil Huyler and Chris B. LeDoux[1]

Abstract: Young-growth hardwood forests in the central hardwood region will require intensive management if they are to help meet the Nation's increasing demand for wood. Such management generally will require entries into the stands when the trees are small. Many small-scale machines are available for harvesting small wood. Time and motion studies were conducted on small-scale logging operations in the Northeast. The small tractors were studied in a wide range of forest and operating conditions. The machines include the Pasquali 933, a Holder A60F, a Forest Ant Forwarder (Skogsmyran), a Same Minitaurus, and a Massey-Ferguson. The use of small tractors in low-volume, small-diameter hardwood stands is feasible. The Forest Ant should be used only as a forwarding machine while the skidding tractors--Holder, Pasquali, Same and Massey-Ferguson--should be used in stands of medium to large stems and with short skid distances.

INTRODUCTION

As the Nation's demand for wood fiber increases for both wood products and as a source of renewable energy, more youth-growth hardwood forests in the central hardwood region will be required to meet this growing demand.

The intensive forest management required to maintain a sustained yield and attain the production potential of the forest land will require the harvesting of small-diameter, low-quality trees that are characteristic of the central hardwood region. Time of entries and suitable harvesting equipment must be evaluated to ensure a profitable operation.

Several small-scale harvesting machines with suitable economic and physical features are an attractive alternative to conventional ground-based machines that have raised profit ability and environmental concerns (Huyler et al. 1984, Turner et al. 1988).[2]

---

[1]Research Forester, Northeastern Forest Experiment Station, George D. Aiken Forestry Sciences Laboratory, 705 Spear Street, So. Burlington, VT 05403, and Industrial Engineer and Project leader, Northeastern Forest Experiment Station, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505.

[2]Huyler, Neil K. and Chris B. LeDoux. Cycle time equations for five small tractors operating in low volume small diameter hardwood stands. USDA For. Serv. Res. Pap. NE-__ (in preparation).

On the basis of time and motion studies, cost comparison and cycle-time equations were developed for five small tractors in select stand conditions. (See Table 1 for characteristics of the study sites.) The harvesting machines included a Pasquali 933, a Holder A60F, a Forest Ant Forwarder (Skogsmyran), a Same Minitaurus, and a Massey-Ferguson (Huyler and LeDoux 1989). This paper compares the productivity and cost of these five small tractors for select stand conditions.

Table 1.--Characteristics of the study sites

Tractor type	Study site No.	Average tree dbh	Basal area		Skidroad slope		Loaded skid direction	Type of cut
			Precut	Postcut	Primary	Secondary		
		-Inches-	--ft^2 per acre--		------Percent------			
Massey-Ferguson	1	9.4	109	80	4	22	Downhill	Selection
Massey-Ferguson	2	10.3	90	0	6	17	Uphill	Regeneration clearcut
Massey-Ferguson	3	10.3	90	0	6	2	Uphill	Regeneration clearcut
Same	4	11.0	110	85	5	15	Downhill	Selection
Pasquali	4	8.6	116	76	0	14	Uphill	Low thinning
Holder	4	8.6	116	76	0	14	Uphill	Low thinning
Forest Ant	5	8.4	96	71	0	12	Uphill	Low thinning

MACHINE DESCRIPTION

The Pasquali Model 993 tractor is manufactured in Italy and was designed for use on small farms, landscaping projects, and light construction work in municipalities. It is powered by a 30-horsepower engine and has an articulated frame with four-wheel drive. The tractor is equipped with a 3-point hitch, live power takeoff (PTO), and a JL-25 Farmi logging winch. The winch has a 5,500-pound line pulling capacity, spooled with 100 feet of 3/8-inch cable. The Pasquali tractor is 4-1/2-feet wide and 8-feet long, excluding a 4-foot bucket. Safety options include liquid loaded front and rear tires, roll bar, skid pan, and wheel chains.

The Holder A60F tractor is manufactured in Germany and was designed for farm use and light forestry operations. It is powered by a 48-horsepower engine with an articulated frame. The tractor is equipped with a 3-point hitch, live power takeoff, and an Ingland Jones 3000 double-drum winch. The winch has a 6,600-pound-line pulling capacity, spooled with 120 feet of 3/8-inch cable. Safety options included wheel weight, forestry cab, roll bar, and skid pan.

The Forest Ant is manufactured in Sweden and was designed to forward stems to the main skid trails in large forest operations. This small four-wheel-drive tractor has a 12-horsepower engine with an articulated frame. It is equipped with a knuckleboom loader and clam bunk. The tractor steering and speed is controlled by a tiller bar in front. The machine has no cab and the operator walks at a comfortable speed with the machine following.

The Massey-Ferguson 184-4, manufactured in the United States, is a medium-size, four-wheel-drive farm tractor. It has a 60-horsepower diesel engine and is equipped with a 3-point hitch and live power takeoff, and a JL-456 Farmi winch with a line-pulling capacity of 10,000 pounds. Tire chains were used on the rear tires and extra weight added to the front tires. All tires were loaded with calcium chloride for weight.

The Same Minitaurus 60 is manufactured in Italy and designed for small farm use. It is a medium-size four-wheel drive tractor with a 60-horsepower engine. It is equipped with a 3-point hitch, live power takeoff, and a JL30 Farmi logging winch. The winch has a 6,600-pound line pulling capacity, spooled with 165 feet of 3/8-inch cable. Optional and safety equipment included a bucket loader, front wheel weights, loaded rear tires, wheel chain and rollover protection. (See Figures 1 through 5 for illustrations of each of the five tractors.)

Figure 1. The Massey-Ferguson 184-4 equipped with JL-456 winch.

Figure 2. The Same Minitaurus with JL-30 winch, roll-over protection bars, and bucket loader.

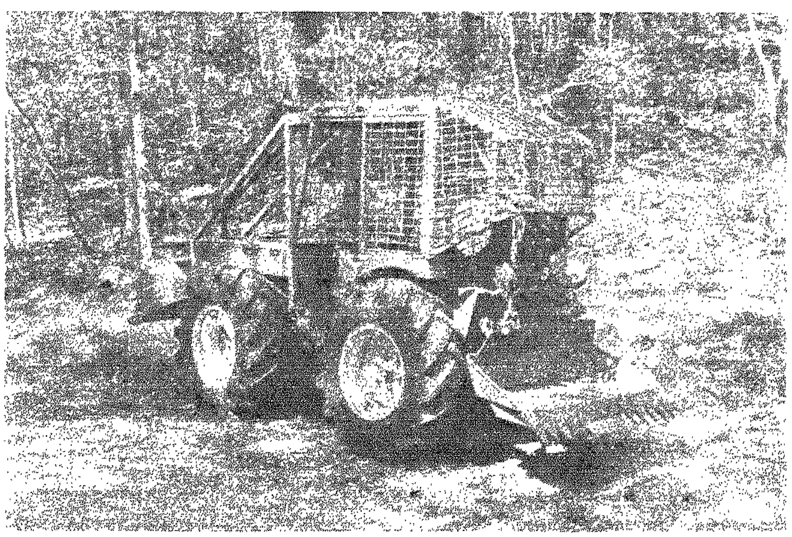

Figure 3. The Holder A60 F equipped with an Igland Jones double-drum winch and roll-over protection.

Figure 4. The Pasquali Model 993 with bucket, roll-over protection, and JL-25 single drum winch.

Figure 5. The Forest Ant equipped with clam bunk and knuckleboom loader.

TRACTOR PRODUCTIVITY AND OPERATING COST

The harvesting areas for both the Massey-Ferguson and Same tractors were in low-quality hardwood stands. Two sites were marked for selection cuts and two sites were marked for regeneration clearcuts. The precut basal area ranged from 90 to 116 square feet per acre for all sites.

Time-study data were summarized and cycle-time equations developed for each tractor. The cycle-time and production estimators were developed using similar variables: slope yarding distance, volume per turn, number of logs per turn, and volume per log. Using similar variables in each cycle time estimator simplifies the comparison of machine cost of production and any simulation effort. Table 2 gives the mean production data for each tractor. The Massey-Ferguson and Holder produced volumes of 46.9 and 50.3 cubic feet per turn, respectively. The Same produced the largest hitch size at 64.8 cubic feet while the Pasquali had the smallest at 18.6 cubic feet per turn. The Forest Ant was slightly higher than the Pasquali at 34.9 cubic feet per turn.

Table 2.--Mean production data for each tractor

Tractor (Number of observations)	Number of stems per turn	Volume per stem	Volume per turn	Mean skid distance
		--ft^3--	--ft^3--	--ft--
Massey-Ferguson (119)	3.78	15.46	46.94	878
Holder (45)	5.62	9.26	50.26	1,147
Same (32)	4.07	19.11	64.77	2,174
Pasquali (65)	3.89	5.19	18.63	947
Forest Ant (30)	7.10	5.15	34.94	253

Table 3 shows owning and operating and labor hourly rate for the five tractors. The investment cost for each tractor was based on 1988 new equipment cost and any added safety and optional equipment.

COMPARISON OF COST

To compare the cost of the five tractors for similar operating conditions, we developed a PC computer program that held certain of the production variables constant while allowing others to change in value, e.g., volume per turn, number of logs per turn, and volume per turn held constant while the slope yarding distance was varied. The four variables significantly influenced productivity and cost for these tractors.[2] The PC program was run several times for each machine and combination of variables. Results were then graphed for comparison.

Table 3.--Owning and operating and labor hourly rates for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors.

Machine	Owning and operating[a]	Labor[b]	Total hourly rate
	----------	Dollars	----------
Pasquali	5.77	6.75	12.52
Forest Ant	4.27	6.75	11.02
Massey-Ferguson	5.40	6.75	12.15
Holder	14.42	6.75	21.17
Same	5.41	6.75	12.16

[a]Based on 1988 new equipment cost, depreciation, insurance, taxes, interest, storage, operating cost (fuel, oil, lubricants, maintenance, and repair).
[b]Labor rate at \$5.00/hour plus 35-percent fringe benefits.

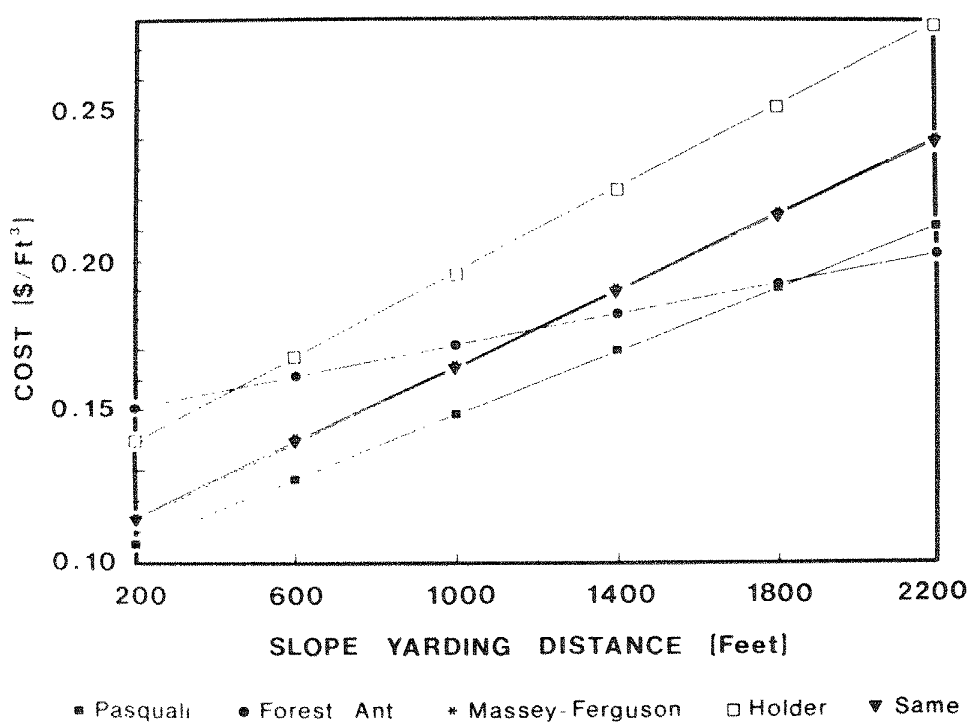

Figure 6. Cost per cubic foot by slope yarding distance for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: number of longs per turn=3, volume per turn=35.67 ft^3, volume per log=11.89 ft^3.

Figure 6 shows the impact of slope yarding distance on cost. Volume per turn was held constant at 35.67 cubic feet. Volume per log was held constant at 11.89 cubic feet with number of logs equal to 3. As slope yarding distance increases, the cost per cubic feet increases for all machines evaluated. The Pasquali tractor is the most competitive until a slope distance of about 1,800 feet is reached, at which time the Forest Ant is the most competitive. The Massey-Ferguson and Same tractors are equally competitive throughout the range of slope yarding distance. The Holder tractor is the least competitive throughout the variable range. At a slope yarding distance of about 1,200 feet, it is more economical to use the Forest Ant Forwarder than to skid the same turn with the Massey-Ferguson, Same, or Holder tractor. This illustrates the advantages of forwarding at longer skid distances.

Figure 7 shows the impact of slope yarding distance on cost with volume per turn, volume per log, and number of logs per turn held constant at 35.67 cubic feet, 4.46 cubic feet, and 8, respectively. For the combination of number of logs and volume per log, the Forest Ant forwarder is the most competitive throughout the range of slope yarding distance. The Same tractor is the next most competitive with the Pasquali close behind.

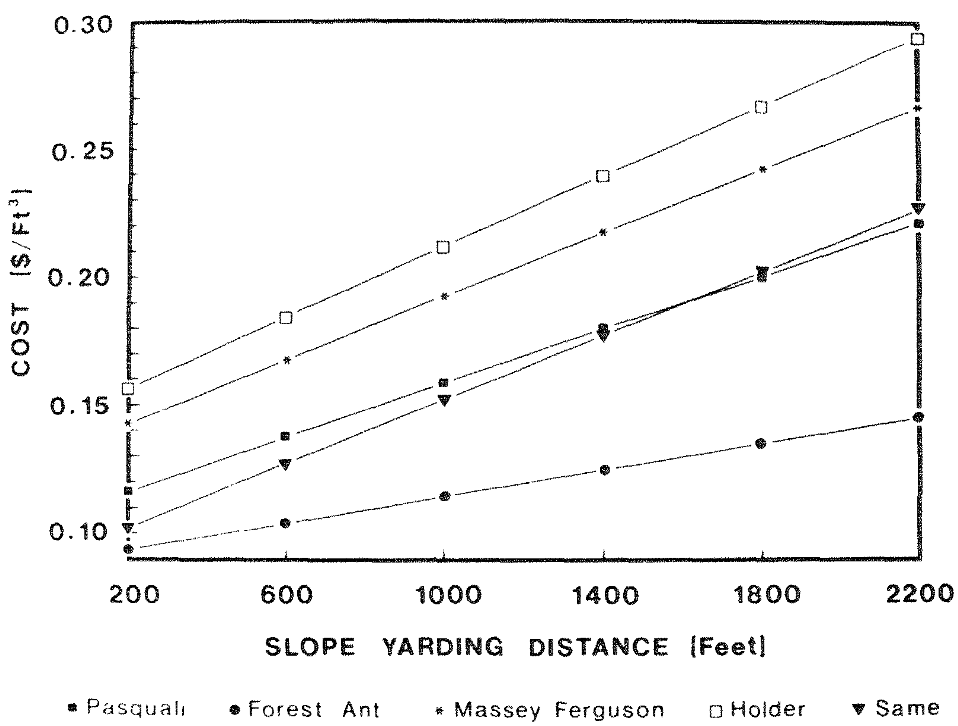

Figure 7. Cost per cubic foot by slope yarding distance for Pasquali, Forest ant, Massey-Ferguson, Holder, and Same tractors. Conditions: number of logs per turn=8, volume per turn=35.67 ft^3, volume per log=4.46 ft^3.

The Massey-Ferguson and the Holder tractors are the least competitive. This matches practical experience in that the tractors are not being used to capacity when this many small logs are being hooked. The Forest Ant is best when one is operating in stands where there are many and small logs.

The impact of number of logs per turn on skidding cost is shown in Figures 8 and 9. In Figure 8, number of logs per turn is allowed to change within the observed range of 1 to 7. The volume per log is held constant at 5 cubic feet with volume per turn ranging from 5 to 35 cubic feet. The slope yarding distance is held constant at 300 feet. The Forest Ant has a slight advantage over the Pasquali and Massey-Ferguson tractors. The Holder and Same are the least competitive, especially when there are 1 to 3 logs per turn and the volume per turn is 5 to 15 cubic feet. These results show that even when the slope yarding distances are short (300 feet), the Forest Ant is still at an advantage when small logs are skidded.

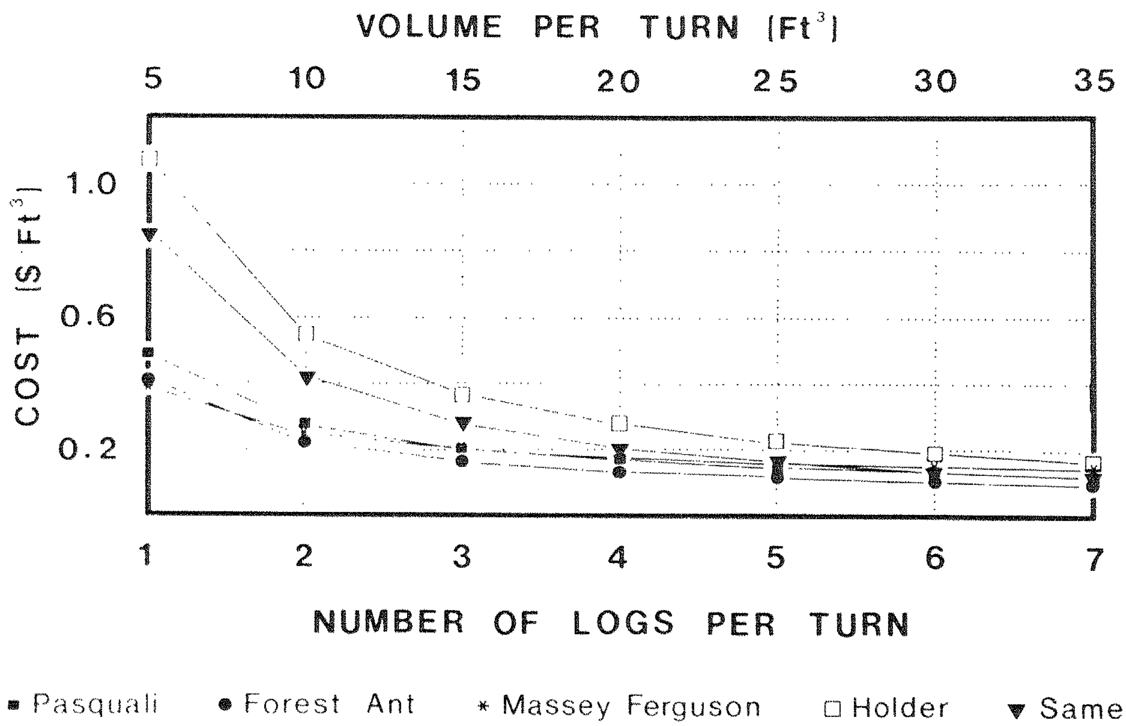

Figure 8. Cost per cubic foot by volume per turn (ft^3) and number of logs per turn for the Pasquali, Forest Ant, Masey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, voume per log=5 ft^3.

