

ECONOMICS OF HARDWOOD SILVICULTURE USING SKYLINE AND CONVENTIONAL LOGGING

John E. Baumgras

Research Forest Products Technologist
USDA Forest Service
Northeastern Forest Experiment Station
Morgantown, WV 26505

Gary W. Miller

Research Forester
USDA Forest Service
Northeastern Forest Experiment Station
Parsons, WV 26287

Chris B. LeDoux

Supervisory Industrial Engineer
USDA Forest Service
Northeastern Forest Experiment Station
Morgantown, WV 26505

ABSTRACT

Managing Appalachian hardwood forests to satisfy the growing and diverse demands on this resource will require alternatives to traditional silvicultural methods and harvesting systems. Determining the relative economic efficiency of these alternative methods and systems with respect to harvest cash flows is essential. The effects of silvicultural methods and roundwood prices on harvesting revenue are presented for skyline and conventional skidder logging. Silvicultural methods evaluated include single-tree selection, group selection, even-age management, two-age management, diameter-limit cutting, and commercial thinning. Results indicate that harvesting systems had less impact on harvesting revenue than silvicultural methods or roundwood prices, and that hardwood markets can significantly affect economic trade-offs associated with forest management alternatives.

INTRODUCTION

As demands for timber, recreational opportunities, and habitat for wildlife continue to increase, the management of central Appalachian hardwood forests is becoming ever more complex. On public lands, the controversy over clearcutting has caused forest managers to implement silvicultural alternatives that include two-age and uneven-age management. And efforts to maximize the scenic beauty of harvest sites have given added impetus to the adoption of partial cutting practices (Pings and Hollenhorst 1993). Conflicting with the demand for more aesthetically pleasing partial cuts is the desire to regenerate shade-intolerant species such as black cherry and yellow-poplar, which are important to wildlife,

the forest industry, and the biodiversity of the central Appalachian hardwood forests. These diverse demands on the forest resource underscore the need for efficient alternatives to traditional silvicultural methods and harvesting systems.

Increasing concern about soil and water resources as well as the long-term health and sustainability of forest ecosystems also have placed added constraints on harvesting operations. During the 1970's, increased awareness of the environmental impacts of timber harvesting resulted in the reintroduction of cable yarding to the Appalachian region (Patric 1980). Substituting skyline yarders for rubber-tired skidders for steep-slope logging reduced soil disturbance and erosion potential associated with the construction of skid roads required for skidder operations (Kochenderfer and Wendel 1978).

Given these multiple-use objectives, particularly on public lands, determining the relative economic efficiency of alternative silvicultural methods and harvesting systems with respect to harvest cash flows is essential. With this information, forest managers can plan commercial timber sales that meet nontimber goals while yielding sufficient revenue to meet objectives for ecosystem management. Among the more important variables affecting harvesting revenue are silvicultural methods, site quality, harvesting systems, and roundwood markets.

This paper presents results of an economic analysis of alternative silvicultural methods applicable in central Appalachian hardwood stands. Estimates of harvesting cost also are presented for both skyline yarding operations and logging with a conventional rubber-tired skidder.

METHODS

The procedure for estimating harvest cash flows includes determining cut stand attributes from initial stand conditions and silvicultural prescriptions, and then simulating the harvesting of the cut stands to obtain estimates of production rates and yield of roundwood products for each harvesting system (Figure 1). Applying machine cost rates and product prices to simulation results yielded estimates of potential net revenue or stumpage available to landowners from each silvicultural treatment harvested with a skidder or by skyline logging.

Five types of regeneration cuts were evaluated: single-tree selection, group selection, deferment cuts to initiate two-age management, clearcuts for even-age management, and diameter-limit cuts. Each regeneration cut was applied to two stands with site indices (SI) of 64 to 70 (50-year basis for northern red oak) (Table 1). Except for the SI 70 single-tree selection cut, treatments in stands with the same site index were applied to identical initial stand conditions. Data were obtained from stands on the Fernow Experimental Forest and the Monongahela National Forest near Parsons, West Virginia. All stands contained second-growth central Appalachian hardwoods that were regenerated following logging from 1905 to 1910. The most prevalent tree species were white oaks, red oaks, black cherry, yellow-poplar, and maples, with lesser amounts of beech, birch, and hickory.