Figure 9 shows the impact of larger volumes per log and number of logs on skidding cost for a slope yarding distance of 300 feet. When the volume per log is 15 cubic feet, the Massey-Ferguson and the Pasquali are most competitive when 1 to 3 logs are hooked. With 4 or more logs per turn, all of the machines are about equally competitive with the Same showing a slight advantage. The Forest Ant forwarder is not competitive when handling 1 to

3 medium-size logs. These results are consistent with previous results in that the forwarder is most efficient when the logs are small.

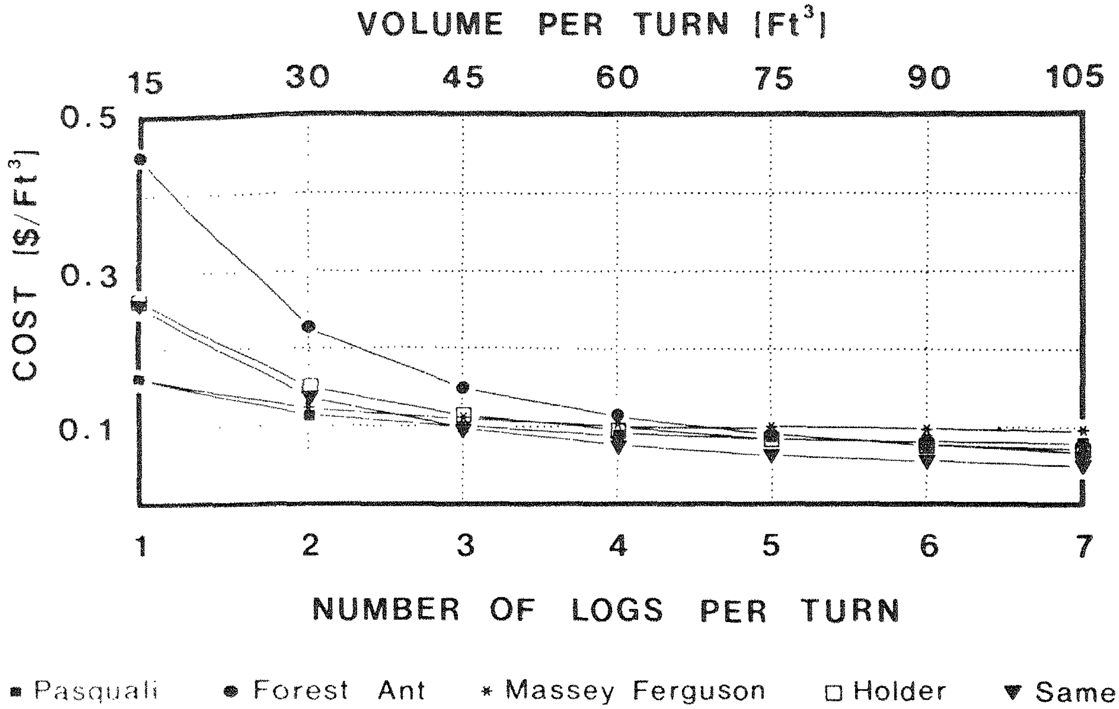

Figure 9. Cost per cubic foot by volume per turn (ft^3) and number of logs per turn for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, volume per log=15 ft^3.

Figure 10 simply confirms previous results. Slope yarding distance and volume per turn were held at 300 feet and 30 cubic feet, respectively, while number of logs per turn and volume per log were allowed to change in value over the observed range. The Pasquali, Massey-Ferguson, and the Same are about equally competitive throughout the range. When the volume per log is 7.5 cubic feet and 4 or more logs are carried per skid, the Forest Ant is the most competitive. The skidding tractors are most efficient when skidding few large logs at short skid distances (Figures 1 and 5).

The impact of increasing volume per turn is shown in Figure 11. Slope distance is held constant at 300 feet with 3 logs per turn. It is interesting that when volume per turn is 25 cubic feet or higher, the cost curve for the Forest Ant is nearly constant. This is true of most forwarders at some payload level. The Massey-Ferguson, Pasquali, Same, and Holder, are about equally competitive when the volume per turn is about 40 cubic feet or larger, with the Same and Holder holding the advantage at volumes per turn of 55 cubic feet or larger. This also matches practical experience in that few large logs are best handled with the tractors and few small logs are best handled with the Forest Ant.

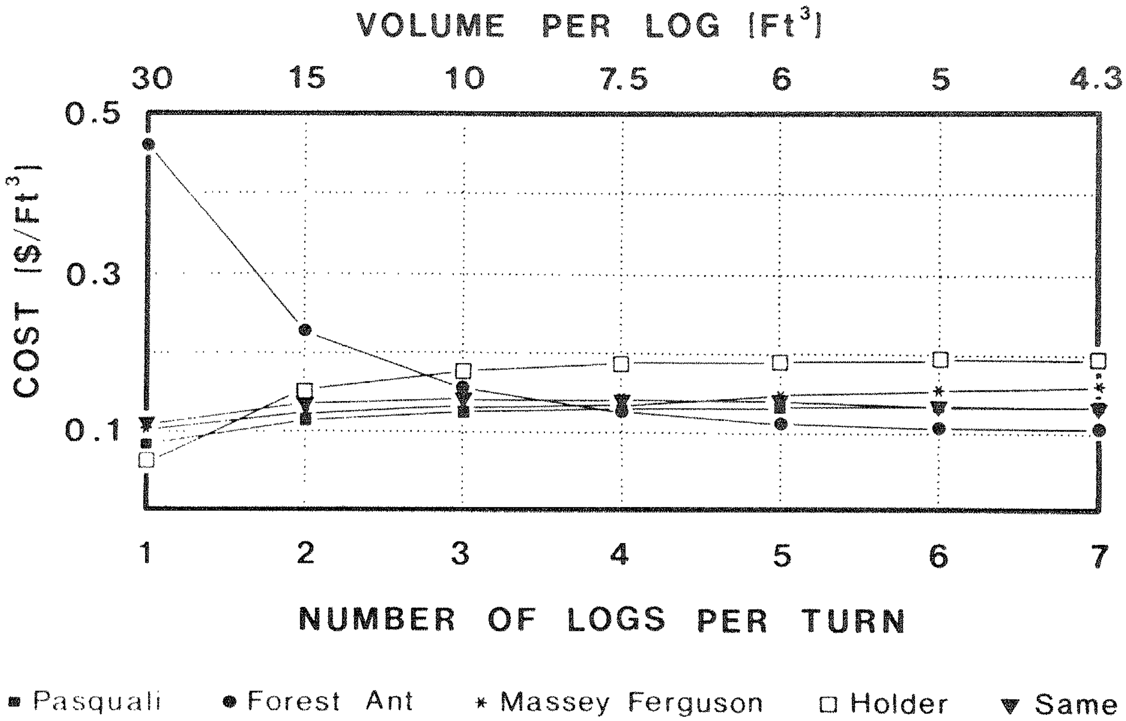

Figure 10. Cost per cubic foot by volume per log (ft^3) and number of logs per foot for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, volume per turn=30 ft^3.

MACHINE APPLICATIONS

The use of small tractors as a harvesting tool in low-volume, small-diameter hardwood stands is feasible. Timing of entry, type of machine, and careful site selection and layout are critical factors for ensuring a profitable operation.

The Forest Ant should be used only as a forwarder and performs best in stands that have many small stems over both short (300 feet or less) and long (1,200 to 1,800 feet) skid distances. Also the terrain should be relatively uniform (slopes up to 15 percent). The skidding tractors--Holder, Pasquali, Same and Massey-Ferguson--are most efficient when used in stands with medium to large stems and with short distances up to 300 feet.

All of the small tractors have good maneuverability over most terrain and in dense small-diameter stands. Other significant advantages observed when using small tractors as a harvesting tool are less soil compaction, ease of movement to and from the harvesting area, and little damage to the residual stand.

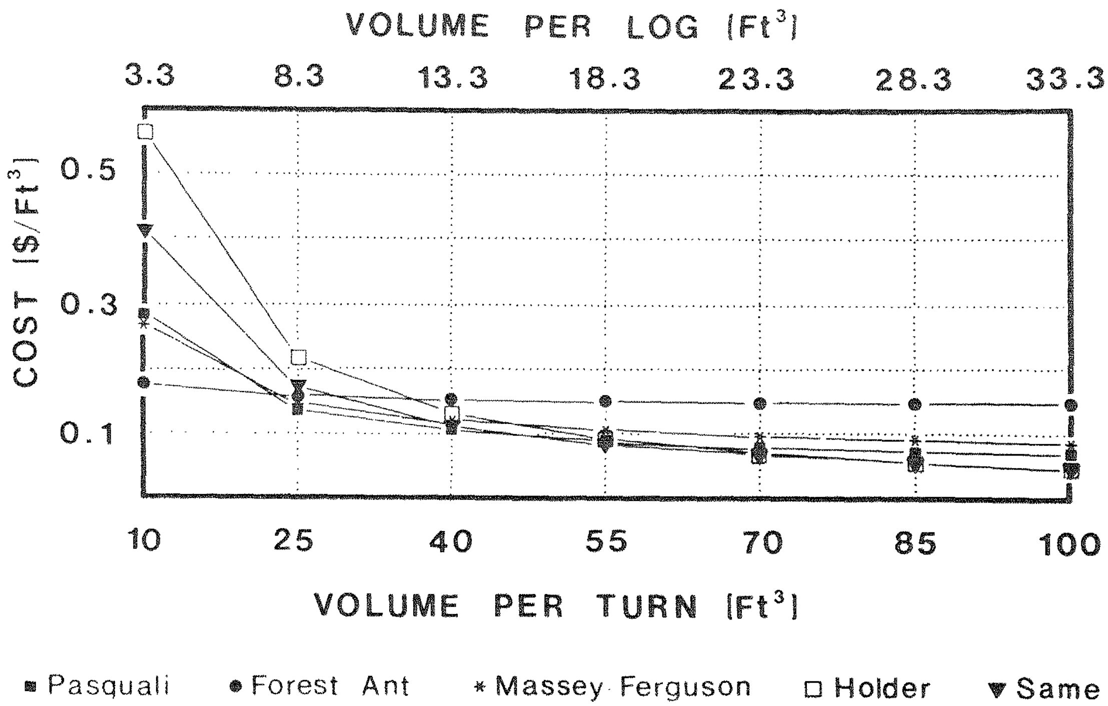

Figure 11. Cost per cubic foot by volume per log (ft³) and volume per turn (ft³) for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, number of logs per turn=3.

CONSIDERATIONS FOR MANAGERS

These results should be valuable to forest managers and planners and to loggers in comparing the potential applications of small tractors operating in low-volume, small-diameter hardwood stands. Although this paper only summarizes the comparison of costs for four production variables, research is progressing to incorporate these and additional simulation results into a computer package for estimating stump-to-mill logging costs.

The cycle-time and production estimators will be developed so that similar variables such as slope yarding distance, volume per turn, logs per turn, and volume per log are included by machine in each cycle-time estimator. The similarity in production variables eases comparison of machine time and production. Including similar variables in each cycle-time estimator also simplifies simulation efforts.

The cycle-time and production estimators shown by machine, along with a range of stand and forest conditions, would be used as input to select various simulation models. The simulators would be run repeatedly over the range of conditions of interest. The resulting cost or production data points by machine and forest condition would be summarized in mathematical equations suitable for incorporation into generalized stump-to-mill models. Computerized stump-to-mill methods that could be used for estimating costs and production would help managers, planners, and loggers determine where specific machines are applicable.

LITERATURE CITED

Huyler, Neil K., Donald E. Koten, Richard V. Lee, and Anthony P. Quadro 1984. Productivity and cost of three small fuelwood skidders. J. For. 82(11):671-674.

Huyler, Neil K., and Chris B. LeDoux. 1989. Small tractors for harvesting fuelwood in low-volume small-diameter hardwood stands. In: Implementing techniques for successful forest operations: Proceedings of the 12th Annual Meeting of the Council on Forest Engineering, August 27-30, 1989, Coeur 'D Alene, ID. p. 61-66.

Turner, Terry L., Neil K. Huyler, and Daniel W. Bousquet. 1988. Farm tractor skidding costs in relation to profitability of a fuelwood harvesting system. North. J. of Appl. For. 5:207-210.

COMPARING PARTIAL CUTTING PRACTICES

IN CENTRAL APPALACHIAN HARDWOODS

Gary W. Miller and H. Clay Smith [1]

Abstract: Variations of diameter-limit and perhaps single-tree selection harvesting are used to regenerate and manage central Appalachian hardwood sawtimber stands. In practice, these methods differ in terms of cut rules, control of stand structure, and cultural treatment of immature stems. Preliminary information is provided to compare the effect of two differing harvest practices on the residual stand--species composition, tree quality, stand structure, and return on residual stand value. Data were obtained from second-growth central Appalachian hardwood stands managed under a given harvesting practice for 30 to 40 years. Results indicate that, for the short term, many single-tree selection goals may be achieved with an easy-to-apply diameter-limit harvest of mature trees. Economic considerations for practical application and potential long-term impacts of each harvesting method are discussed.

INTRODUCTION

Partial harvest practices, such as diameter-limit cutting and single-tree selection cutting, can be used to manage and regenerate central Appalachian hardwood stands. Appropriately applied, single-tree selection is classical unevenage management, while diameter-limit cutting is mentioned often when discussing unevenage management because it also involves periodic partial harvests. What are the on-the-ground differences between a high minimum diameter-limit and single-tree selection? These two practices differ in terms of cut rules, control of residual stand structure, and culture of immature growing stock. Selection represents more intensive silviculture by virtue of its strict control of stand structure, while diameter-limits simply remove all stems over a given size-class. Do these practices lead to residual stands with distinct characteristics and different implications for long-term management?

This paper provides additional information for comparing selection and high-minimum diameter-limit practices. Key factors affecting both economic returns and sustained yield are compared for second-growth stands managed under each harvesting method for 30 years. Comparisons are based on changes in: species composition, tree quality, residual stand structure, and return on residual stand value. Finally, economic considerations for applying these harvesting methods over extended planning periods are discussed.

---

[1]Economist and Project Leader, respectively, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Parsons, WV 26287.

Repeated partial harvests over long periods can influence species composition and quality of merchantable products. Intolerant species have difficulty developing under partial shade maintained by periodic partial harvests. So, even a stand initially composed of largely intolerant species will regenerate to more tolerant species over time. How do selection and diameter-limit practices differ in their influence on species composition?

Partial harvest practices may also have some affect on product quality. For example, selection practices afford an opportunity to culture immature stems by removing undesirable stems and providing available growing space to trees of better potential grade. By contrast, diameter-limit harvests commonly make no removals below a specific d.b.h. size-class, so this practice provides little direct influence on quality of the residual trees. How do selection and diameter-limit practices differ in their influence on product quality?

Forest managers should make provisions for sustained yield of wood products when applying a partial harvest practice over long periods of time, say 100 years or more. Single-tree selection, as applied in these stands, controlled residual basal area (RBA), largest diameter tree (LDT), and diameter distribution quotient (q-factor) to provide for long-term sustained yield (Smith and Lamson 1982). The diameter-limit practice did not have residual stand targets as in the selection practice. As applied in this study, the d.b.h. cutting limit was 17.0 inches, relatively high for most eastern hardwood markets. The higher limit allows trees to become large enough for grade 1, the highest sawtimber grade, before harvest. How do selection and diameter-limit practices differ in their ability to establish desirable regeneration following each harvest and provide a sustained yield of wood products?

Each factor discussed has an important influence on financial returns from timber production using a partial harvest management system. Frequency and value of periodic revenues are directly related to growth characteristics and product quality of the species which regenerate following each harvest. In addition, within a particular species group, individual tree quality plays an equally important role in determining the unit value of merchantable products sold each cutting cycle. And finally, a harvest practice must provide for sustained yield or else periodic revenues may be interrupted in the future, requiring costly, unexpected stand reestablishment. How do selection and diameter-limit practices compare in terms of potential rate of return?

The information presented here provides a basis for evaluating partial harvest practices. The preliminary results shed light on the returns possible during transition from a second-growth evenaged stand to an unevenaged stand in which periodic yields are regular. Trends observed also indicate the likely species composition, tree quality, and regeneration potential for stands managed over long periods with partial harvest practices. Information regarding the transition period and clues about the character of the future stand make it possible to estimate the long-term returns possible from selection and diameter-limit practices.

In summary, the information presented here can help the forest manager evaluate two types of partial cutting practices and decide which practice is best suited to management objectives.

DATA

Data were obtained from stands located on the Fernow Experimental Forest near Parsons, West Virginia. The study area receives about 55 inches of precipitation annually, distributed evenly throughout the year. Stands compared in this study are located on site index 70 for northern red oak (*Quercus rubra* L.). Management began in the early 1950's when the second-growth stands were about 45 years old. Some old residuals from the early logging in 1905 and some stems resulting from regeneration following death of the American chestnut in the 1930's were present in the study area when the first partial harvests were made. The study stands contained three age classes when management began.

Stand data were obtained from 100 percent cruises taken every 5 years and before each harvest. Small reproduction consisted of any woody species from 1.0 foot tall to 0.99 inches d.b.h., tallied on 1/1000-acre plots randomly located throughout the study areas. Large reproduction was composed of any woody species 1.0 to 4.9 inches d.b.h., tallied on 1/100-acre plots randomly located throughout the study areas. Sawtimber quality was measured using U.S. Department of Agriculture, Forest Service log grades on a random sample of trees measured during the periodic inventories. Current (at the time of harvest) average stumpage prices for each species group were used to determine harvest and residual stand values.

TREATMENTS

In this study, diameter-limit cutting was applied using 17.0 inches as the minimum cutting diameter. Harvests were planned on a 15-year cutting cycle. Two diameter-limit areas totalling 87 acres have been cut three times since the early 1950's. Cultural practices such as vine control were applied throughout the stand before logging, but culls and undesirable growing stock below the 17.0-inch diameter limit were not cut. Cut trees were marked during the 100 percent inventory, thus relieving the logging contractor of the responsibility of measuring d.b.h.

Single-tree selection was applied according to guidelines described by Smith and Lamson (1982). In this study, selection stands were marked to achieve a residual basal area of 65 sq ft per acre (including trees 5.0 inches d.b.h. and larger) with a largest tree of 26 inches d.b.h. and a q-factor of 1.3. Marking was controlled by cut ratios for each 2-inch-diameter class, 11.0 inches d.b.h. and larger. Vines and culls were cut during each harvest operation. Harvests are planned on a 10-year cutting cycle. Since the early 1950's, two selection areas totalling 54 acres have been cut three and four times, respectively.

Data from two control areas totalling 83 acres also were included to detect changes not related to the cutting treatments. Control areas were unmanaged over the study period and received no vine control or cull treatments.

RESULTS AND DISCUSSION

In general, both selection and diameter-limit practices provided adequate regeneration to continue making periodic harvest cuts for at least an additional 40 years. Development of advance regeneration also was favorable for continued management using these harvest methods. The first 40 years of applying partial harvest practices promoted the establishment of tolerant species. Moreover, evidence from surveys of small and large reproduction indicated that continued partial harvests eventually will eliminate intolerant species, and, that sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) will dominate harvest volume as long as these practices are continued.

The first three or four cutting cycles in managing second-growth hardwoods using partial harvest practices resulted in economical, commercial harvests which provided periodic income. The early cutting cycles also provided valuable clues about the nature of periodic income in the distant future. Results from the initial 30 years of management may improve the reliability of growth and value projections for the next several cutting cycles and beyond.

Initial Harvests

The study areas were 45-year-old second-growth stands when partial harvests were first applied in the 1950's. In single-tree selection stands, initial harvests removed old residuals, undesirable species, and high-risk trees throughout merchantable size-classes. In diameter-limit stands, no attempt was made to condition smaller merchantable growing stock, but some merchantable trees below the 17.0-inch d.b.h. cut limit were removed for roads and incidental damage.

Stand data for the initial harvest treatments are presented in Table 1. Planned cutting cycles were 15 years and 10 years for the diameter-limit and selection practices, respectively. Periodic annual merchantable volume growth is expected to be about 350 bd ft/acre, so periodic harvests could range from 3000 to 5000 board feet per acre, depending on the cutting cycle. Eventually, periodic harvests will equal periodic growth, but as exhibited in this study the initial cuts may exceed growth as old residuals are removed.

Initial harvest treatments removed 25 to 42 trees per acre. Cut trees averaged 16 inches d.b.h. in the diameter-limit, 14 inches d.b.h. in the selection stand. Harvest volume in the selection stand was slightly higher due to removal of several large old residuals and some removals in small sawtimber to achieve residual stand goals. Note that residual stands from both treatments were similar following the initial partial harvests. This initial similarity helped clarify the effect of cutting practices as the stands developed over the next 30 to 40 years. Once the old residuals were harvested, a review of subsequent harvests clarified actual differences between diameter-limit and selection practices.

Table 1.--Stand data for initial partial harvests in 45-year-old second-growth Appalachian hardwoods, 5.0 inches d.b.h. and larger.

Treatment	Stand	No. trees/a	BA/ac	Bd ft/ac	Cu ft/ac
Control	Initial	156	98	9,200	2,200
D-Limit	Initial	158	89	7,900	1,950
	Cut	25	33	4,900	840
	Residual	133	56	3,000	1,110
Selection	Initial	144	91	8,800	2,040
	Cut	42	44	5,700	1,070
	Residual	102	47	3,100	970

Later Harvests

The diameter-limit stands were harvested two additional times: 17 years and 32 years after the initial harvest. Selection stands also were harvested two additional times: 15 years and 25 years after the initial harvest. Cutting cycles were slightly longer after the initial harvest to allow the stands to rebuild growing-stock volume following the relatively heavy initial harvests. However, the time between the second and third cuts was equal to the desired cutting cycle: 15 years for diameter-limit and 10 years for selection. Data collected at these third harvests can be compared because these stands have been under management for about the same length of time. Trends are beginning to develop and harvests will be made on a regular cycle in the future. The comparison also sheds light on stand changes that occur during the transition to long-term unevenage management.

Table 2 contains stand data for the third diameter-limit and selection harvests. Note that harvest volume is roughly equal to periodic growth, although the diameter-limit harvest is still a little heavy. Both practices removed about twenty trees per acre, but cut trees in the diameter-limit averaged 17 inches d.b.h. compared with 14 inches d.b.h. in selection. Once again, the residual stands to begin the growth period before the next harvest were similar. Stocking in the diameter-limit stand was slightly lower than in the selection stand, but the cutting cycle was longer and harvests were heavier and less frequent than in this selection practice.

Stand data presented in Tables 1 and 2 indicate only slight differences between the treatments. And the difference in cutting cycle length may be the primary cause of slight dissimilarities at this point in the transition period. Because the stands were similar to begin with, and both have been cut three times, it is not surprising that the stands are similar after 30 years.

Table 2.--Stand data for partial harvests after 30 years of management, 5.0 inches d.b.h. and larger.

Treatment	Stand	No. trees/ac	BA/ac	Bd ft/ac	Cu ft/ac
Control	Recruise	132	151	19,900	3,720
D-Limit	Recruise	163	110	11,600	2,500
	Cut	19	31	5,300	790
	Residual	144	79	6,300	1,710
Selection	Recruise	171	107	10,200	2,400
	Cut	21	22	2,900	540
	Residual	150	85	7,300	1,860

At this point, it may be helpful to examine changes in species composition, tree quality, and stand structures to enhance the comparison of these practices. After all, timber sale revenues and sustained yield are influenced greatly by these factors over time. Changes occurring now, in the transition period, will affect profitability and feasibility of these practices in the future. A closer look also may reveal important modifications needed to improve the effectiveness of these harvesting systems in achieving landowner goals.

Changes in Species Composition

Preliminary evidence indicates that harvest revenues in the future will be based primarily on sales of sugar maple stumpage. The species diversity characteristic of evenage second-growth stands is giving way to commercial tolerant species such as sugar maple, American beech, and red maple. The merchantable growing stock (11.0 inches d.b.h. and larger) after 30 years of management under a partial harvest system still contains valuable intolerant species such as black cherry (*Prunus serotina* Ehrh.) and yellow-poplar (*Liriodendron tulipifera* L.), as well as northern red oak, white ash (*Fraxinus americana* L.), and other species of intermediate tolerance. Three harvest cuts have removed larger sawtimber trees and provided growing space for advance regeneration present in the 1950's to develop into the sawtimber trees present today (Figure 1). In fact, the species composition in merchantable sawtimber size-classes has changed very little over the study period. There are a few more sawtimber trees per acre in all treatment areas including control, but in general, changes in merchantable species composition will not be evident for several more cutting cycles.

A slight increase in the proportion of tolerant species is evident in the poletimber in each treatment area (Figure 2). Under full shade of the control area and partial shade of the managed stands, intolerant species are not replacing established intolerant poles as they grow into sawtimber sizes. In the diameter-limit stands, however, some intolerant species are

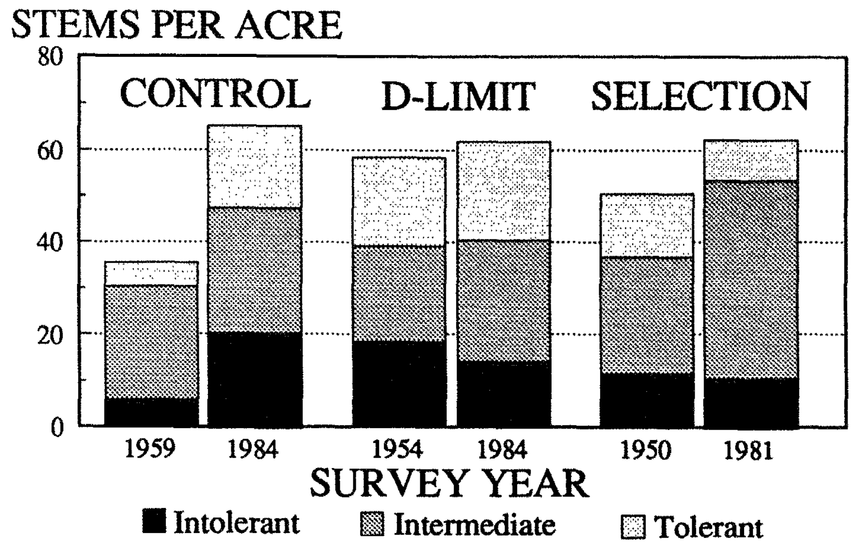

Figure 1. Species composition of sawtimber by tolerance.

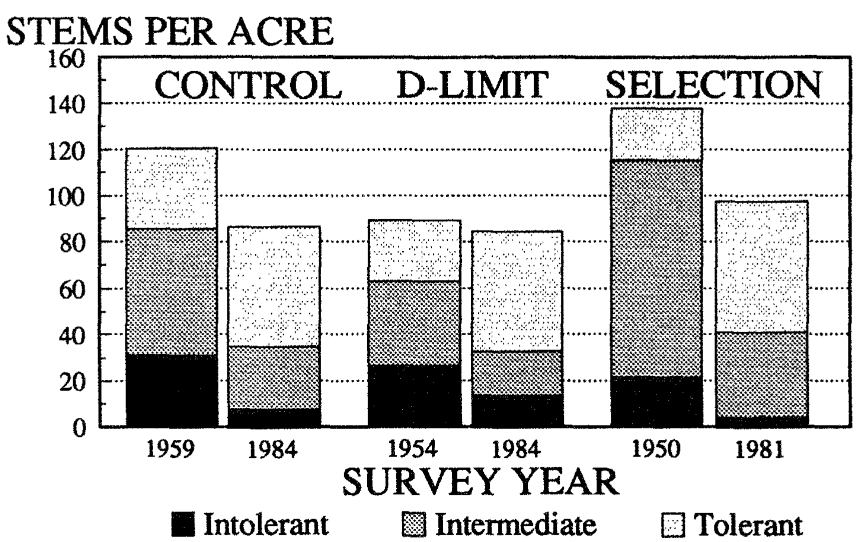

Figure 2. Species composition of poletimber by tolerance.

developing in the poletimber classes. In the selection stands, an effort is made to distribute the cut evenly throughout the stand, if possible. Openings large enough for intolerants to flourish are less likely in selection practices than in diameter-limits. Still, a small proportion of the stand will have some intolerant species develop for either practice, but more intolerants will develop under a diameter-limit practice.

Surveys of large reproduction indicate a decrease in the total number of saplings per acre in all treatments, with the vast majority of advance reproduction made up of tolerant sugar maple in these study areas (Figure 3). Although intolerant species made up a minor part of large reproduction at the beginning of the study when the canopy was closed, only the diameter-limit stands showed an increase in the proportion of intolerant species over the study period.

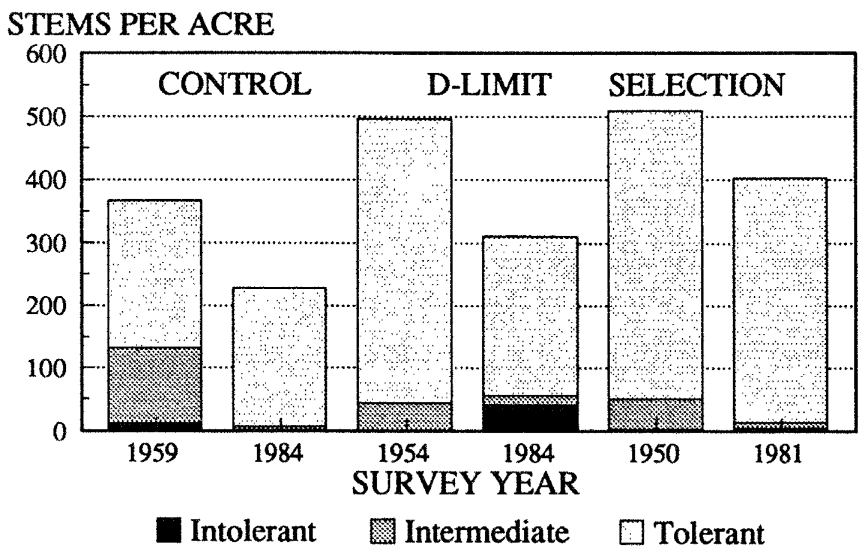

Figure 3. Species composition of large reproduction by tolerance.

Trees were aged in the study area to determine when regeneration was established. Intolerant poles in the treated areas were less than 40 years old, indicating they were established as a result of the partial regeneration harvests made since management began. Only the smaller (1 to 2 inches d.b.h.) tolerant saplings became established as a result of management. Other tolerant poles were probably small saplings in the understory when the first cuts were made in the 1950's.

Small reproduction contained a minor component of intolerant species after 30 years of management. Diameter-limit stands contained the most intolerant reproduction, about 500 stems per acre (Figure 4). Selection stands contained over 5,000 sugar maple seedlings per acre at the 30-year survey, almost twice as many as the control or diameter-limit areas. Although surveys of small reproduction show that regeneration is established after every partial cut, they do not indicate adequately the future stand composition (Trimble 1973). Some intolerants like black cherry can be tolerant when small and young, but without adequate light, they lose their early tolerance and die before they become part of the large reproduction. So, high counts of intolerants in the small reproduction do not indicate a component of merchantable intolerants in the distant future.

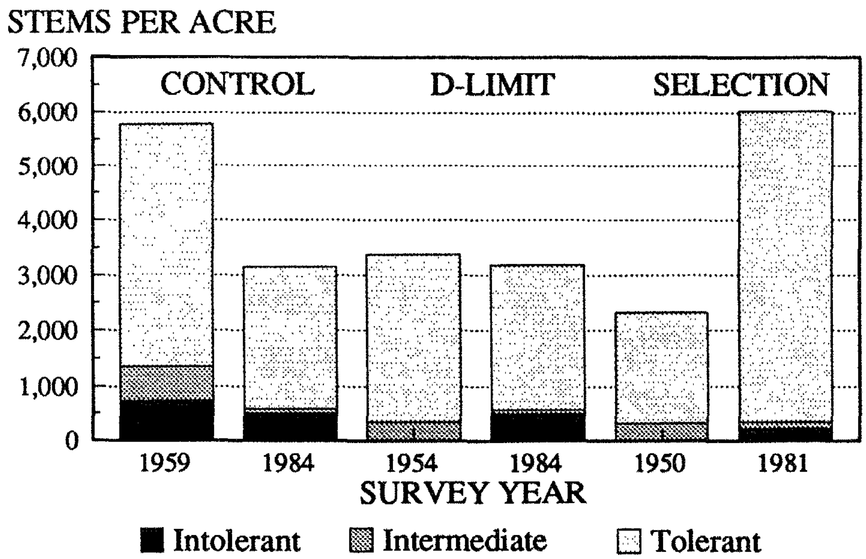

Figure 4. Species composition of small reproduction by tolerance.

Without question, continued application of partial harvest practices will lead to stands made up of tolerant commercial species if they are present and can be regenerated at each harvest. Results indicate, also, that diameter-limit cutting may allow more intolerants to become established compared to selection practices. The longer cutting cycle with a heavier, less frequent harvest is a major reason why the diameter-limit areas contained more intolerants. Also, removal of clumps of mature trees also created favorable light conditions for intolerants to develop. Forecasting species composition in the distant future is often difficult, but trends indicate that sugar maple will dominate these stands. Some intolerants will continue to play a minor role. In comparing the practices, diameter-limit stands will be composed of 10 to 20 percent intolerants, black cherry, and yellow-poplar in the study area, while selection stands will be 5 to 10 percent intolerants. The actual impact of the intolerant component will depend on how stumpage prices compare with sugar maple prices at each of the partial harvests. If the intolerant species is black cherry, the added revenue may give diameter-limit a slight advantage over selection, other things equal. If the intolerant species is yellow-poplar, the practices may provide similar returns because sugar maple and yellow-poplar prices differ only slightly in many markets. Thus, there may be no incentive to choose diameter-limit cutting to favor development of some additional intolerants if they are not high-value species.

Changes in Tree Quality

An important difference between selection and diameter-limit management is the cultural treatment of immature stems. Selection harvests remove some trees from all merchantable diameter classes. The main objective in cutting throughout a range of d.b.h. classes is to control stand structure, but selection also cultures immature merchantable stems. So in addition to controlling numbers of stems, the selection practice affords an opportunity to influence quality of the residual stand. Diameter-limit, on the other hand, disregards stand structure and tree quality development in stems smaller than the cut limit.

Samples of butt-log grade taken during preharvest cruises provided a basis for comparing the effects of selection and diameter-limit cutting on stand quality development. Some improvement in grade is due to trees growing into larger size-classes where grade rules are more forgiving of surface defects. Total board foot stand volume in grades 1 and 2 (highest sawtimber grades) increased by about 10 percent in unmanaged stands over a 25-year period (Figure 5). Diameter-limit areas had a similar increase in stand quality over a 30-year period, but there was a slight decrease in quality between the 15- and 30-year sample. Apparently, quality in the diameter-limit areas may fluctuate as it does in an unmanaged area because trees below the cut limit are not improved through periodic harvests.

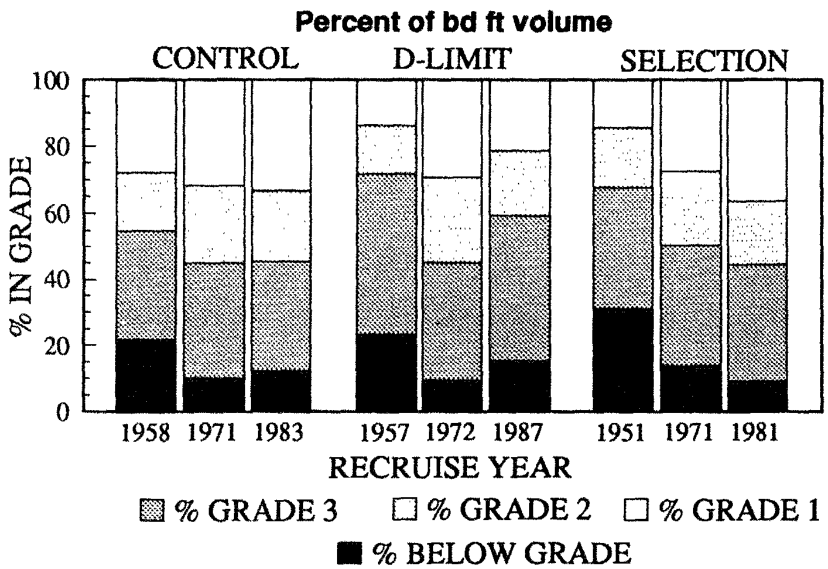

Figure 5. Distribution of sawtimber by volume by butt-log grade.

In selection stands there was a distinct improvement in quality over 30 years. These stands were cut three times, continually reducing the proportion of volume in trees below sawlog grade. Most of the quality improvement was from an increasing proportion of volume in grade 1 and a decreasing proportion of volume below grade. Proportion of volume in grades 2 and 3 remained relatively stable.

Each harvest removed trees of lower grade, leaving behind trees with the greatest potential for making grade 1. As the chosen residual 12- and 14-inch trees grow into larger d.b.h. classes, the percent of volume in grade 1 or 2 increases. Because the number of 12- and 14-inch d.b.h. trees is fairly stable under selection management and these classes are too small for grade 1, it is understandable that the percent of volume in grades 2 and 3 is fairly stable also. Percent of volume in grade 1 increases as stands are converted to unevenage management because the larger sawtimber growing stock is made up of "best" trees favored at each periodic harvest.

Volume in grades 1 and 2 increased by 35 percent in selection areas and only 15 to 20 percent in the diameter-limit areas. For the next three or four periodic harvests, selection areas will yield 15 to 20 percent more grade 1 and 2 sawtimber volume than diameter-limit areas. Stumpage prices and sale revenues will reflect the higher quality products. As stands under both management systems are converted to predominantly unevenaged tolerant species, grade differences will be more predictable because grade variations among various species groups will be eliminated.

For projecting grade distributions for managed unevenaged stands, Table 3 contains an unbiased estimate of sugar maple butt-log grade distribution. Data were obtained from grade samples taken in stands managed under single-tree selection for 30 years or more, each stand cut from 3 to 5 times. Proportions of trees in each grade by diameter class can provide an estimate of tree quality for repeated selection harvests. Note that well over half of the residual trees in a managed stand are in grades 1 and 2.