Also evaluated were two commercial thinnings (Table 1): a 60-year-old cherry-maple stand (SI 75), and a predominantly yellow-poplar and red oak hardwood stand (SI 80).

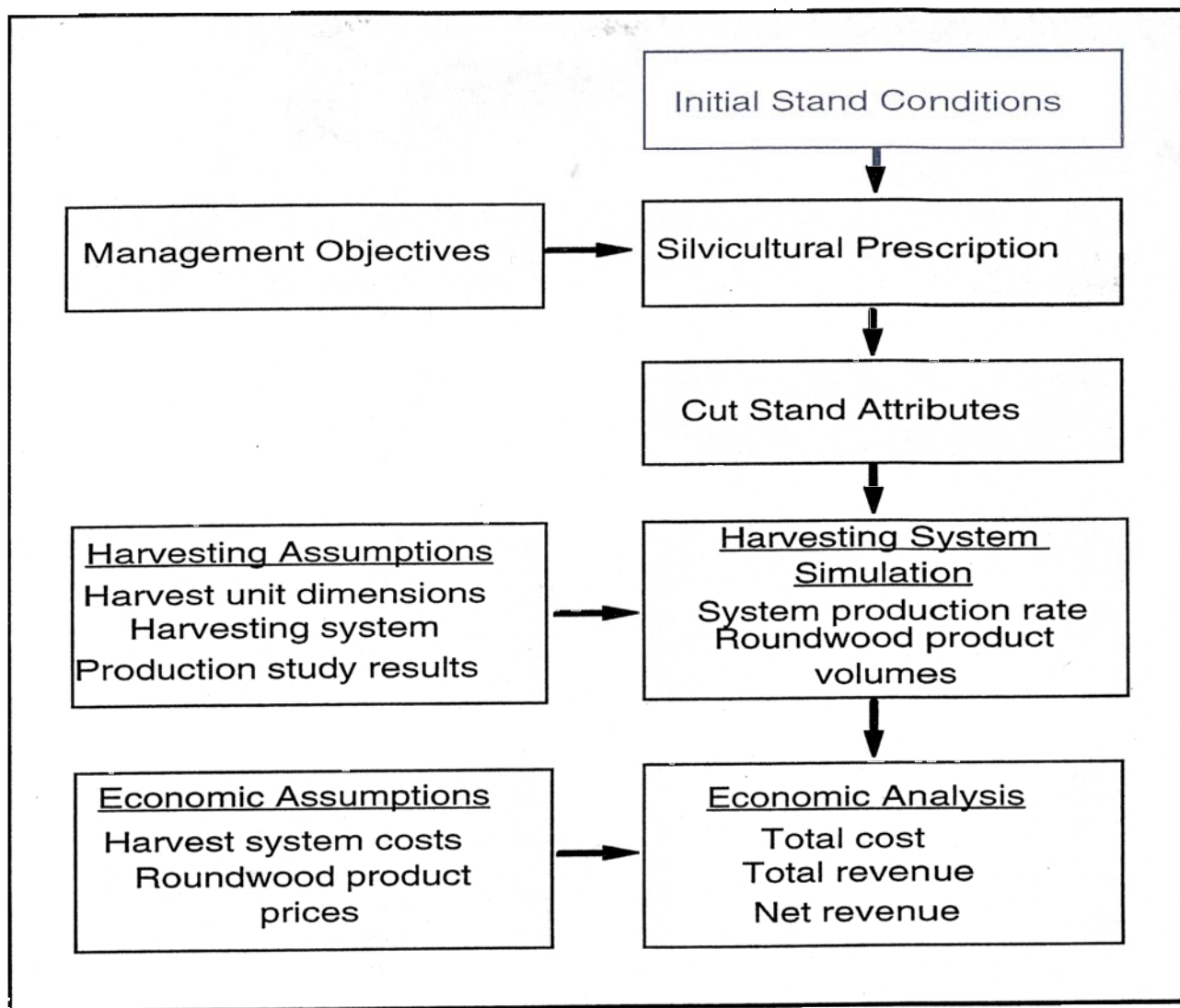


Figure 1: Flow diagram of procedure for estimating net revenue.