Table 3.--Butt-log grade distribution for sugar maple in managed selection stands.

D.b.h.	No. Trees	% Grade 1	% Grade 2	% Grade 3	% Below Grade
12	32	-	-	91	9
14	29	-	52	45	3
16	31	39	35	23	3
18	29	55	31	14	0
20	30	44	23	33	0
22	37	41	32	27	0
24	41	51	17	27	5
26 plus	99	48	26	24	1
Total	328				

Changes in Residual Stand Structure

Providing for sustained yield is an important consideration when applying partial harvests over long planning horizons. Selection harvests are planned with a goal residual stand in mind, primarily to ensure enough trees in smaller diameter classes to continue periodic harvests in the near future. In addition, residual basal area goals are set to ensure adequate regeneration after each harvest and to provide continual recruitment of trees for the distant future.

In the central Appalachians, partial harvests using an 18-inch diameter-limit have not created deficit d.b.h. classes which could lead to disruptions of regular periodic yield. Prior to the most recent harvest, both diameter-limit and selection stands had stand structures similar to the original stand structures when management had begun 30 years earlier (Figure 6). There were adequate numbers of trees in each merchantable d.b.h. class to meet a residual stand goal suitable for sustained yield.

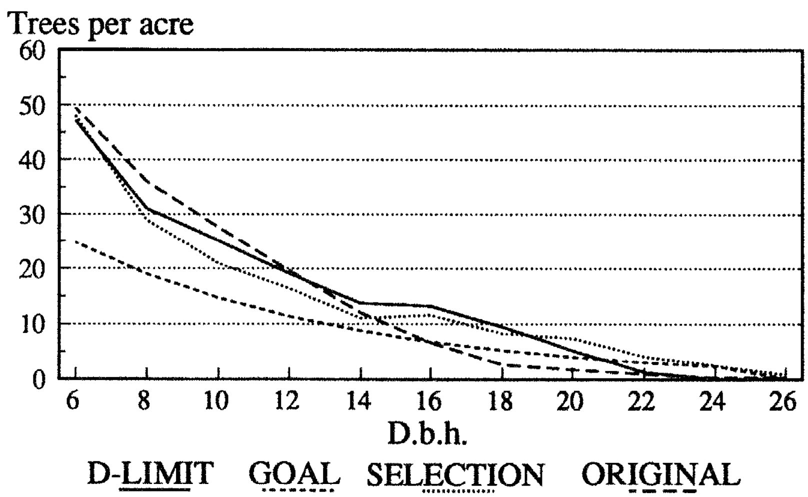

Figure 6. Stand structure before most recent harvest.

Selection harvests were made to achieve gradually a residual stand goal, so it is not surprising that after four harvests stand structure is very near the goal (Figure 7). There is still a small surplus in the 16- to 18-inch d.b.h. classes, reflecting a conservative attitude toward marking in the early periodic harvests, before marking guidelines were fully evaluated. Future harvests will bring the residual stand closer to the goal because preliminary results indicate that it is adequate for regeneration and sustained yield, and retaining surplus trees is no longer warranted.

Forest managers may question the feasiblity of diameter-limit cutting because the cut rule does not ensure that sustained yield conditions can be maintained over time. A review of residual stand structures revealed that diameter-limit areas met some of the residual stand targets used to practice selection even though periodic harvests were not explicitly planned to do so. For example, the diameter-limit areas had a residual basal area of 79 sq ft per acre, similar to the selection practice. In addition, the residual stand structure had adequate numbers of trees in each d.b.h. class to meet a stand structure goal for a q-factor equal to 1.3 (Figure 7). So, the diameter-limit stands appear to provide adequate regeneration and tree recruitment throughout merchantable diameter classes to continue the practice for at least three or four cutting cycles in the future. Although a 17.0-inch d.b.h. cut limit was

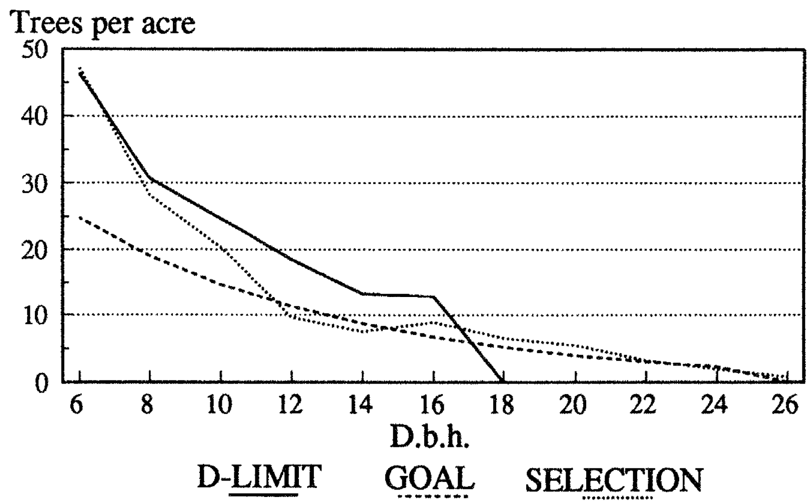

Figure 7. Stand structure after most recent harvest.

appropriate for the stands studied, a higher limit may be needed in some stands to avoid overcutting. Still, residual basal area goals can be achieved using either selection or diameter-limit practices.

Both partial harvest practices examined here have brought about adequate regeneration and recruitment of smaller trees to meet sustained yield guidelines over the first 40 years of application. Preliminary results indicate that these practices can be used for up to 80 years, allowing six to eight periodic commercial timber sales. Further study will define in more detail implications of partial harvest practices over even longer periods. For now, forest managers can apply partial harvest practices so long as a desirable tolerant species is present and can be regenerated after each periodic harvest. Later, adjustments may be needed to account for changes in species composition that are certain to occur.

Return on Residual Stand Value

Actual stumpage revenues from selection and diameter-limit harvests were used to compute periodic rates of return during the study period. For computing real returns, stumpage values at the time of each harvest were adjusted for inflation using Producer's Price Index for all commodities. Inflation averaged 3.7 percent during the study period.

The two-diameter-limit cutting areas earned an average 9.8 percent market rate of return and a 5.9 percent real rate of return. These rates were competitive with other long-term investments available during the same period. Earnings in the two single-tree selection areas averaged 10.0 percent market rate of return and 6.1 percent real rate of return. Selection areas earned slightly higher average returns because one area was harvested four times compared to three times in other treatment areas. The additional payoff helped boost average rate of return. For the control stand, where no harvests were made, earnings averaged an 8.3 market rate of return and a 4.4 real rate of return.

Managed stands provided higher earnings than the control stand mainly because periodic partial harvests reduce the time required to receive income. Periodic annual board-foot-volume growth was about the same for each of the three treatments, 370 to 400 board feet per acre. Thus, the main reason for higher average earnings in managed stands is the more frequent harvest income. Comparing single-tree selection and diameter-limit cutting, as applied in this study, earnings were about the same over the first 30 years of management.

SUMMARY

Partial harvest practices can help meet a range of management objectives. Evidence indicates that commercial sales 10 to 15 years apart can provide periodic timber income for 80 years or more without adverse effects on residual growing stock. In visually sensitive areas, these practices provide a continuous cover of trees while growing and harvesting timber products.

Each practice has important advantages and disadvantages. Single-tree selection improves tree quality and affords explicit control of residual stocking for sustained yield. Selection can be more difficult to apply, in practice, because it requires marking by cut ratios and accurate counts of cut and leave trees during marking. Yield from selection harvests is distributed among small and large sawtimber, thus increasing the unit harvesting costs and reducing stumpage value compared to diameter-limits.

Diameter-limit cutting is very easy to apply. Harvest volume is in relatively large trees (18 inches d.b.h. and larger) so harvesting costs are lower than for selection cutting, other things equal. Stands observed in this study did regenerate following each harvest, and residual stand structure was adequate for sustained yield even though no attempt was made to achieve a given residual stocking. The greatest drawback of diameter-limit cutting is the lack of influence on the quality of immature merchantable trees. The quality of trees growing into larger sizes classes is left to chance.

Trimble, Mendel, and Kennell (1974) suggested a compromise between single-tree selection and diameter-limit cutting for managing hardwood stands using a partial cutting practice. Mature trees are harvested using a flexible diameter-limit based on financial performance of residual trees. In addition, merchantable immature growing stock receives an improvement cut at each periodic harvest. Residual basal area guidelines are used to adjust the minimum d.b.h. cut limits for mature trees to provide for sustained yield. This method offers the simplicity of diameter-limit cutting in the field--each species has its own minimum d.b.h. cut limit. It also offers the intensity of selection management--the forest manager can control residual stand stocking and quality better.

Partial cutting practices, if properly applied, can earn competitive returns on residual growing stock while providing the nonmarket benefits of continuous forest cover. In this study, average annual volume growth was 370 to 400 bd ft per acre for selection and diameter-limit, respectively. Harvests of periodic stand growth in the future will yield 3,000 to 5,000 bd ft per acre every 10 to 15 years, varying only slightly with each cutting cycle. Using local stumpage prices near the study area, periodic income will be $250 to $500 per acre depending on the length of the cutting cycle.

Assuming observed trends continue in the study stands, real (net of inflation) return on residual stand value will be 5.4 percent for diameter-limit and 4.9 percent for selection. These rates compare favorably with alternative investments available to forest landowners. This is not to say that diameter-limit cutting is more profitable in all cases. But once again, diameter-limit cutting (with a high minimum d.b.h. limit) and single-tree selection as applied in this study, are similar.

Results from this study indicate that partial cutting practices have merit, and diameter-limit cutting achieves many of the residual stand goals of single-tree selection. Selection did result in improved stand quality. However, the diameter-limit practice earned a similar rate of return and may earn a higher rate of return in the future because periodic timber sales are made up of mostly larger trees. Both practices established desirable regeneration following each harvest, and had enough residual trees to provide for sustained yield. Diameter-limits also promoted the development of some valuable intolerant species, although, in general either practice will lead to a stand of mostly tolerant species over time.

A high minimum-diameter-limit appears to be a much easier method for applying partial cutting management in central Appalachian hardwoods than single-tree selection. The observable effects on development of the residual stand and economic benefits were similar in this study. If diameter-limit practices are used, trees should be allowed to reach minimum requirements for a grade 1 butt log (16 inches d.b.h.). A higher minimum d.b.h. cutting limit is recommended--at least 17.0 inches as applied in this study.

LITERATURE CITED

Smith, H. Clay and Neil I. Lamson. 1982. Number of residual trees: A guide for selection. Gen. Tech. Rep. NE-80. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 33 p.

Trimble, George R., Jr. 1973. Regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice. Res. Pap. NE-282. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 14 p.

Trimble, George R., Jr., Joseph J. Mendel, and Richard A. Kennell. 1974. A procedure for selection marking in hardwoods -- combining silvicultural considerations with economic guidelines. Pap. NE-292. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

INTEGRATING FOREST GROWTH AND HARVESTING COST MODELS TO IMPROVE FOREST MANAGEMENT PLANNING

John E. Baumgras and Chris B. LeDoux[1]

Abstract: Two methods of estimating harvesting revenue -- reported stumpage prices - and delivered prices minus estimated harvesting and haul costs were compared by estimating entry cash flows and rotation net present value for three simulated even-aged forest management options that included 1 to 3 thinnings over a 90 year rotation. Revenue estimates derived from stumpage prices indicated that all thinnings were economically feasible and that net present value was maximized by initiating thinning at age 40. Revenue estimates derived from estimated harvesting costs and delivered prices revealed that thinning at age 40 yielded the lowest net present value due to high harvesting costs and negative first-entry cash flows. Stumpage-based revenue estimates also were very unstable and highly dependent upon the sawtimber utilization assumptions of the economic analysis. The results show that integrating harvesting cost models with growth-and-yield simulators can provide more stable and reliable revenue estimates over the wide range of harvesting conditions required to evaluate forest management alternatives.

INTRODUCTION

The recent development of mathematical forest growth-and-yield models has provided researchers and forest managers with very powerful and versatile tools. Models applicable to eastern hardwoods include: FIBER, OAKSIM, TWIGS, SILVAH, and STEMS (Shifley 1987). One application of these computer models is regional inventory projections (Solomon and Hosmer 1987). Another application of growth-and-yield projections, and the focus of this paper, is the economic analysis of forest management alternatives. Several of the available growth-and-yield models have been utilized to evaluate management practices such as precommercial and commercial thinnings; comparing economic returns resulting from these practices with returns from the no-thin option (Risbrudt and Pitcher 1986). This and numerous other studies have evaluated forest management alternatives by applying reported stumpage prices to projected product yields. Because stumpage prices are an integral part of those economic analyses, it is important to identify potential limitations of stumpage-price applications and to define a more reliable alternative.

Stumpage prices represent the unit price paid to forest-land owners for standing timber. The mean or median and range of prices for each tree species are reported for a state or

[1]Research Forest Products Technologist and Industrial Engineer and Project Leader, USDA Forest Service, 180 Canfield Street, P.O. Box 4360, Morgantown, West Virginia 26505.

geographical regions within a state (Ohio Agric. Stat. Serv. 1989, Pa. State Univ. 1988). The price range reported for each tree species generally indicates that stumpage prices are extremely variable. Consequently, published price reports often caution users that average prices reflect only market trends and largely ignore the harvest tract attributes that affect stumpage prices. These attributes include tree size, species composition, tree quality, volume harvested per acre, tract volume, accessibility, and distance to roundwood markets. As a result, reported average stumpage prices are adjusted so that prevailing regional or local harvesting and market conditions are reflected in the stumpage price paid for a specific tract.

Valuable insight regarding the application of reported stumpage prices can be obtained from the surveys of nonindustrial private forest-land (NIPF) owners conducted in four major hardwood producing states: Kentucky (Birch and Powell 1978), Ohio (Birch 1979), Pennsylvania (Birch and Dennis 1980), and West Virginia (Birch and Kingsley 1978). These survey results define the source of stumpage prices with respect to the attributes of the NIPF timber harvests representing most of the reported prices. Collectively, these surveys indicate that NIPF harvests are cash-flow oriented with little concern for silvicultural treatments. Results also indicate that sawlogs and veneer logs are the products of primary interest; that diameter limit and selection cutting account for half of the acres harvested; and that foresters are involved in tree selection on only 9 to 32 percent of the acres harvested. The harvests described often equate to high grading, or removing only the most valuable timber. Accordingly, average reported stumpage prices probably reflect the least costly method of obtaining the most valuable sawtimber.

If the average stumpage prices applied are not sensitive to stand attributes and harvesting practices, their application to the economic analysis could introduce substantial error. Prices derived from prevailing harvesting practices may not be consistent with the tree selection and wood utilization assumptions of a specific growth-and-yield projection. This can be very important when the growth-and-yield projections include thinnings in young stands, or removal of low-quality growing stock in regeneration cuts. Furthermore, applying constant stumpage prices to all scheduled entries largely ignores harvesting cost trends that have been documented for ground-based systems (Stuart 1982) and for cable-yarding systems (LeDoux 1987). These and other studies show harvesting costs decreasing with increasing tree volume and volume per acre. This trend is particularly important when growth projections include revenue estimates from early thinning, which are costly to harvest.

The objective of this study was to compare two methods of estimating net revenue from thinning and regeneration entries. One method applied reported stumpage prices. The other method estimated revenue as the residual of reported delivered-product prices minus estimated harvesting and hauling costs. This residual is often termed conversion return or conversion surplus. Comparisons include entry cash flows and the net present value (NPV) ranking of selected forest management options. These comparisons were conducted to determine the effects of stand age, harvesting conditions, and sawtimber utilization practices on estimated harvesting revenue.

METHODS

The revenue analysis utilized stand tables representing trees harvested from thinnings at ages 40 to 70 years and even-aged regeneration cuts at age 90. The growth projections were made using the OAKSIM model (Hilt 1985) to simulate growth of even-aged upland oak stands on site index 70. The initial stand table represented a fully-stocked upland oak stand at age 40 (Schnur 1937). The three even-aged forest management options compared were:

Forest Management option	Thinning	Regeneration
	----------- Age (years)	--------------
1	40,55,70	90
2	50,70	90
3	60	90

These options were selected to provide variable ages at first thinning and number of thinnings, yet conform to the 50-year projection-period constraint imposed by the OAKSIM model. All simulated thinnings reduced residual stocking to 60 percent of full stocking.

Costs and revenues were estimated for each scheduled entry using a computer program to simulate the timber harvesting operation and to estimate product yields (Baumgras 1990). This program performs two primary functions: (1) simulation of the harvesting system production rate, and (2) estimation of product yields that include factory grade sawlogs, sawbolts, and pulpwood-fuelwood. The production-rate estimates provide information required to predict stump-to-truck harvesting costs. The product-yield estimates are the basis of revenue estimates.

The timber harvesting simulation is a stochastic process that applies logging-machine-cycle time equations and delay-time distributions developed from time-and-motion study data collected in West Virginia. Machine production is modeled as a function of cut stand attributes. System production is modeled as a function of system component production to reflect system interactions. The simulated system included manual chainsaw felling with two saw operators, one mid-sized rubber-tired skidder, and a loader-slasher combination to handle bucking, sorting, and truck loading.

The simulated harvesting assumed a 50-acre tract with a maximum skid distance of 1,600 feet and a 200-foot spacing between parallel skid roads. To satisfy silvicultural objectives, all cut trees 3 inches diameter at breast height (dbh) and larger in the cut-stand tables obtained from OAKSIM were felled in each thinning or regeneration entry. However, only trees 8 inches dbh and larger were skidded and utilized. Cost rates required to estimate harvesting costs from simulated production times were based on 1989 wage rates sampled from West Virginia loggers ($6.50/hour to $8/hour plus 33 percent payroll costs) and machine investment requirements and operating costs reported by Burgess and Cubbage (1988). The resulting harvesting-cost estimates represent the cash flow required by the logger to cover all expenses and to provide an after-tax cash flow to cover capital investment plus a 12-percent return on invested capital.

The harvesting simulation did not include trucking. Instead, estimated trucking costs were deducted from delivered prices. Trucking costs were estimated from rates published by Koger (1981), which were updated using current truck machine rates (Burgess and Cubbage 1988). Hauling cost estimates were based on a tractor-trailer combination hauling 1 mile over woods roads, 2 miles over gravel roads and the balance over 2 lane-paved roads. To estimate the impact of haul distance on net revenue, the analysis included one-way haul distances of 15, 30, and 60 miles.

The procedure for estimating product yields employs tree taper functions developed for Appalachian hardwood tree species (Martin 1981). The procedure also estimates sawlog volume by USDA Forest Service factory log grades by applying the sets of equations developed by Yaussey and others (1988), together with equations for estimating tree grade distributions by species and dbh developed for oak stands from Pennsylvania forest survey data (Dale and Brisbin 1985). Estimated sawlog volume included only logs with a scaling diameter 10 inches diameter inside bark (dib) and larger, a limit imposed by many mills that saw grade lumber. The primary analysis also imposed a 14-inch dbh limit on sawtimber trees, with limits of 12 to 15 inches tested in a sensitivity analysis.