The following descriptions of each silvicultural practice include the factors that influenced the marked cut and economic returns:

Single-tree Selection

With single-tree selection, stand characteristics, management objectives, and site productivity are used to establish a residual stand structure that assures sustained yield. The target residual stand structure is defined by residual basal area, largest diameter residual tree, and q-value, which defines how residual trees are distributed among diameter classes (Smith and Lamson 1982). After each periodic cut, the residual stand has essentially the same structure; over time, tree age and dbh are correlated within a species group. Over many periodic cuts, tree recruitment into larger size classes results in sustained yield if reproduction includes commercial shade-tolerant species.

The entry in the SI 64 stand represents the first cut in an 80-year-old even-aged stand. This entry removed 89 trees/acre 5.0 inches dbh and larger with a basal area of 74 ft²/acre (Table 1). The SI 70 cut is the fourth periodic cut in a stand under uneven-age management for 40 years. This entry removed 14 trees/acre 5.0 inches dbh and larger with a basal area of 24 ft²/acre. Removals from the SI 64 and 70 stands included 64 and 12 merchantable trees/acre 8.0 inches dbh and larger averaging 14.2 and 18.7 inches dbh, respectively.

Group Selection

Group selection is similar to single-tree selection in that periodic cuts are used to remove merchantable products, improve growth and quality of the residual stand, and stimulate reproduction after each periodic cut. However, trees are removed in groups, covering areas up to one acre in size. Openings in the canopy are large enough and provide sufficient sunlight for shade-intolerant species to reproduce. Cuts are regulated by methods that control volume coupled with guidelines on residual basal area (Miller and others 1995). Each cut removes the equivalent of stand periodic volume growth. The majority of

Table 1. Stand attributes for five regeneration cuts and two thinnings.

Silvicultural practice	site index	Number of trees/acre			Basal area/acre		
		initial	cut	residual	initial	cut	residual
single-tree selection	64	162	89	73	124	74	50
	70	140	14	126	125	24	101
Group selection	64	162	24	138	124	22	102
	70	173	25	148	142	26	116
Two-age management	64	162	149	13	124	104	20
	70	173	159	14	142	121	21
Even-age management	64	162	162	0	124	124	0
	70	173	173	0	142	142	0
Diameter-limit	64	162	28	134	124	62	62
	70	173	40	133	142	85	57
Thinning (cherry/maple)	75	324	177	147	151	67	84
Thinning (y. pop/red oak)	80	235	146	89	142	81	61

Dbh $\geq$ 5 inches.

the cut is from small group-selection openings in which all trees 1.0 inch dbh and larger are cut. Each opening regenerates after logging, including a variety of desirable species. Over time, the stand is uneven-aged, with many recognizable age classes.

The two group-selection cuts removed 24 and 25 trees/acre with a basal area of 22 and 26 ft²/acre, respectively (Table 1). Approximately 15 percent of the total stand area was harvested, with groups averaging 0.5 acre each. The values for group-selection cuts in Tables 1-3 represent the total stand, not the area within the harvested groups. Removals from the SI 64 and 70 stands included 19 and 18 merchantable trees/acre 8.0 inches dbh and larger averaging 14.6 and 15.6 inches dbh, respectively.

Two-age Management

Two-age management entails leaving 15 to 20 codominant trees/acre and cutting all other trees 1.0 inch dbh and larger. Residual basal area ranges from 20 to 40 ft²/acre depending on the average age and dbh of the residual trees (Smith and Miller 1991). This practice is similar to clearcutting in that both shade-tolerant and shade-intolerant species are abundant and well distributed in the regeneration. Residual trees are selected based on management objectives—sawtimber production, aesthetics, wildlife habitat, or biodiversity. After logging, the stand resembles one that received a seed-tree cut. However, residual trees are retained for many years, sometimes as long as a complete sawtimber rotation (80 years in the Appalachians), at which time the practice is repeated. A two-age stand structure is maintained and two vertical strata usually are visible.

The two-age cuts removed 149 and 159 trees/acre 5.0 inches dbh and larger with a basal area of 104 and 121 ft²/acre, respectively (Table 1). Residual trees ranged from 16 to 20 inches dbh. Removals from the SI 64 and 70 stands included 104 and 100 merchantable trees/acre 8.0 inch dbh and larger averaging 12.9 and 14.2 inches dbh, respectively.

Even-age Management

Under even-age management, all trees are cut every 60 to 80 years depending on site productivity and yield objectives for roundwood products. Areas as large as 25 acres may be cleared in a single operation. Depending on local markets, merchantable stems are removed while all other stems 1.0 inch dbh and larger are cut and left on the site. Natural reproduction after logging is from seedlings and sprouts and includes a variety of species—the more valuable black cherry, white ash, red oak, and white oak.

The clearcuts associated with even-age management removed 162 and 173 trees/acre 5.0 inches dbh and larger with a basal area of 124 and 142 ft²/acre, respectively (Table 1). Removals from the SI 64 and 70 stands included 116 and 114 merchantable trees/acre 8.0 inches dbh and larger averaging 13.5 and 14.4 inches dbh, respectively.

Diameter-Limit Cuts

Diameter-limit cutting is common in the Appalachians, with the buyer and seller agreeing on a lump-sum price for all merchantable timber. All merchantable products that result in a net positive cash flow for

the buyer and/or logger are cut and removed. No marking is required and no effort is made to control residual stocking for sustained yield. Because merchantability usually is determined by local markets and defined by tree dbh, trees equal to or larger than a specific size are removed. Miller and Smith (1993) described a flexible diameter-limit practice that provides for sustained yield and improves residual stand quality, though data on timber inventories and marking of individual trees for harvest are required.

In this analysis, a diameter limit of 15 inches dbh removed 28 and 40 trees/acre with a basal area of 62 and 85 ft²/acre, respectively (Table 1). Removals for the SI 64 and 70 stands averaged 20.1 and 19.6 inches dbh, respectively.

Commercial Thinning

Commercial thinning reduces competition among trees of approximately the same age, increases growth of residual stems, and improves residual stand quality. Thinnings also capture and utilize potential mortality. Logging operations remove one-third to half of the merchantable sawtimber volume plus other roundwood products from smaller trees. Two-thirds of the cut is removed from below and the remainder is removed from above the average stand diameter to maximize sawtimber production.

The two thinnings reduced stocking to 60 percent, removing 177 and 146 trees/acre 5.0 inches dbh and larger with a basal area of 67 and 81 ft²/acre, respectively (Table 1). The thinning in the cherry-maple stand removed 107 trees/acre 8.0 inches dbh and larger (average: 9.5 inches dbh). The thinning on the yellow-poplar and red oak stand removed 97 trees/acre 8.0 inches dbh and larger (average: 11.6 inches dbh).

Harvesting Operations

The conventional harvesting operation included a 90-hp rubber-tired skidder and a crew of three. The skyline yarding operation included a crew of four and a shop-built, two-drum yarder with a 37-foot tower and a gravity outhaul carriage. Both systems included felling with a chain saw. For consistency, it was assumed that both systems used a hydraulic loader/slasher combination to handle log bucking, sorting, and loading.

The harvesting simulations assumed that the skidder worked on skid trails spaced 200 feet apart, with an average one-way skid distance of about 800 feet. Except for the group-selection cut, the skyline yarding simulations assumed that each corridor yarded an area 150-feet wide and 800-feet long. The group-selection cuts were 150 by 150 feet located 400 feet from the yarder. The harvesting simulations also assumed that all designated cut trees 8.0 dbh and larger were harvested and utilized to a 4-inch top diameter. Smaller trees were cut but not skidded or yarded.

The GB-SIM model (Baumgras and others 1993) was used to simulate the ground-based harvesting system. The THIN model (LeDoux and Butler 1981) was used to simulate skyline yarding operations. Both simulations incorporated results of time and motion studies of the machines modeled, conducted on sites similar to those evaluated in this study. Data were obtained on machine cycle-time equations,

delay-time distributions, payload capacities, and time required to change yarding corridors or move the yarder between harvest units.

For this type of comparative analysis, the harvesting simulation allowed standardization of many of the important variables affecting cost and production for all treatments evaluated. It is seldom feasible to conduct production studies for all systems and potential applications. Also, it often is difficult to directly compare field results because of differences between study sites with respect to equipment, crew size, harvest-unit dimensions, topography, and delay times unrelated to silvicultural treatments.