The stumpage prices and prices paid for delivered roundwood are based on 1988 prices reported for Ohio (Ohio Agric. Stat. Serv. 1989) and Pennsylvania (Pa. State Univ. 1988). These two sources report stumpage price by species and delivered prices by species and grade. Sawlog stumpage and delivered prices represent a simple average of 1988 Ohio and Pennsylvania prices (Table 1). Pulpwood prices include a delivered price of \$45/100 ft^3 cubic feet of wood and bark (Ccf), approximately \$15/ton; and a stumpage price of \$6/Ccf, approximately \$2/ton. The pulpwood prices also were obtained from the Ohio and Pennsylvania price reports and were consistent with other published price reports.

Net revenue derived from stumpage prices (NRSP) is the product of estimated product volume and stumpage prices, where sawlog prices and yields are based only on tree species. Net revenue estimates derived from delivered prices (NRDP) reflect species, grade, harvesting costs, and haul distances of 15 miles ($NRDP_{15}$), 30 miles ($NRDP_{30}$), and 60 miles ($NRDP_{60}$). Sawtimber net revenue is the product of estimated sawlog volume and reported delivered prices minus haul costs, where volume and price reflect both species and log grade. Haul costs also were deducted from delivered pulpwood price. To simplify the analysis it was assumed that pulpwood and sawlogs were hauled the same distance.

RESULTS

The following comparisons define the potential limitations of stumpage prices when cash flows are affected by harvesting cost trends, haul costs, and sawtimber utilization practices.

These results also demonstrated the potential advantages of integrating harvesting cost models with forest growth-and-yield models to improve revenue estimates.

Table 1.--Average reported sawtimber stumpage prices and prices paid for sawlogs delivered to sawmills; for Ohio and Pennsylvania in 1988.

Tree species	Stumpage[1] price	Delivered price log grade[2]		
		1	2	3
	---------------------- $/Mbf, Int. 1/4 ----------------			
White oak	158	341	180	95
Red oak	234	412	238	104
Others[3]	80	160	109	86

[1]Reported only by tree species.
[2]USDA Forest Service factory log grades.
[3]Includes yellow-poplar and red maple.

Stand Attributes and Harvesting Cost

Important differences between thinning and regeneration entries are demonstrated by the cut-stand attributes and harvesting costs estimated for each entry (Table 2). The differences in harvesting costs largely can be attributed to total volume harvested and average merchantable volume per tree, with larger trees and heavier removals resulting in lower costs. Because of this, the timing of the first thinning is very important. Estimated first-entry stump-to-truck costs range from $59/Ccf at age 40, to $34/Ccf at age 60. Postponing of thinning for 20 years, until age 60, permitted total volume harvested to increase from 3.5 Ccf/acre to 10.1 Ccf/acre. Average volume per tree increased from 10.9 ft^3 to 16.0 ft^3 (Table 2).

Successive thinning entries of forest management options 1 and 2 also show significant harvesting cost reductions. Under option 1 estimated harvesting costs decline from $59/Ccf at age 40 to $28/Ccf at age 70 (Table 2). In contrast, harvesting cost estimates were very similar for all three regeneration entries.

The results presented in Table 2 demonstrate very important harvesting cost trends that affect potential harvesting revenue from thinning versus regeneration entries. These cost estimates are a function of the equations and distributions incorporated into the simulation model and the cost rates applied to the simulation results. Because these entries are subject to variation, the results are also variable. However, more important than the estimated cost levels are the trends that indicate cost reductions and potential revenue gains with increasing age and volume, results supported by numerous harvesting studies.

Table 2.--Simulated cut stand attributes and stump-to-truck harvesting costs for each entry tested.

Forest mgt. option	Harvesting entry[1]	Volume harvested[2] Total	Average tree	Cost
	- type-age -	- Ccf/ac. -	- ft^3 -	- \$/Ccf -
1	T-40	3.5	10.9	59
	T-55	4.2	15.6	38
	T-70	5.3	23.9	28
	R-90	35.7	33.3	18
2	T-50	6.9	13.5	41
	T-70	6.8	21.2	30
	R-90	35.5	32.0	18
3	T-60	10.1	16.0	34
	R-90	37.4	29.4	20

[1]Thinning = T, Regeneration = R, age = years
[2]Trees 8-inches dbh and larger to a 4-inch top dib.

Cash Flow

The variations in estimated harvesting costs are directly reflected in the comparisons of estimated net revenue (Table 3). Revenue estimates derived from average reported stumpage prices necessarily yield a positive cash flow. However, deducting estimated harvesting and haul costs from reported delivered prices yielded several negative cash flows. These include: all age 40 thinnings, thinning at age 55 with 60-mile haul, and first thinning at age 50 with 30- or 60-mile hauls (Table 3). These negative cash flows indicate that harvesting would not be economically feasible for the logger, and would require the landowner to subsidize the thinnings. Estimates of thinning revenue derived from average stumpage prices always were greater than or equal to estimates derived from delivered prices.

Table 3.--Estimated net revenue per entry by method of estimating revenue and haul distance.

Forest mgt. option	Entry[1]	Net revenue estimate[2]			
		NRSP	$NRDP_{15}$	$NRDP_{30}$	$NRDP_{60}$
	- Type-Age -	dollars/acre			
1	T-40	21	-59	-69	-83
	T-55	25	15	5	-12
	T-70	123	109	96	73
	R-90	1382	1417	1321	1152
2	T-50	41	7	-10	-38
	T-70	139	110	93	64
	R-90	1283	1360	1265	1100
3	T-60	85	85	60	18
	R-90	1247	1306	1206	1036

[1]Thinning = T, Regeneration = R, age = years
[2]NRSP = stumpage based estimate
NRDP = estimate based on delivered price, harvest cost, haul cost for hauls of 15, 30, and 60 miles.

Given the relatively low cost of harvesting large sawtimber and the NIPF survey results that indicate most stumpage prices are derived from sawtimber harvests, it is not surprising that the two methods of estimating revenue produced similar results from the three regeneration entries tested. At haul distances of 15 and 30 miles, the two types of revenue estimates differed by only 2.5 to 6.0 percent of the stumpage price estimate. Increasing haul distance to 60 miles results in significant revenue reductions for all entries, a variable not reflected in stumpage prices.

Net Present Value

To compare the net present value of each forest management option, all cash flows in Table 3 were discounted to time = 40 years, using a 4 percent real interest rate and constant product prices (Table 4). Age 40 represents the time the decision is made to thin at age 40 or to postpone thinning. However, the discount period affects only the magnitude of all NPV's, not the NPV ranking of forest management options. Were a management option selected, using the NPVs derived from stumpage prices, option 1 would be selected (Table 4). The positive cash flows from each entry and the increased final harvest revenue resulting from early thinning all favor option 1. By contrast, option 1 consistently yields the lowest ranking NPV when cash flows reflect varying harvesting and haul costs. These NPV's favor option 2 at haul distances of 15 and 30 miles, and option 3 when all products are hauled 60 miles. Furthermore, if the landowner is reluctant to invest in thinning and requires a positive cash flow from all entries, then management option 2 is also infeasible with a 30-mile haul because of the negative first-entry cash flow (Table 3).

Table 4.--Net present value of discounted harvesting cash flows for each forest management option, by method of estimating net revenue.

Forest mgt.	Source of revenue estimates			
Option	NRSP	$NRDP_{15}$	$NRDP_{30}$	$NRDP_{60}$
	------------ NPV (dollars/acre)[1] ------------			
1	268[2]	182	149	95
2	251	230[2]	200[2]	149
3	214	222	197	154[2]

[1]Net cash flows discounted to time = 40 years.
[2]Maximum NPV for method and haul distance.

These results indicate that the method of estimating harvesting cash flows can have a large impact on estimated NPV and forest management decisions. If we assume that the harvesting and hauling cost estimates are reasonably reliable, depending solely on stumpage prices and ignoring cost trends did not identify infeasible entries or the NPV-maximizing management options. Furthermore, ignoring harvesting cost trends implicitly assumes that the harvesting firm, not the landowner, absorbs the high cost of harvesting wood from early thinnings. Given the large supply of low-quality hardwoods, this is an unlikely scenario.

Sensitivity Analysis

The results in Tables 2 through 4 were developed applying a 14-inch dbh limit to sawtimber trees by calculating sawlog volumes only for trees 14 inches dbh and larger. Trees 8 to 13 inches dbh were utilized only for pulpwood. Although smaller trees can yield 8-inch dib grade-3 sawlogs, communications with several forest products utilization specialists in the northeast indicates that many sawmills manufacturing factory grade lumber buy only logs 10 or 12 inches dib and larger. To determine the impact of minimum sawtimber dbh on estimated revenue, dbh limits of 12 to 15 inches were evaluated with both revenue estimating methods. This comparison was conducted using the cut-stand table representing the regeneration harvest under management option 1.

Increasing the minimum sawtimber dbh reduced total sawlog volume from 9.1 Mbf/acre to 4.6 Mbf/acre, but increased the proportion of total sawlog volume in log grades 1 and 2 from 37 percent to 57 percent (Table 5). These results also show NRSP decreasing 40 percent in direct proportion to the sawlog volume reduction, declining from $1833/acre to $1093/acre (Table 5). Conversely, when decreasing the minimum sawtimber dbh from 15 to 12 inches the NRSP estimate assumes that the unit value of the incremental volume of small low-grade logs equals that of the larger sawlogs. NRSP applies the same unit value to all sawlog volume of a given species. $NRDP_{30}$ reflects both tree species and log grade. As a result, $NRDP_{30}$ decreased only 6.6 percent; from $1,349/acre to $1,258/acre (Table 5). Most of the sawlog volume reduction resulting from the increased minimum dbh was low-value grade 3 logs. When these logs are marketed as pulpwood, the relative reduction in $NRDP_{30}$ is much less than the relative reduction in sawlog volume.

Table 5.--Estimated sawlog volume harvested, percent of harvested sawlog volume by factory log grades, and net revenue by minimum sawtimber dbh. Results represent the regeneration entry under management option 1.

Minimum[1] sawtimber Dbh	Total sawlog volume	Log grades 1 and 2	Net revenue[2]	
			NRSP	$NRDP_{30}$
- Inches -	- Mbf/acre -	- Percent -	------ Dollars/acre ------	
12	9.1	37	1833	1349
13	7.9	42	1636	1345
14	6.2	50	1382	1321
15	4.6	57	1093	1258

[1]Trees smaller than minimum dbh are used only for pulpwood.
Total volume of pulpwood and sawlogs remains constant at 35.7 Ccf/acre.
[2]Harvesting cost is constant for all minimum dbh levels.

The implicit assumption of the stumpage-based estimate is that unit stumpage value is independent of wood utilization practices and the resulting log grade mix, or the wood utilization assumptions incorporated in the analysis are representative of the harvesting practices reflected in the reported stumpage prices. The large variation in NRSP estimates reflect the magnitude of the error that could result if these assumptions were invalid. For example, if reported stumpage prices reflected a 15-inch dbh limit, yet the economic analysis applied a 12-inch dbh limit with no unit price adjustment, the results would overestimate revenue by 68 percent. By comparison, the relative stability of $NRDP_{30}$ significantly lessens the impact of erroneous wood utilization assumptions (Table 5).

DISCUSSION

Both methods of projecting harvesting revenue are subject to the uncertainties affecting all economic forecasts. However, since stumpage prices represent actual landowner receipts, then these prices are conceptually a better estimator of expected revenue. Revenue estimates derived as the residual of delivered prices minus extraction costs represent only maximum stumpage payments consistent with estimated harvesting and hauling costs. Although conceptually superior, reported average stumpage prices appear to be reliable estimators only when applied to harvesting conditions and utilization practices similar to those prevalent in the stumpage price sample. When this is not the case, results indicate that large errors could occur. Whereas stumpage prices indicate that it is economically feasible to thin at ages 40 or 50 years, the inclusion of harvesting costs in the revenue estimate indicates that these thinnings could lose $10 to $83/acre (Table 3). Furthermore, erroneous assumptions regarding stumpage prices and prevalent sawtimber utilization practices could overestimate regeneration revenue by $740/acre (Table 5). In terms of cash flows, the differences in regeneration-cut revenues greatly exceed the differences in thinning revenues estimated by each method. However, the NPV effects of the two sources of error are similar.

The two methods of estimating revenue produced similar results when applied to regeneration entries and moderate haul distances, assuming a 14-inch dbh limit for sawtimber trees. This result can be interpreted as a validation of the NRDP estimates since landowner survey results indicate that stumpage prices are generally derived from sawtimber harvests, and grade lumber mills seldom utilize small grade 3 logs. For other harvesting conditions and utilization options, the large difference between revenue estimates demonstrates that estimates derived from average reported stumpage prices are insensitive to stand attributes and are very unstable over a range of sawtimber utilization options.

This research indicates that the application of delivered prices and estimated extraction costs can provide more stable and reliable revenue estimates over the wide range of harvest entries required to simulate economic returns to forest management alternatives. To reflect harvesting conditions accurately for each simulated entry, the cut stand attributes required to estimate harvesting cost can be obtained from the stand tables produced by the growth simulations. The stochastic harvesting simulation model applied in this study is not yet available. However, cost estimating programs currently available include EASTCOST (LeDoux unpub.), as well as the Auburn Harvesting Analyzer, the Harvest System Analyzer, and the Harvest System Simulator (Reisinger and others 1988). MANAGE (LeDoux 1986) is one of the few available forest planning models that integrates growth-and-yield results with detailed stump-to-mill cost estimates for eastern hardwoods.

To utilize fully the capabilities of growth-and-yield models it is important that developments in the economic analyses of forest management alternatives keep pace with the developments in growth-and-yield modeling. This requires harvesting revenue estimates that accurately reflect quality and value as well as volume, and that harvesting cost trends are an integral part of the economic analysis. Results presented demonstrate the potential effects of revenue estimation methodology on revenue estimates and management decisions. These results also indicate the importance of integrating harvesting cost models with growth-and-yield models to improve revenue estimates.

LITERATURE CITED

Baumgras, J. E. 1990. The effects of product markets and multiproduct harvesting on the economics of managing even-aged upland oak stands. Ph.D. dissertation. West Virginia University, Morgantown. 210 p.

Birch, T. W., and D. F. Dennis. 1980. The forest-land owners of Pennsylvania. USDA For. Serv. Resour. Bull. NE-66. 90 p.

Birch, T. W. 1979. The forest-land owners of Ohio - 1979. USDA For. Serv. Resour. Bull. NE-74. 84 p.

Birch, T. W., and N. P. Kingsley. 1978. The forest-land owners of West Virginia. USDA For. Serv. Resour. Bull. NE-58. 76 p.

Birch, T. W., and D. S. Powell. 1978. The forest-land owners of Kentucky. USDA For. Serv. Resource Bull. NE-57. 101 p.

Burgess, J., and F. Cubbage. 1988. 1988 Timber harvesting equipment costs. For. Eng. 6.9. Univ. of Georgia, School of For. Resources. Athens, GA. 3 p.

Dale, M. E., and R. L. Brisbin. 1985. Butt log quality of trees in Pennsylvania oak stands. USDA For. Serv. Res. Pap. NE-568. 8 p.

Hilt, D. E. 1985. OAKSIM: an individual tree growth and yield simulator for managed even-aged upland oak stands. USDA For. Serv. Res. Pap. NE-562. 21 p.

Koger, J. L. 1981. Transportation methods and costs for sawlogs, pulpwood, and longwood. Tech. Note B46. TVA Div. of Lands and Forests. Norris, TN. 36 p.

LeDoux, C. B. 1987. Estimating yarding costs for the Clearwater cable yarder. USDA For. Serv. Res. Pap. NE-609. 4 p.

LeDoux, C. B. 1986. MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management. USDA For. Serv. NE-GTR-112. 7 p.

LeDoux, C. B. Unpub. EASTCOST - stump-to-mill timber production cost equations and computer program. Unpub. report on file at USDA For. Serv. Northeast. For. Exp. Sta., 180 Canfield St., Morgantown, WV.

Martin, A. J. 1981. Taper equations for selected Appalachian hardwood species. USDA For. Serv. Res. Pap. NE-490. 22 p.

Ohio Agriculture Statistics Service. 1989. Ohio timber prices, Feb. 1, 1989. Ohio Agric. Stat. Serv., Columbus. 2 p.

Pennsylvania State University. 1988. Pennsylvania timber market report. The Pennsylvania State Univ. School of Forest Resour., Coop. Ext. Serv., University Park. 5 p.

Reisinger, T. W., D. W. Greene, and J. F. McNeel. 1988. Microcomputer-based software for analyzing harvesting systems. South. J. Appl. For. 12(1):37-41.

Risbrudt, C. D., and J. A. Pitcher. 1986. Financial returns from timber stand improvement investments. North. J. Appl. For. 3:52-58.

Schnur, G. L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. USDA Tech. Bull. 560. Washington, DC. 87 p.

Shifley, S. R. 1987. Evaluating management alternations with TWIGS and ERGYS. In: Economics of eastern hardwood management. March 9-11, 1987, University park, PA. The Pennsylvania State Univ., University, Park. P. 168-187.

Solomon, D. S., and R. A. Hosmer. 1987. A growth and yield model (FIBER) for multiple species stands within different forest types. USDA For. Serv. Gen. Tech. Rep. NC-120. p. 217-223.

Stuart, W. B. 1982. Logging cost by diameter class. In: Harvesting small timber: waste not, want not. April 28-30, 1983, Syracuse, NY. For. Prod. Res. Soc., Madison, WI. p. 75-83.

Yaussey, D. A., R. L. Brisbin, and M. J. Humphreys. 1988. Predicting volumes and numbers of logs by grade from hardwood cruise data. USDA For. Serv. Res. Pap. NE-613. 15 p.

COMPUTERIZED ALGORITHMS FOR PARTIAL CUTS

Richard L. Ernst and Susan L. Stout[1]

Abstract: Stand density, stand structure (diameter distribution), and species composition are all changed by intermediate treatments in forest stands. To use computer stand-growth simulators to assess the effects of different treatments on stand growth and development, users must be able to duplicate silviculturally realistic treatments in the simulator. In this paper, we review the computer algorithms for partial cuts associated with the FIBER, NE-TWIGS, OAKSIM, SILVAH and YIELD-MS computer programs. We assess these algorithms with respect to flexibility, comprehensiveness, and their ability to mimic cuts prescribed in management guides for timber production. The paper also suggests directions for developing a new algorithm that incorporates the strengths of several of the existing algorithms.

INTRODUCTION

One effect of the microcomputer revolution on forestry has been the development of computer-based growth simulators and their use to test the projected outcome of alternative treatments in forest stands. The utility of these tests is greatest if the computer can duplicate effects achieved on the ground with a minimum of user effort. This paper examines the partial-cutting algorithms in five forest growth simulators, and contrasts them with respect to flexibility, comprehensiveness, and ability to duplicate the kinds of treatments recommended by silvicultural research for the production of timber products. Our focus will be on the algorithm used to implement intermediate thinnings under even-aged silviculture, but we will indicate which of the programs make provisions for other partial cuts, such as those for stands being managed under uneven-aged silvicultural systems.