The harvesting simulations estimated production rates and operating hours for each machine type. Using these rates, harvesting costs were calculated using skyline yarder cost rates obtained from USDA Forest Service appraisal guides, and published machine costs and rates for chain saws, skidders, loaders, and trucking (Burgess and Cubbage 1988; Koger 1981). All rates were inflated to 1994 levels using the producer price index for all commodities.

To illustrate the sensitivity of revenue estimates to regional and cyclical variations in roundwood prices, three price levels were applied to each roundwood product. Sawlog prices by tree species and log grade were obtained from published price reports (Pa. State Univ. 1990-1993). On the basis of cumulative frequency distributions of sawlog prices, low prices represented the 20th percentile, medium prices the 50th percentile, and high prices the 80th percentile. A similar process was used for delivered sawbolt and pulpwood prices. The sawbolt classification includes roundwood suitable for the manufacture of low-quality sawn products such as wooden pallets and rustic fencing. The pulpwood classification included roundwood pulpwood, fuelwood, and roundwood for composite panel products.

Net revenue was estimated by subtracting estimated harvesting and hauling costs from the value of the roundwood based on delivered prices. All hauling costs assumed a one-way haul of 40 miles. This residual value approximates the maximum stumpage price consistent with the assumptions of the cost estimates and reported prices.

RESULTS

The volume of wood harvested per acre and average volume per tree harvested are two of the more important variables linking silvicultural treatments and harvesting revenue. Both of these variables affect production rates and roundwood-product yields.

Volumes Harvested

For the five regeneration cuts, volume harvested ranged from 784 ft³/acre for the SI 64 group-selection cut to 5,186 ft³/acre for the SI 70 clearcut (Table 2). Because the two group-selection cuts harvested only 15 percent of the total stand area, yields per acre were relatively low. However, since these cuts targeted patches of the largest or most mature trees, volume harvested per acre for the patches actually cut exceeded the yields from clearcutting by approximately 25 percent. The difference in yields between the two single-tree selection cuts was large because the cut in the SI 64 stand represents the first entry in an 80-year-old stand, while the cut in the SI 70 stand was the fourth entry over a period of 40

years. Compared to clearcutting, the residual trees left under two-age management reduced sawlog volume by 24 percent, and total volume by 16 to 19 percent. By not harvesting trees smaller than 15 inches dbh, the diameter-limit cuts removed 17 to 23 percent less sawlog volume and 31 to 42 percent less total cubic volume than the clearcuts. For all but the single-tree selection cuts, which are not directly comparable, site index had an appreciable impact on yields.

The two thinnings yielded less total cubic volume than all but the single-tree and group-selection cuts. The thinning in the cherry-maple stand yielded less sawlog volume than all treatments (Table 2).

The estimated average volume per tree harvested for the two diameter-limit cuts and the single-tree selection cut in the SI 70 stand were approximately twice that for the other regeneration cuts. Compared to the clearcuts, average volume per tree was approximately 20 percent greater for the group-selection cuts. Comparing two-age and even-age management, the residual sawtimber trees left in the two-aged stands reduced average tree volume by only 5 to 9 percent. Comparison of diameter-limit cuts with even-age management indicates that leaving trees 8 to 15 inches dbh increased the average volume of trees harvested by 44 to 52 cubic feet. As expected, the average volume of trees removed in the thinnings was much less than that for all regeneration cuts.

Average volume per tree harvested is closely correlated with roundwood-product yields; the larger trees yielded proportionately more volume in grade 1 and 2 sawlogs and less volume in sawbolts and pulpwood. For the SI 70 diameter-limit cut and the clearcut, the estimated proportion of total volume in grades 1 and 2 sawlogs was 55 and 38 percent, respectively. Forty percent of the clearcut volume was in sawbolts and pulpwood compared to 28 percent of the total volume harvested with the diameter-limit cut. With trees averaging only 17.0 cubic feet, wood removed from the thinning in the cherry-maple stand was 80 percent sawbolts and pulpwood and only 3 percent grade 1 and 2 sawlogs.

Production Rates

Estimated production rates ranged from 261 to 606 ft³/hour for the skidder operation and 197 to 534 ft³/hour for skyline yarding (Table 2). Thinnings resulted in the lowest production rates, and diameter-limit cuts the highest. These rates reflect estimated machine cycle times, volumes per cycle, and sampled production delay times included in the simulations. Skidder rates also reflect interactions between felling and skidding production rates that result in lost production. For skyline yarding, the entire unit is felled before yarding begins. However, yarding delays can be significant when the skyline is moved between yarding corridors, or when the yarder is moved to the next unit. For each system, the differences in estimated production rates are linked closely with cut stand attributes such as volume harvested per acre and average tree volume. These variables are positively correlated with volume per machine cycle and the resulting production rate.