Among the principal effects of intermediate thinnings are changes in stand density, stand structure, species composition, the average quality of residual trees, and spacing and uniformity of the residual stand. Silvicultural guidelines for mixed hardwoods managed for timber production, including the central and northern hardwood types of the northeastern United States (Leak and others 1987, Marquis and others 1984, Roach 1977, Roach and Gingrich 1968), consistently recommend that intermediate treatments should remove poor-quality and high-risk trees and improve residual spacing and uniformity. Residual stand density is specified through either stocking guides or residual basal area, and may vary with

[1]Research Foresters, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 928, Warren, PA 16365.

stage of stand development. We will report how each of these parameters is controlled in the thinning algorithms of the different computer programs.

COMPUTER MODELS

The life cycle of a growth and yield model typically includes periods of data collection, data analysis, model development, and finally implementation of the model in computer program code. The data collected usually cover a long span of time, in stands that have been managed in various ways. The analysis strives to identify the factors that are most highly associated with tree growth. The mathematical representation of those processes are built into a computer program.

In these models, the processes of stand development (ie. growth, mortality, management) are simplified and stated as algorithms. These algorithms are the steps that are systematically followed to mimic each actual process, much like a recipe from a cookbook. The algorithms can then be translated into computer code for inclusion into the growth and yield simulator.

Model developers make several assumptions in developing the algorithms. For all the models described in this paper, there is an assumption that the stand is uniform throughout with respect to size, species composition, quality and spacing. If a user inputs data from a stand for which this assumption is not true, the results can be absurd. As an extreme example, suppose a user entered as a single stand data from an area that was predominantly poletimber in its eastern half and and predominantly medium sawtimber in its western half. The average stand characteristics such as diameter or volume are not appropriate to either half of the stand. Any recommendation for intermediate thinning would likely be inappropriate also. In such a stand, applying a cut that emphasizes removal of small trees or large trees may result in wiping out one half of the stand while leaving the other half untouched.

Another assumption is made about growth of residual trees. The data used in building these models come from carefully controlled experiments. If the user requests removals from stands in ways that were not tested, the predicted growth response may not bear any resemblance to reality. For example, in most even-aged research plots used to develop growth response models, the residuals after intermediate treatments are some of the biggest and best trees in the stand. A simulator developed from such data would likely do a poor job of predicting growth after a cut that removed all of the big trees, leaving suppressed and intermediate trees.

Intermediate management in even-aged stands is generally in the form of thinnings. Most computerized growth and yield models allow the user to interact in some way to specify thinnings. Options range from the very interactive (such as allowing the user to specify individual trees to be removed) through completely automatic procedures. The lowest levels are very tedious and require considerable specification by the user to implement a thinning. On the other hand, the automatic modes fully control density and structure, relieving the user of making the detailed specifications. In this paper, we review the manual specifications in the next section, then progress to the more automatic procedures in the following.

The models explored in this paper were developed using data from mixed hardwood stands in the Eastern United States. The primary purpose of these models is to estimate growth and yield from forest stands of mixed hardwoods managed primarily for the production of wood products. Each contains at least one procedure for simulating partial cuts. The procedures range from manually selecting trees from an on-screen tree list to fully automatic procedures or algorithms that simultaneously control several important characteristics of the residual stand. The following sections describe the models and the associated thinning procedures.

The simulators in FIBER, NE-TWIGS, OAKSIM, SILVAH, and YIELD-MS are distance-independent, individual-tree or stand-table projection types of simulators. They all begin with an enumeration of trees by species and diameter, and all are capable of producing a similar enumeration after projection. All simulators are available for public use on IBM compatible microcomputers. Most are being used by forest managers in central and northern hardwood forest types. Further basic information about the simulators and associated programs follows.

FIBER Version 2.0 (Solomon and others 1987)

FIBER was developed for the spruce-fir and northern hardwood forest types of New England. It is based on data from 359 spruce-fir research plots in Maine and 48 northern hardwood research plots in New Hampshire. In addition, some 2,500 growth plots, mostly from forest industry, were utilized; these plots are scattered throughout Maine, New Hampshire, Vermont, and northern New York.

Variables used in FIBER growth and mortality equations include: d.b.h., initial stand basal area, residual stand basal area, percent hardwoods, and percent species (for ingrowth).

FIBER is a two-stage matrix model. One stage is a set of linear regression equations that predicts transition probabilities of tree growth and mortality as a function of stand density, tree size, and proportion of hardwoods. These predicted probabilities are the elements of stand projection matrices used to project the distribution of diameters over a 5-year period. Projection periods in FIBER are 5 years. Minimum tree size is 5 inches; maximum tree size is 30 inches. FIBER is the one of two programs tested that currently contains an ingrowth function.

A run of FIBER is defined at the outset, and thinning can be performed during a simulation either by specifying the interval between thinnings in years or by specifying a volume or basal area that will trigger a thinning.

Various thinning strategies can be specified with a few simple parameters. The user specifies when and how much to thin. The residual level for the partial cut is specified as a basal area, a volume, or the B-level on northern hardwood, mixed-wood, or spruce-fir stocking guides reproduced in the FIBER documentation.

Thinning treatments can be specified as 1) no thinning, 2) thin-from-above, 3) thin-from-below, 4) diameter class removal, 5) uniform thinning, and 6) q-line thinning. The no thinning option continues to grow the stand. For the thin-from-above, -below, and uniform, a percentage of the total cut to remove from each species must be specified. If that specification results in removing more than is present, then the excess is distributed to other species in the priority that the user assigns to each species. With the thin-from-above option, the user specifies a beginning diameter and the program removes trees starting at that diameter and continues to smaller size classes until the amount specified has been removed. The thin-from-below is similar except that the program removes trees starting at the specified diameter and continues to larger diameters. The uniform thinning spreads the amount to be removed from each species evenly over all diameter classes of that species. The diameter class removal option is used interactively, and allows the user to specify the number of trees to remove from a given species and diameter class. The final option, q-line thinning, allows the user to specify the structure for an uneven-aged cut.

NE-TWIGS Version 2.0 (Hilt and Teck 1989)

NE-TWIGS was developed for general use throughout the Northeastern United States. It used the large data base of the Forest Inventory and Analysis Unit, which includes more than 4000 permanent 0.20 acre plots. Growth records on these plots cover an average of 12 years and include all forest types and species growing in the Northeast.

NE-TWIGS utilizes the computer shell developed by the North Central Forest Experiment Station for their Lake States and North Central TWIGS simulators (Belcher 1982). However, the growth and mortality equations in the NE variant differ in several ways from the NC and LS variants.

NE-TWIGS is a distance-independent, individual tree simulator. It works either from a tree list or a stand table, and is capable of handling fractional trees (it will accommodate a unit as small as 0.1 tree/acre).

Variables used in NE-TWIGS to estimate growth and mortality include: species, d.b.h., BAL (basal area in trees larger than the tree in question), and site index. As with the other TWIGS models, the NE variant calculates potential growth, then reduces that growth by competitive position (BAL). NE-TWIGS projects in growth periods of 1 year. Minimum diameter is 1 inch; maximum diameter is 30 inches. NE-TWIGS is one of two programs tested that currently contains an ingrowth function.

Runs of NE-TWIGS can be automatic, with user-defined interactive management at specified intervals, or highly interactive, with user specifications of reports, management activities, and additional projections at the end of each projection period. There is no mode in which management occurs whenever simulated stand development reaches a threshold basal area or relative density.

Thinnings are specified by creating a list of priorities from nine different removal procedures. Up to five procedures may be combined to generate the marking rules used by practicing foresters. Of the nine removal procedures, the first six specify the trees to be removed until the target residual-basal area is reached. The last three are procedures that override the target residual-basal area. The procedures are, 1) remove rough and rotten from size class, 2) remove smallest trees of all species not specified to leave, 3) remove largest trees of all species not specified to leave, 4) remove smallest trees of specified species, 5) remove largest trees of specified species, 6) shelterwood cut leaving the largest diameter and highest crown ratio trees, 7) reduce the number of trees to specified residual level, 8) remove overtopping trees, essentially a diameter limit, and 9) remove all trees of a user specified size and species.

OAKSIM (Hilt 1985a, 1985b)

OAKSIM was developed for oak-hickory forests of the upland central hardwood region. Growth and mortality data come from 20-year records on 77 permanent growth and yield plots in southern Ohio and southeastern Kentucky. White oak, black oak, and scarlet oak were the most common species on the plots, with other upland hardwoods represented in varying amounts. A single growth equation is used for all species, but there are four mortality equations; one each for black oaks, white oaks, other trees (primarily hickory), and understory trees. Adjustments are made to total stand growth by use of equations from GROAK (Dale 1972), a stand level simulator developed from the same data set.

Variables used in OAKSIM equations include: d.b.h., quadratic mean stand diameter (QMD), total stand basal area, site index, and species (mortality only).

OAKSIM is a distance-independent, individual tree simulator. It works from a tree list and treats each tree in that list (each sample) as an entity, either killing it or growing it in its entirety.

Runs of OAKSIM are defined at the beginning of a run. Thinnings are scheduled by the user, who specifies the age, residual density, the intensity codes for each species group, and the residual density (in percent stocking by the Oak Stocking Chart) for each thinning.

If a thinning is desired, the user specifies the residual density, and the entire distribution is done automatically. The distribution of cut is based on a mathematical model of actual thinnings. Application of this thinning algorithm ensures residual stands that duplicate as closely as possible the actual study plot residuals. The percentage to cut from any diameter class is a function of the residual density and the cumulative frequency of live trees in the stand. While this ensures that irregularities in the original stand are not increased, it does nothing to alter these irregularities.

The user can specify three options to control the species composition effects of this thinning algorithm. While the number of trees to cut within any diameter class is fixed by an equation, the user can specify the allocation of that cut across species within each class. The choices are to 1) maintain the same proportion in each species as in the unthinned stand, 2) double the cut for a species, or 3) eliminate a species.

There are no provisions for partial cuts under uneven-aged silvicultural systems or for user-designed cuts in the OAKSIM program. The research plots that were used to provide the data from which OAKSIM was developed were all even-aged.

SILVAH Version 4.04 (Marquis 1986)[2]

SILVAH was developed for use in hardwood forests of the Allegheny Plateau region of Pennsylvania, New York, West Virginia, Maryland, and Ohio. The SILVAH program is primarily a decision-support system used in making silvicultural decisions, but it includes a stand growth simulator as an important component.

Growth data in SILVAH comes from two major sources. Data on the cherry-maple and beech-birch-maple types came from approximately 370 tallies of long-term research plots in northwestern Pennsylvania, some of which span 55 years of continuous record. These data have been used to develop separate growth and mortality equations for black cherry, red maple, sugar maple, and American beech. Other non-oak species are calculated from the equations of one of these species. Equations for growth of species of the oak-hickory type in SILVAH came from OAKSIM. The equations were simply taken from OAKSIM, and used for all oak species. Growth adjustments included in OAKSIM based on the stand growth simulator GROAK are not included in SILVAH.

Variables used in SILVAH growth and mortality equations include: species, d.b.h., relative diameter (d.b.h./stand diameter), relative stand density (total basal area for oaks), and site index (oaks only). SILVAH is a modified stand table projection simulator. SILVAH works with per acre data, and permits fractional trees/acre to die or move in d.b.h. class.

SILVAH offers a range of run options, from interactive through automatic. In the most automatic mode, partial cuts are triggered by growth to a program-set threshold density. Volumes available for cutting must also meet user-specified levels for the program to implement an automatic cut. In the most interactive mode, a user selects any treatment(s), including customized ones, at the end of each growth period. SILVAH does not include a facility for editing the current stand table as one way of describing a partial cut.

---

[2]Marquis, David A. and Richard L. Ernst. In preparation. User's guide to SILVAH: a stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies. Available from the authors.

The thinning algorithm in the SILVAH programs is described in detail elsewhere[3]. For even-aged partial cuts, the distribution procedure uses a negative exponential function to ensure that a specified proportion of the cut density is removed in trees smaller than the medial stand diameter (MD). The medial stand diameter represents the point where half the basal area is below and half the basal area is above. This distribution procedure does not account for any irregularities in the existing diameter distribution, however, and can result in severe cutting in some size classes in stands with irregular distributions. For all-aged cuts, an idealized inverse J-shaped curve, based on q, is transformed into the equivalent relative density. All density in excess of this curve is removed. If the original stand is deficient with respect to the target density in any size class, additional density is left in smaller classes to compensate. The automatic thinning algorithm assigns a cut proportion to each diameter class, and maintains the species composition of each diameter class as it was in the unthinned stand.

In addition to the automatic prescription generation option, users may either select a standard silvicultural prescription (alternatives include precommercial, combined precommercial/commercial, and commercial thinnings, thin-harvests, shelterwood seed cuts, and selection system cuts). Users may also design a partial cut by combining information about species, density, and structure. For each of these criteria, a single value, or a range of values can be specified; trees that simultaneously meet all three conditions are removed. In addition, this option allows the user to specify the priority for each removal; the user specifies those trees that are to be removed unconditionally, or subject to a minimum residual density.

YIELD-MS Version 1.1 (Hepp 1988)

YIELD-MS is the timber yield and planning module of the Tennessee Valley Authority's (TVA's) package of inventory, analysis, and economic analysis programs for timber managers working in mixed species stands. The YIELD-MS component is where the user has the opportunity to impose management procedures, such as partial cuts, and obtain stand growth projections.

Growth projections in YIELD-MS are stand table projections. Each species group and diameter class has a d.b.h. growth rate and a survival probability. Users may enter d.b.h. growth rates from a file, from increment core data particular to a stand, or by direct user entry. However, the preferred mode of growth projection is use of growth and survival probability equations from any of four other stand-growth simulators. These are OAKSIM, SILVAH, TWIGS (Shifley 1987), and G-HAT (Harrison and others 1986a, 1986b). The growth projection routine in YIELD-MS uses these equations but does not use any modifiers from the original programs. So, the results of simulating the growth of a stand with YIELD-

[3]Ernst, Richard L. and Susan L. Stout. In preparation. A computerized method for developing marking guides for forest stands. Available from the authors.

MS, using the OAKSIM equations, for example, may not be the same as simulating the growth of that stand using OAKSIM.

Data entry and inventory processing are accomplished in other programs in the TVA package. Diameters must be in 1-inch classes. Minimum diameter is 1 inch; there is no apparent maximum diameter.

Runs of YIELD-MS are interactive. Selecting trees for thinning can be in manual or automatic tree marking modes. The automatic tree marking mode allows the user to specify a percentage of a species, product, and size to remove. The program calculates the basal area in all trees that meet the three criteria, then removes the proportion of those trees as specified by the user. The product criteria consists of specifying grades 1 through 5 and pulpwood. The size criteria allows the user to specify that the removals occur equally across all diameters, from the biggest trees, from the smallest trees, from the most valuable trees, or from the least valuable trees.

The manual marking mode allows the user to edit the contents of the individual cells of a stand table on-screen. Although tedious, this method allows the most flexibility. The stand table is displayed on the screen, and it can be in any of the units supported such as number of trees, volume, value, and so on. The user changes the value in the cell, and the tables for cut and leave are adjusted.

SUMMARY OF PARTIAL CUT ALGORITHM OPTIONS

Tables 1 and 2 summarize the partial-cut options in these computer programs. In Table 1, the options for automatic partial-cut implementation are summarized. These are the options that allow the user to specify a few characterizing parameters, from which the computer program develops a comprehensive description of the cut. Table 2 summarizes the tools each program provides for users to develop customized partial cuts. The array of possibilities is extensive, as these tables and this summary show. There are uniquely advantageous features in each program, but no program includes all features.

Our assessment of the flexibility and comprehensiveness of the partial-cut procedures in these programs is necessarily subject to our own biases, experience, and computer use styles. We suggest that those programs with many customizing features in Table 2 are the most flexible. Those with many automatic features in Table 1 are the most comprehensive. Mastering any of these computer programs requires a learning period. While this period may be shorter for programs with the fewest options on both tables, those with many automatic features are easiest to use if many alternatives are to be tested. It is possible to construct most common silvicultural treatments with FIBER,NE-TWIGS, SILVAH, and YIELD-MS.

Table 1.--Automatic cut generation features

Simulator	Thinning timing[1]	Density control[2]	Even-age structure control[3]	Uneven-age structure control[4]	Other[5]
FIBER	A, Y, T, I	BA, V, ST	D	Q, MX	Q
NE-TWIGS	Y, I	BA	-	Q, MX	Q
OAKSIM	A,Y	ST	F	-	Q, S
SILVAH	Y, T, I	RD	P	Q, MX	Q, N
YIELD-MS	I	BA	-	-	Q

[1]A = Thin at given age, Y = thin after given number of years, T = thin when stand reaches threshold, I = interactive
[2]BA = basal area, V = volume, NT = number of trees, RD = relative density, ST = stocking guide level
[3]D = default quality and species removal priorities, P = power function, F = fitted function to research data
[4]Q = quotient, MX = max tree size
[5]Q = quality adjustment, S = species adjustment, N = select treatment by name

Table 2.--Customized cut generation features.

Simulator	Density control[1]	Cut from above	Cut from below	Cut uniform	Cut species	Save species	Cut dia class	Cut poor quality	Combine	Tree list edit	Other[2]
FIBER	BA, V, ST	•	•	•	•		•				
NE-TWIGS	BA	•	•		•	•	•	•	•		
OAKSIM	ST				•		•				
SILVAH	RD			•	•		•	•	•		N
YIELD-MS	BA				•		•	•	•	•	

[1]BA = basal area, V = volume, NT = number of trees, RD = relative density, ST = stocking guide level
[2]N = select treatment by name

AUTOMATIC CUTS FOR EVEN-AGE STRUCTURE CONTROL

Three of the programs considered in this paper offer automatic structure control when applying even-aged thinnings. These automatic cutting options are important for a variety of reasons. The first is that these automatic cutting algorithms usually represent the model developer's best effort to mimic the kind of thinnings implemented on the research plots from which the model was developed, and the model should most closely mimic the growth of real stands cut in these ways. The second is that because these options are often the easiest to implement, users take advantage of them, and a fuller understanding of their consequences improves use of the models. As we will show in this paper, the algorithms act in different ways on stands with different structures. An understanding of these differences also improves use of the models. Finally, a discussion of the algorithms actually used in different programs will enable those working on future model development to draw on the best of several existing algorithms.

Users of FIBER may request a thinning to the B-line of any of the stocking guides reproduced in the FIBER documentation (Solomon and others 1987), but this documentation does not describe the implementation of this procedure. Both OAKSIM and SILVAH use mathematical functions to distribute removals among diameter classes and species.

We will show the effects of these two procedures on two different oak stands, with quite different original structures. The first example is based on Schnur's (1937) yield table for 90-year-old oak on a site index 70 site (Figures 1a and 1b). This stand is typical of the structure and species composition of stands used to develop the OAKSIM model. The second stand is from a transition oak stand in northwestern Pennsylvania (Figures 2a and 2b), and is typical of the stand structure, density, and species composition found in that region and other areas in which stands of northern red oak and northern hardwood species are common (Stout in press). It is similar in structure to the stands used to develop the growth and yield model in SILVAH.