For the even-age, two-age, and diameter-limit cuts, estimated production rates for skyline yarding were only 5 to 12 percent less than for the skidder operation. Differences between estimated production rates for the two systems were greatest with the single-tree and group-selection cuts. Skyline yarding production was 37 to 42 percent less than skidder production for the group-selection cuts, and 30 to 33

percent less than skidder production for the single-tree selection cuts. The group-selection cuts were constrained to 0.5-acre patches and the single-tree selection cuts removed relatively low volumes per acre. Both cases resulted in a relatively high proportion of potential production time spent changing yarding corridors versus operating the yarder. For these two treatments as well as the two thinnings, reductions in volume per yarder or skidder cycle attributed to low volumes per acre or volume per tree were more pronounced for yarding than skidding. Simulation assumptions based on personal observation allowed the rubber-tired skidder to make two or more hooking and winching cycles per skidding cycle to partially offset the effects of low volume per acre or per tree.

Net Revenues

The combined effects of silviculture and harvesting systems is shown by the estimates of net revenue in Table 3. For each simulated harvest, the difference in net revenue between the two harvesting systems represents the difference in estimated harvesting costs for skidder and skyline logging. Estimated haul costs, approximately \$10/100 ft³, are the same for both systems. Price levels affect net revenue but not the difference in net revenue between harvesting systems.

Table 2. Estimated harvest volumes and system production rates.

Silvicultural practice	Site index	Average volume/ tree ^a ft ³	Sawlog volume ^b bf/ac	Total volume ^c ft ³ /ac	System production ^d	
					skidder	skyline
					-----ft ³ /hr-----	
Single-tree selection	64	41.6	8,569	2,554	524	368
	70	82.5	3,829	954	472	315
Group selection	64	44.5	2,678	784	514	300
	70	54.7	3,602	975	542	340
Two-age management	64	33.8	10,251	3,429	429	382
	70	43.8	14,943	4,341	486	430
Even-age management	64	37.1	13,439	4,230	453	423
	70	45.9	18,180	5,186	506	479
Diameter Limit	64	89.1	10,338	2,466	554	490
	70	90.0	15,011	3,569	606	534
Thinning (cherry/maple)	75	17.0	1,680	1,785	261	197
Thinning (y. pop/red oak)	80	25.6	5,602	2,401	361	284

^aDbh ≥ 8.0 inches.

^bInternational 1/4 inch log scale.

^cWood and bark, trees dbh ≥ 8 inches to 4-inch top.

^dVolume per scheduled hour.

For the five regeneration cuts, the differences in harvesting costs between systems ranged from \$86/acre for the SI 64 diameter-limit cut to \$199/acre for the SI 70 two-age cut. For the two thinnings, differences in net revenue attributed to harvesting systems ranged from \$217 to \$244/acre. In all cases, skyline yarding costs were highest. These differences in harvesting costs per acre reflect different production rates shown in Table 2 as well as differences in fixed and operating costs and in volume per acre harvested for each silvicultural treatment.

The relative reduction in net revenue attributed to harvesting systems depends on the silvicultural treatment and price levels for roundwood. With medium prices, skyline yarding versus skidder logging reduced net revenue per acre by 4 to 15 percent; the lowest impact was associated with the diameter-limit cuts and the highest with the group-selection cuts. Skyline yarding reduced net revenue from the group-selection cuts by 20 to 30 percent with low prices versus only 8 to 9 percent with high prices.

Except for the thinning in the cherry-maple stand, all other treatments yielded a positive cash flow at all price levels (Table 3). However, the cost estimates do not include possible additional costs associated with timber sale administration, cruising, marking, consultation and legal fees, truck-road and skid-trail construction, or best management practices (BMP) compliance. Because these costs are highly variable and often site-specific, they were omitted from the analysis. In some harvesting situations, net revenue with low to medium prices for the group-selection cuts and thinnings may not cover these additional costs.

The effects of silviculture on net revenue is most pronounced with high rather than low prices. With the latter, estimated net revenue for the five regeneration cuts and skidder logging ranged from \$293 to \$2,095/acre (Table 3). This spread increased to \$2,769/acre with medium prices, and \$4,501/acre with high prices. As expected, the single-tree and group-selection cuts with shorter cutting cycles and more frequent periodic incomes yielded the lowest net revenue per entry. For the SI 70 stands, all price levels, and both harvesting systems, single-tree selection cuts provided 25 to 30 percent of the revenue available under even-age management. Group-selection cuts harvested 15 percent of the stand area and returned 19 to 22 percent of the net revenue available under even-age management.

Comparing all revenue estimates for two-age versus even-age management indicates that leaving residual sawtimber trees to improve visual quality reduced net revenue by \$377 to \$481/acre with low prices and \$1,050 to \$1,177/acre with high prices. Although the clearcuts conducted with even-age management netted more revenue than the diameter-limit cuts, this advantage is contingent on efficient multiproduct harvesting and marketing sawbolts and pulpwood. Otherwise, the added cost of removing small trees to regenerate an even-age stand likely would reduce net revenue below that estimated for diameter-limit cuts.

In affecting volume per acre and average volume per tree, site index also affected estimated net revenue. With medium prices, the difference in estimated net revenue between site index 64 and 70 was \$139 to \$142/acre for the group-selection cuts, and \$626 to \$641/acre under even-age management (Table 3).

Because of relatively high harvesting costs and low product values, the cherry-maple thinning required high prices to net more than \$250/acre. With larger trees and higher volumes, net revenue from the

Table 3. Estimated net revenue^a for skidder and skyline logging at low, medium, and high prices.

		<u>Low price</u>		<u>Medium price</u>		<u>High price</u>	
Silvicultural practice	Site index	Skidder	Skyline	Skidder	Skyline	Skidder	Skyline
		-----Dollars/acre-----					
Single-tree selection	64	896	724	1853	1681	3178	3006
	70	614	518	978	882	1409	1313
Group selection	64	293	204	591	502	1006	917
	70	463	371	733	641	1165	1072
Two-age management	64	916	748	2019	1851	3598	3430
	70	1636	1437	2668	2469	4457	4258
Even-age management	64	1293	1131	2719	2557	4769	4607
	70	2095	1918	3360	3183	5507	5330
Diameter-limit	64	1184	1098	2310	2224	3829	3743
	70	1657	1539	3199	3081	5356	5238
Thinning (cherry/maple)	75	-27	-271	246	2	786	542
Thinning (y. pop/red oak)	80	264	47	716	499	1661	1444

^aValue of roundwood delivered to the mill minus harvesting and haul cost.

thinning in the yellow-poplar and red oak stand generally was comparable to that for the group-selection cuts.

CONCLUSIONS

Given the inherent variability of timber harvesting costs and revenue and the number of important assumptions required to conduct this type of comparative analysis, the results presented here demonstrate only the potential effects of the silvicultural methods and harvesting systems we evaluated. On the basis of comparisons of estimated net revenue for skyline yarding and conventional skidder logging, it seems that using a skyline yarder to reduce soil disturbance would not appreciably reduce revenue for the five regeneration cuts evaluated. Differences in estimated net revenue between harvesting systems generally were much smaller than those attributed to silvicultural methods or price levels for roundwood. However, the added cost of skyline yarding combined with low roundwood prices could limit the application of this technology for thinning operations. It is important to recog-

nize that the use of skyline yarding can be constrained by irregular topography, the location of existing truck roads, and the number of logging contractors who use this technology.

The alternative price levels for roundwood did not alter the relative ranking of regeneration cuts by net revenue. However, roundwood prices had a significant effect on the magnitude of the differences in net revenue estimated for each silvicultural treatment. These results clearly indicate that hardwood markets significantly affect the economic trade-offs associated with forest management decisions. Although results represent only one entry, the magnitude of the differences among forest management options may well influence the decisions of private forest land owners with relatively short planning horizons.

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*PROCEEDINGS OF THE TWENTY-THIRD
ANNUAL HARDWOOD SYMPOSIUM*

*Advances in Hardwood Utilization:
Following Profitability from the Woods
Through Rough Dimension*

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