The OAKSIM procedure is described in detail in the OAKSIM documentation (Hilt 1986b). The function used was developed to describe the removals on the research thinning plots that yielded the data used to develop OAKSIM. Users may adjust the application of this procedure by species and residual density, but may not adjust the minimum cutting diameter, which is set at the smallest diameter class in the stand. The function determines the cut frequency in each diameter class as a function of the cumulative frequency from the smallest class and of the residual thinning density. This procedure automatically ensures that in irregularly small classes, the cut will be small, and in irregularly large classes, the cut will be large, still ensuring that the designated total cut is achieved. Nothing is done to smooth such irregularities. Figures 1a and 2a show the diameter distribution of Schnur's SI 70, 90-year-old oak stand and the Pennsylvania oak stand, respectively, with each diameter class separated into cut or leave trees according to the OAKSIM thinning function.

The SILVAH procedure uses a modified negative exponential function, which guarantees that for cuts from below (those in which more than half the cut will come from trees lower than MD), the largest proportion of the cut will come from the smallest class for cutting, and each successive class will have a slightly smaller cut. After the equation is applied to 1- or 2-inch diameter classes, the cut from several adjacent classes (the 6- through 11-inch classes for poletimber, for example) is accumulated into a class proportion. This reduces the smoothness of the cut, but yields a more realistic marking guide for woods use. Users may adjust the residual relative density and the proportion of the cut to be made in trees less than MD. Users have some control over the minimum diameter in which cutting is to occur. The

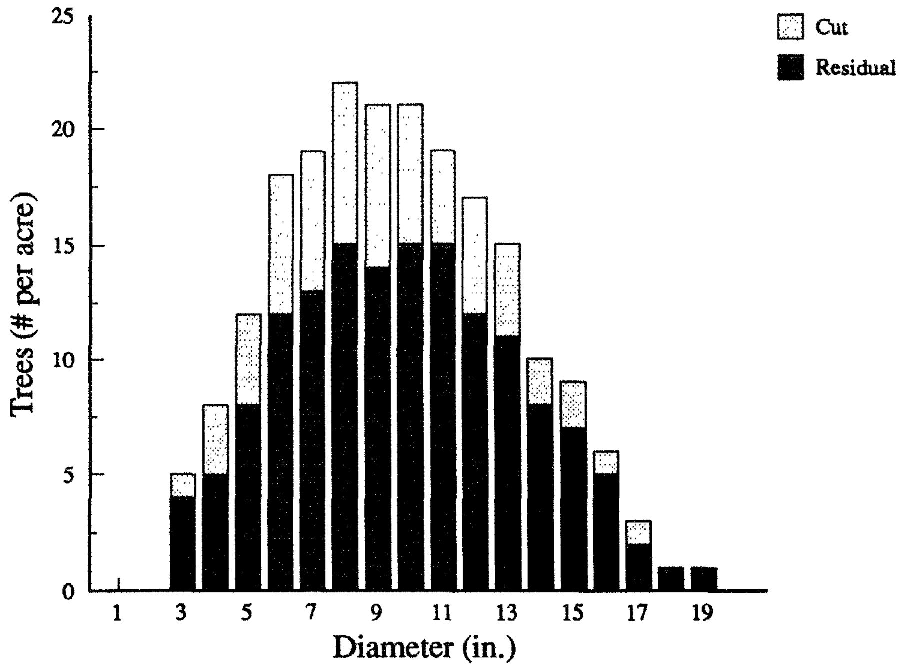

Figure 1a. Cut and residual trees in Schnur's SI 70, 90-year-old stand after a thinning as prescribed by OAKSIM.

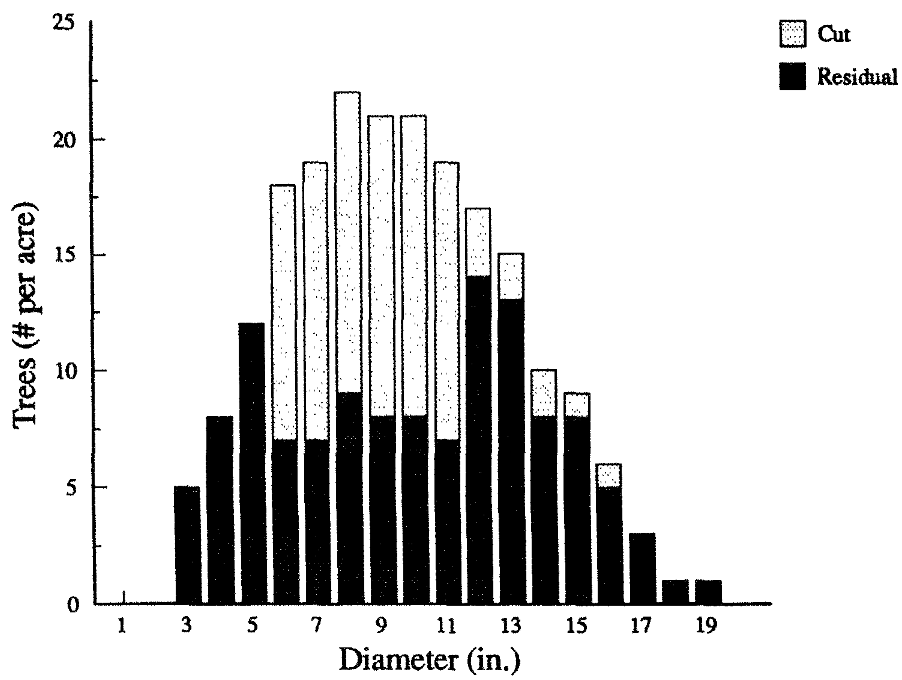

Figure 1b. Cut and residual trees in Schnur's SI 70, 90-year-old stand after a commercial thinning with 75 percent of the density removed in trees smaller than MD as prescribed by SILVAH.

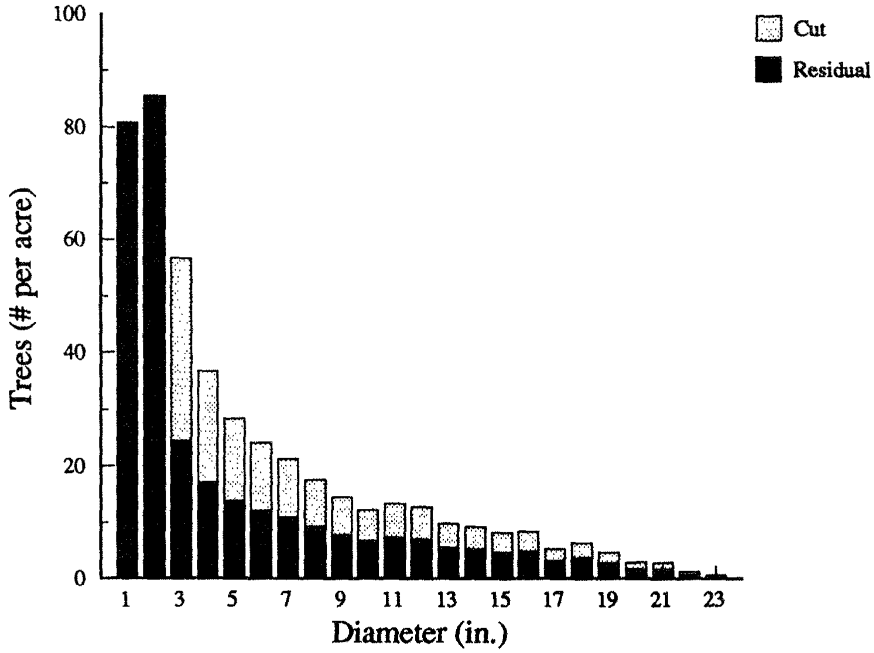

Figure 2a. Cut and residual trees in a Pennsylvania oak stand after a thinning as prescribed by OAKSIM.

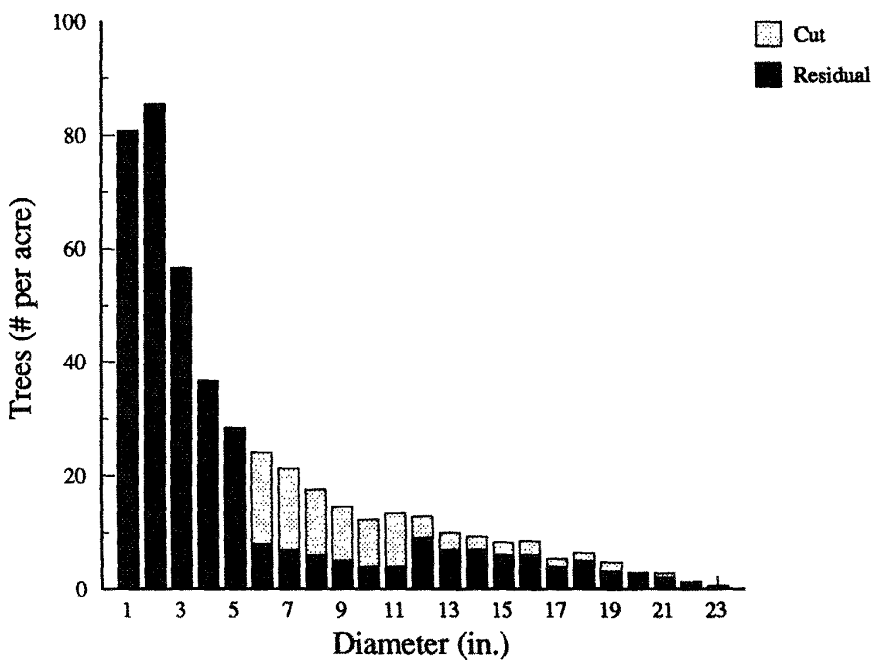

Figure 2b. Cut and residual trees in a Pennsylvania oak stand after a commercial thinning with 75 percent of the density removed in trees smaller than MD as prescribed by SILVAH.

procedure largely ignores irregularities in the original diameter distribution, although adjustments are made when the procedure calls for removal of more trees than are present in a diameter class.

Figures 1b and 2b show the same stands as Figures 1a and 2a, with each diameter class divided into cut or leave trees according to the SILVAH default function for a commercial thinning. The two procedures have quite different effects on both of these stands. In each stand, there are differences in the smallest size classes and differences in the overall structure of the residual stand. Each of these differences is a consequence of the thinning algorithm and its constraints.

The Schnur stand has the even-aged stand structure, or diameter distribution, traditionally associated with forest types in which the species are similar in growth rate and tolerance to shade. In this stand, the OAKSIM algorithm identifies trees for cutting from the 3-inch through the 17-inch class, all in proportion to their presence in the existing stand (Figure 1a). SILVAH's algorithm includes no cutting in the sub-merchantable size classes in this stand. In addition, SILVAH's algorithm stipulates that 75% of the density to be removed will be in trees with diameters smaller than MD. In this stand, this results in a much heavier cut in the poletimber classes and somewhat lighter cut in the sawtimber classes (Figure 2a). Both residual stands have a bell-shaped distribution in the merchantable classes. In the OAKSIM distribution this bell-shape extends into the sub-merchantable classes.

The Pennsylvania transition oak stand has the inverse-J shaped diameter distribution frequently found in even-aged hardwood stands with a mix of species of different growth rate and tolerance for shade. Once again, differences in threshold diameter for cutting are apparent in the residual stands, although in this stand, the fact that trees less than 3 inches in diameter are not processed by OAKSIM is apparent. SILVAH's algorithm concentrates the cut in this stand in the 6-, 8-, and 10-inch classes, and establishes a bell-shaped distribution, particularly in the 10- through 24-inch classes. The residual from the OAKSIM thinning algorithm retains its original, inverse-J shape.

A comparison of the effects of thinning algorithms on different stands is made more difficult by the absence of a universal measure of relative density. Both algorithms use relative density to control the total amount of removals, but the density measure is different. OAKSIM uses the Oak Stocking Guide (Roach and Gingrich 1968), while SILVAH uses a tree-area ratio based measure with three species groups (Marquis and others 1984, Stout and Nyland 1986).[4] In stands with species from more than one species group, similar basal areas may represent different densities, and similar densities may represent different basal areas (Stout and others 1987). It is very difficult to impose thinnings that leave residual stands that are similar in both absolute and relative density across the two measures. For the purposes of focusing on the thinning algorithms, we have concentrated on the structure of the cuts, rather than on the absolute amounts removed.

---

[4]Ernst, Richard L. and Susan L. Stout. In preparation. A computerized method for developing marking guides for forest stands. Available from the authors.

Both procedures allow the user to specify the residual density for thinnings in the density measure associated with the model. OAKSIM uses the residual density in the cumulative cut function and varies both the absolute amount to be cut in each class and the proportion of the cut assigned. SILVAH maintains the same proportions for the cut, but increases or decreases the absolute amount in each size class according to the selected residual densities. Users may, however, specify the proportion of the cut to be assigned to diameter classes below MD, and hence the proportion of the cut in each size class.

CONCLUSIONS

This examination of the computerized procedures for implementing partial cuts in computerized forest stand-growth simulators points to an opportunity to develop a new procedure for implementing even-aged thinnings automatically. OAKSIM uses a cumulative distribution function, but is inflexible with respect to structure. While SILVAH is flexible, its procedure is relatively insensitive to the original stand structure. Both procedures are tightly tied to the structure of the stands in the data bases from which they were developed. Neither procedure alters the prescribed residual to compensate for irregularities in the existing distribution, and the SILVAH procedure actually can worsen these irregularities if applied blindly.

One new approach would be to use a distribution function for the cut, as SILVAH does, and then to distribute it on a cumulative basis as OAKSIM does. This would eliminate the shortcomings of both methods. Such a function could include built-in flexibility to handle different structures for thinnings or shelterwood cuts near stand maturity, for example.

Another approach would be to develop automatic procedures for partial cuts under even-age systems that mimic the procedures in wide use for partial cuts under uneven-age systems. The procedures for distributing partial cuts under uneven-age systems involve description of a target residual distribution by size class and removal of those trees that exceed the target distribution. Some procedures include a step to modify the target distribution to compensate for deficiencies in the present stand. The various silvicultural guides in use throughout the Central Hardwood region suggest that even-age thinnings should be applied to increase the stand diameter (shorten the rotation length), and favor the biggest and best trees. Some guides specify narrowing the range of diameters. These characteristics could be translated to a target residual structure for even-aged stands and a procedure used that would prescribe cutting the trees in excess of the target distribution.

This examination of the computerized partial cut procedures available in commonly used computer stand-growth simulators has demonstrated the wide range of alternatives available, and can form the basis for development of an integrated, flexible, comprehensive and user-friendly set of procedures for future versions of existing simulators or new decision support programs, such as that being developed under the auspices of the Northeastern Forest Experiment Station (Marquis 1990). All programs examined here control density, quality, and structure in the residual stands either directly or indirectly. A complete partial cutting module could be derived by using the best components of each of the individual procedures. Such a module should allow for totally automatic distribution of cut that controls density, quality, and structure. It should also allow complete and flexible manual intervention.

LITERATURE CITED

Belcher, David M. 1982. TWIGS: The woodsman's ideal growth projection system. In: Microcomputers: A new tool for foresters. Proceedings of a conference sponsored by Purdue University Department of Forestry and Natural Resources and Society of American Foresters Systems Analysis Working Group and Inventory Working Group; May 18-20, 1982; West Lafayette, IN: Purdue University.

Dale, Martin E. 1972. Growth and yield predictions for upland oak stands 10 years after initial thinning. USDA For. Serv. Res. Pap. NE-241. 21 p.

Harrison, W. C., T. E. Burk, and D. E. Beck. 1986a. Individual tree basal area increment and total height equations for Appalachian mixed hardwoods after thinning. South. Jrnl. of Appl. For. 10:2.

Harrison, W. C., T. E. Burk, and D. E. Beck. 1986b. Growth and yield of Appalachian hardwoods after thinning. Blacksburg, VA: Virg. Polytechnical Inst. and State Univ., School of For. and Wildl. Resources Publ. No. FWS-1-86.

Hepp, T. E. 1988. A user manual for YIELD-MS timber yield planning tool for mixed stands. Version 1.1. Norris, TN: Tennessee Valley Authority, 63 p.

Hilt, D. E. 1985a. OAKSIM: An individual-tree growth and yield simulator for managed, even-aged, upland oak stands. USDA For. Serv. Res. Pap. NE-562, 21p.

Hilt, Donald E. 1985b. User's guide to OAKSIM: an individual-tree growth and yield simulator for managed, even-aged, upland oak stands. USDA For. Serv. Gen. Tech. Rep. NE-104. 22 p.

Hilt, Donald E. and Richard M. Teck. 1989. NE-TWIGS: An individual-tree growth and yield projection system for the northeastern United States. The Compiler 7(2):10-16.

Leak, W. B., D. S. Solomon, and P. S. DeBald. 1987. Silvicultural guide for northern hardwood types in the Northeast (revised). USDA For. Serv. Res. Pap. NE-603, 36 p.

Marquis, David A. 1986. SILVAH: A stand analysis, prescription, and management simulator program for hardwood stands in the Alleghenies. In: Wiant, Harry V., Jr.; Yandle, David O.; Kidd, William E., eds. Forestry Microcomputer Software Symposium, Morgantown, WV. Morgantown, WV: West Virginia University. 224-240.

Marquis, David A. 1990. A multi-resource silvicultural decision model for forests of the northeastern United States. In Proceedings: Division1, Volume 1, XIX IUFRO World Congress, August 5-11, 1990, Montreal, Canada. 419-431.

Marquis, D. A., R. L. Ernst, and S. L. Stout. 1984. Prescribing silvicultural treatments in hardwood stands of the Alleghenies. USDA For. Serv. Gen. Tech. Rep. NE-96, 90p.

Roach, B. A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. USDA For. Serv. Res. Pap. NE-373. 30 p.

Roach, B. A. and S. F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. USDA For. Serv. Agric. Handb. 355, 39 p.

Schnur, G. Luther. 1937. Yield, stand, and volume tables for even-aged upland oak forests. U.S. Dep. Agric. Bull. 560.

Shifley, S. R. 1987. A generalized system of models forecasting Central States tree growth. USDA Forest Service Res. Pap. NC-279.

Solomon, D. S., R. A. Hosmer, and J. H. T. Hayslett. 1987. FIBER handbook: A growth model for spruce-fir and northern hardwood forest types. USDA For. Serv. Res. Pap. NE-602, 19p.

Stout, Susan L. in press. Stand density, stand structure, and species composition in transition oak stands of NW Pennsylvania. In Proceedings, 8th Central Hardwoods Conference, Pennsylvania State University, March 4-6, 1991.

Stout, Susan Laurane and Ralph D. Nyland. 1986. Role of species composition in relative density measurement in Allegheny hardwoods. Can. J. For. Res. 16:574-579.

Stout, Susan L., David A. Marquis, and Richard L. Ernst. 1987. A relative density measure for mixed species stands. J. For. 85(7):45-47.

THE INTERACTIVE IMPACT OF FOREST SITE AND STAND ATTRIBUTES AND LOGGING TECHNOLOGY ON STAND MANAGEMENT

Chris B. LeDoux and John E. Baumgras[1]

Abstract: The impact of selected site and stand attributes on stand management is demonstrated using actual forest model plot data and a complete systems simulation model called MANAGE[2]. The influence of terrain on the type of logging technology required to log a stand and the resulting impact on stand management is also illustrated. The results can be used by managers and planners in making decisions on how best to manage the hardwood resource.

INTRODUCTION

Intensive management of immature eastern hardwood stands has received increased attention (U.S. Department of Agriculture 1981, Smith and Eye 1986). Economic returns to management activities in these stands are affected by logging and processing technology and transport costs (LeDoux 1988a). Hardwood market trends, stand growth-and-yield response, stand composition, and landowner objectives also influence hardwood management decisions.

Decision makers and planners need to know which site and stand attributes affect costs and benefits and to understand how these variables interact for a particular management plan. Plans must incorporate short- and long-term effects of site and stand variables on management. Additionally, the choice of logging technology significantly can constrain stand management options.

---

[1]Industrial Engineer and Project Leader, and Research Forest Products Technologist, U.S. Department of Agriculture, Forest Service, 180 Canfield Street, Morgantown, WV 26505

[2]The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

METHODS

In this article, the effect of site and stand attributes, and logging technology on stand management is evaluated with a complete systems simulation model called MANAGE (LeDoux 1986). MANAGE, a computer program written in FORTRAN 77, integrates harvesting technology, silvicultural treatments, market prices, and economic criteria over the life of a stand. The simulation combines discrete and stochastic subroutines to model harvesting cost, silvicultural treatments, growth projections, and to conduct discounted cash flow (SEV) analysis. The model can be used to develop optimal management guidelines for eastern hardwoods. The results also can help planners and managers understand the impact of site and stand variables on costs, benefits, and returns to management practices.

Stand Tables

The stand tables used to initiate the simulations were those published by Schnur (1937) for even-aged upland oak forests (Table 1). These tables represent projected conditions by site index and age for fully stocked upland oak stands. To insure that all first thinning entries were economically feasible, the ages of the stand tables selected to initiate the simulations varied by site index. For example, the average diameter of the initial stands averaged about 8 inches and the starting volume averaged about 2500 ft^3/acre (Table 1). Because it takes longer to attain average d.b.h. of 8 inches or poor sites than better sites, simulation begins later for low site indexes.

The initial tree lists by site index were entered into MANAGE and the growth and yield was projected for a variety of management scenarios. Cable and ground-based logging technology were evaluated by site index for each stand. The costs and benefits by site index were simulated and summarized on a cash flow and discounted cash flow soil expectation basis.

Logging Technology

The interaction of logging technology and stand attributes by site index was evaluated by assuming that the stands shown in Table 1 were located on both steep and gentle terrain. The Clearwater[3] yarder (LeDoux 1987) was used to simulate harvesting of the stands for the steep terrain applications. The Clearwater yarder is a medium size yarder capable of yarding small and large logs. A John Deere 540B rubber-tired skidder was used to simulate the harvest of

[3]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

the stands on gentle terrain applications (LeDoux 1985; LeDoux 1988b). The John Deere 540B is a medium size skidder capable of skidding small and large logs. Figures 1 and 2 show the John Deere 540B and Clearwater yarder, respectively. The costs for the above machines were estimated using EASTCOST (LeDoux 1988b). The streams of cost and benefits were summarized by treatment, site index, and logging technology and presented on a soil expectation basis. The delivered product prices used are shown in Table 2 and were obtained from Coastal Lumber Company, Hopwood, PA and Forest Product Price Bulletins (Ohio, 1989; Penn State, 1989; Tennessee, 1989).

Table 1.--Initial attributes of timber stands; average d.b.h., ft^3 volume, age, trees, and species mix, by site index, for even-aged upland oak stands.

					Species				
Site index	Mean DBH	Vol	Age	Trees/ acre	Red maple	White ash	White oak	Red oak	Hickory
	Inches	Ft^3/ acre	Years		Percent				
50	8.3	2535	90	284	5.0	6.0	57.0	25.0	7.0
60	8.4	2474	70	271	6.0	6.0	51.0	32.0	5.0
70	8.8	2596	60	258	5.0	6.0	45.0	38.0	6.0
80	8.9	2612	50	249	5.0	6.0	38.0	45.0	6.0

Table 2.--Delivered prices for sawlogs and fuelwood/pulpwood by species.

Species	Large[1] sawlogs	Medium[2] sawlogs	Small[3] sawlogs	Fuelwood/[4] pulpwood
	$/Mbf (Doyle Rule)			-$/Cord-
Red Maple	210	160	80	30
White Ash	500	300	100	30
White Oak	500	300	100	30
Red Oak	600	350	100	30
Hickory	210	160	100	30

[1]Minimum small end diameter $\geq$ 13 inches, length $\geq$ 10 feet.
[2]Minimum small end diameter $\geq$ 11 inches, length $\geq$ 8 feet.
[3]Minimum small end diameter $\geq$ 10 inches, length $\geq$ 8 feet.
[4]89 ft^3/cord, minimum small end diameter $\geq$ 4.0 inches that will not make large, medium, or small sawlogs.

Figure 1. The John Deere 540B skidder.

Management Objectives

For comparison purposes, the stands were subjected to one thinning and then projected to optimal (The maximizing of SEV.) rotation age by logging technology. Soil expectation value (SEV) is used to compare returns[4]. Initial thinning ages were defined as the earliest age that a stand could be commercially thinned by the logging technology specified and pay for itself or at least break even. Area versus crop-tree-release thinnings were simulated with the objective of producing quality sawlogs at final harvest.

[4]The soil expectation value is a maximizing of the present net worth of revenues minus costs from an acre of bare ground and all future stands on that acre.

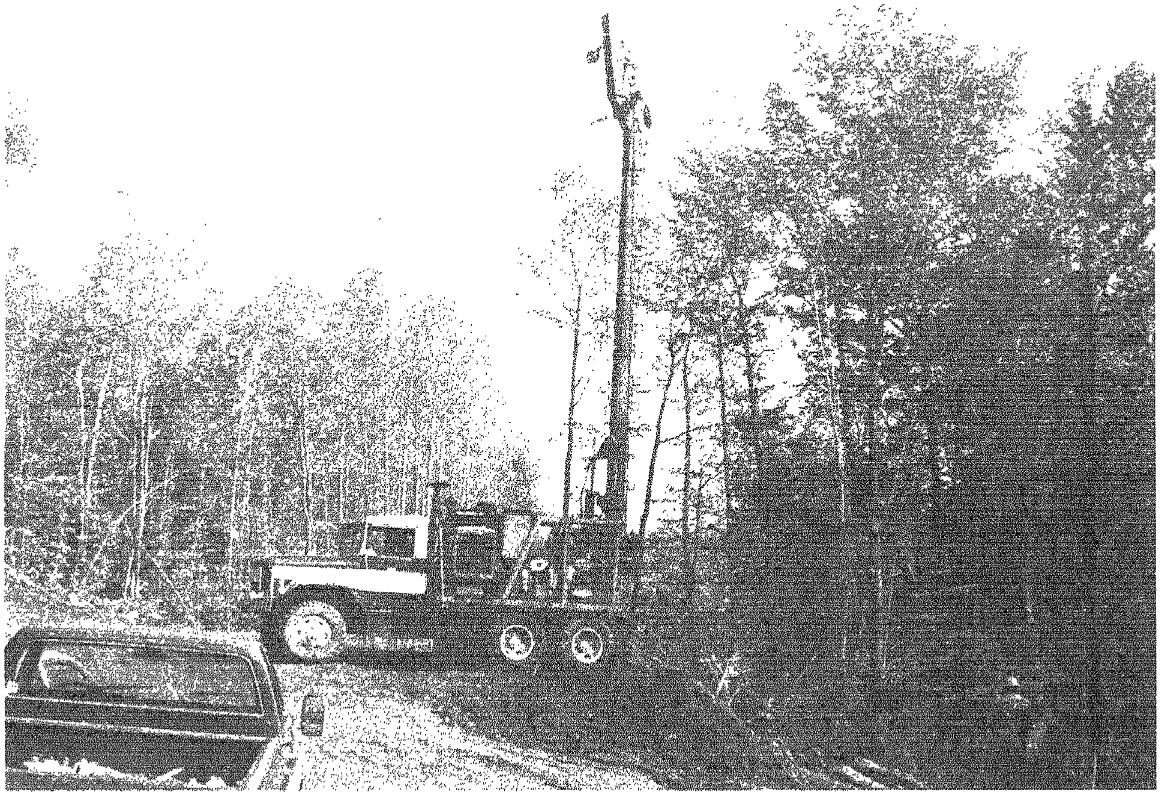

Figure 2. The Clearwater cable yarder.

RESULTS

The results indicate that lower site-index stands have lower soil expectation values and longer optimal rotations. Comparing the optimal rotation length for the John Deere 540B skidder by site index shows the effect of site index on soil expectation and rotation length. For example, site index 50 has a soil expectation value of $2.03/acre with an optimal rotation age of 195 years. By contrast, a site-index-80 stand has a soil expectation value of $32.55/acre with an optimal rotation age of 130 years (Fig. 3). Higher site indexes generally resulted in larger average d.b.h. trees at optimal rotation and greater yields. It is interesting to note that the optimal rotation ages generally are producing trees that average 15 to 16 inches d.b.h.

The effects of logging technology also are shown in Figure 3. Generally, use of cable logging to harvest the stands resulted in optimal rotation lengths 10 years longer than when using the ground-based system, the John Deere 540B skidder. This is due to delaying of thinnings by 5 years and harvesting more trees and volume from thinnings to offset the high

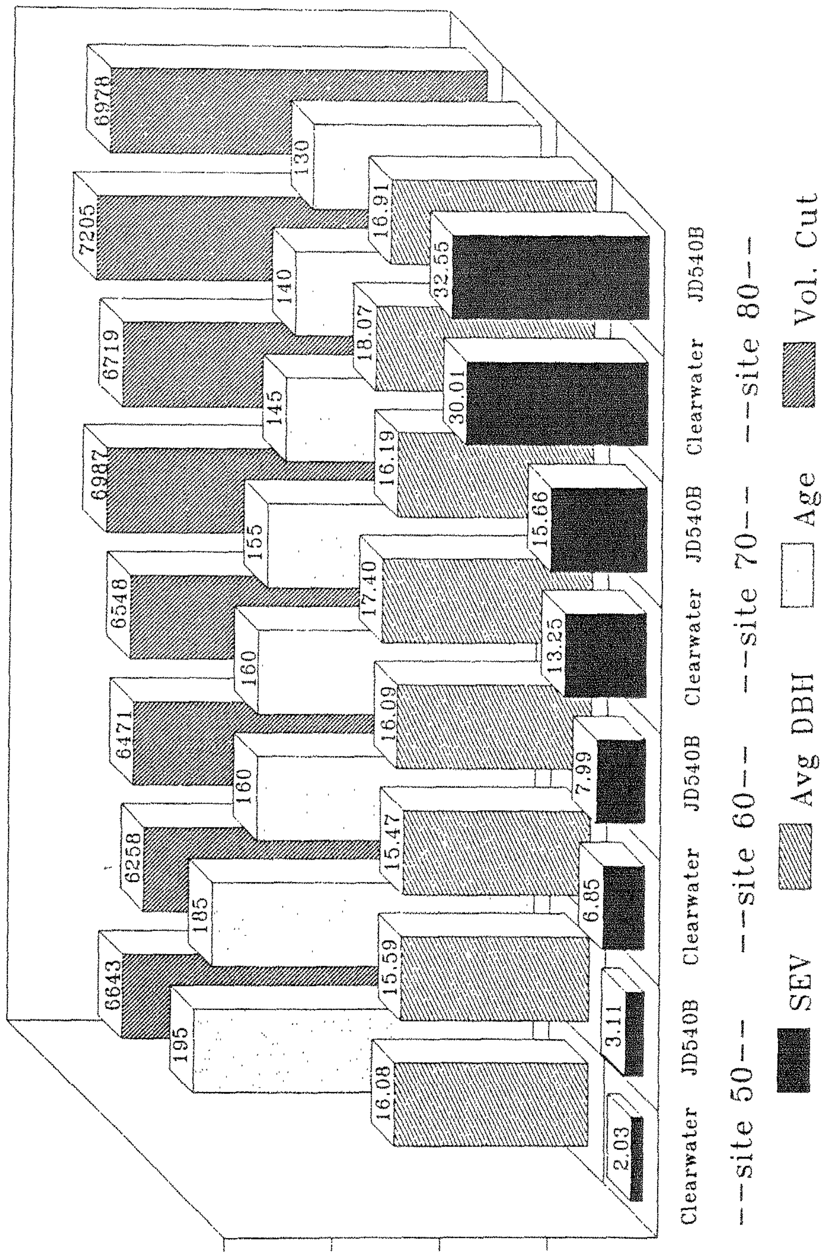

Figure 3. Soil expectation, average d.b.h., optimal rotation length, and total volume harvested at optimal rotation age by site index and logging technology.

costs of expensive skyline logging systems. As a result, the average d.b.h. and value of trees removed in thinning were greater when cable logging technology was applied. The increase in average d.b.h. results from stands being grown 10 years longer than when ground-based systems were used. Figure 3 shows the soil expectation value for the optimal rotation length by site index. The results include cash flows from both thinnings and final harvests.

Table 3.--Net cash-flow components from commercial thinning (CT) and final harvest (FH) by logging technology and site index.

Entry (years)	Average d.b.h.	Volume removed	Gross revenue	Total stump-to-mill cost	Net cash flow
	Inches	ft^3/acre	Dollars/acre		
		Site Index 50 and John Deere 540B			
CT-110	12.51	2304.80	1063.09	939.94	123.15
FH-185	12.59	3952.73	3435.14	1368.7	22066.42
		Site Index 50 and Clearwater			
CT-115	13.05	2493.32	1280.99	1180.98	100.01
FH-195	16.08	4149.84	3692.20	1749.54	1942.66
		Site Index 60 and John Deere 540B			
CT-90	12.65	2558.52	1142.38	1019.43	122.95
FH-160	16.09	3989.97	3690.82	1364.11	2326.71
		Site Index 60 and Clearwater			
CT-95	13.17	2781.67	1477.27	1307.57	169.70
FH-160	15.47	3689.72	3051.62	1589.45	1462.17
		Site Index 70 and John Deere 540B			
CT-75	12.65	2462.80	1089.15	987.70	101.45
FH-145	16.19	4256.28	4469.47	1443.78	3025.69
		Site Index 70 and Clearwater			
CT-80	12.94	2911.28	1533.95	1379.20	154.75
FH-155	17.40	4075.24	4496.52	1655.87	2840.65
		Site Index 80 and John Deere 540B			
CT-65	12.83	2663.76	1187.14	1047.97	139.17
FH-130	16.91	4313.79	4960.93	1438.74	3522.19
		Site Index 80 and Clearwater			
CT-70	13.11	3096.87	1712.40	1455.60	256.80
FH-140	18.07	4108.00	4893.95	1641.78	3252.17

Table 3 shows the average d.b.h., volume harvested (ft^3), undiscounted cash flows by entry and final harvest for each site index and logging technology. Generally, stands could be thinned at an earlier age for each site index when using ground based systems. This is due largely to the use of cable systems resulting in higher harvesting cost and the thinning delayed by 5 years until the trees were larger and were valuable. Thinnings become economical for the rubber-tired skidder when the trees average about 12 inches d.b.h. By contrast, the stands need to average about 13 inches for the Clearwater. The 12- and 13-inch-d.b.h. economic-feasibility limits range from a stand age of 70 to 110 years for site index 80 versus a site index of 50. Further, in most cases the initial commercial thinning must remove approximately 2,300 ft^3/acre when using ground-based systems and approximately 2,500 ft^3/acre when using cable technology. Earlier thinnings would require either subsidy by the landowner or higher prices for low quality roundwood.

CONSIDERATIONS FOR MANAGERS

We deliberately started with stands of different ages but similar mean d.b.h., volume, and species composition so that reasonable comparisons could be made between site indexes and logging technology. Results show that one commercial thinning can be initiated at age 65 on site index 80 with ground-based technology and at age 115 on site index 50 with cable-logging technology. Optimal rotation ages for the residual stands range from age 130 on site index 80 with ground-based technology to age 195 on site 50 with cable-logging systems. Cash flows for the thinnings range from about $100/acre on poor sites to $257/acre on good sites. Cash flows for the final harvest at rotation age range from $1,462/acre on poor sites to $3,522/acre on good sites.

The average tree d.b.h. and volume removed per acre significantly affect logging costs and the way a stand is managed to maximize soil expectation value. Site index, in turn, influences d.b.h. and volume growth, thus having an important influence on the way even-aged oak stands are managed. The terrain on which a stand is located dictates the kind of logging technology that must be used during thinnings and harvests. As we have shown, logging technology can influence timing of thinning entry and optimal rotation age. For example, soil expectation values can range from $2.03/acre on site index 50 to $32.55/acre on site index 80 or a difference of about 1503 percent when using cable-logging technology. By contrast, soil expectation values range from $30.01/acre to $32.55/acre when using the Clearwater and John Deere 540B on site index 80, or a difference of about 8 percent. The effect of logging technology on soil expectation is more pronounced on poorer sites (53 percentage difference) than on good sites (8 percentage). SEV was maximized using the John Deere 540B on all sites.

The objective of this paper was to demonstrate the interactive impacts of site and stand attributes and logging technology on the way a stand is managed. We did that for two logging technologies and five site indexes with a fixed set of delivered prices to a sawmill. Although the timing of thinning entry and optimal rotation ages are specific to the values and stands used in this evaluation, the results do show the importance of considering site and stand attributes during planning of stand management scenarios.

The results for timing of thinning entry and optimal rotation age will change with other site indexes, species composition and mix, logging technology, and delivered prices. However, the impact of site and stand attributes on stand management still remain significant. Other scenarios could be evaluated by making additional simulation runs.

LITERATURE CITED

LeDoux, C.B. 1985. Stump-to-mill timber production cost equations for cable logging eastern hardwoods. Res. Pap. NE-566. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

LeDoux, C.B. 1986. MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management. NE-GTR-112. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

LeDoux, C.B. 1987. Estimating yarding costs for the Clearwater yarder. Res. Pap. NE-609. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

LeDoux, C.B. 1988a. Impact of timber production and transport costs on stand management. Res. Pap. NE-612. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

LeDoux, C.B. 1988b. EASTCOST-- stump-to-mill timber production cost equations and computer program. Unpublished report on file at U.S.Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, 180 Canfield St., Morgantown, WV 26505.

Ohio Agricultural Statistics Service. 1989. Timber Prices. Columbus, Ohio: February. 2 p.

Pennsylvania State University. 1989. Pennsylvania woodlands timber market report. University Park, PA: April-June. 3 p.

Schnur, L.G. 1937. Yield, stand, and volume tables for even-aged upland oak forests. Tech. Bull. No. 560, Washington, D.C: U.S. Department of Agriculture. 87 p.

Smith, H. Clay; Eye, Maxine C.; eds. 1986. Guidelines for managing immature appalachian hardwood stands: Workshop proceedings; 1986 May 28-30; Morgantown, WV. SAF Publ. 86-02. Morgantown, WV: West Virginia University Bookstore. 283 p.

Tennessee Division of Forestry. 1989. Tennessee Forest Products Bulletin. April-June. Nashville, Tenn. 13 p.

U.S. Department of Agriculture. 1981. Proceedings of the national silviculture workshop on hardwood management; 1981 June 1-5; Roanoke, VA. Washington, D.C.: U.S. Department of Agriculture, Forest Service, Timber Management. 304 p.