HARDWOOD SILVICULTURE AND SKYLINE YARDING ON STEEP SLOPES:

ECONOMIC AND ENVIRONMENTAL IMPACTS

John E. Baumgras[1] and Chris B. LeDoux[2]

Abstract: Ameliorating the visual and environmental impact associated with harvesting hardwoods on steep slopes will require the efficient use of skyline yarding along with silvicultural alternatives to clearcutting. In evaluating the effects of these alternatives on harvesting revenue, results of field studies and computer simulations were used to estimate costs and revenue for skyline yarding operations. The methods evaluated include group selection and three treatments each for conventional shelterwood, thinning, diameter limit, and irregular shelterwood to initiate two-age management. Harvesting costs ranged from \$15.97 to \$42.22/100 ft^3, gross revenue from \$59 to \$131/100 ft^3, and net revenue from \$58 to \$2,809/acre. Environmental impacts observed at field sites and those reported in the literature indicate that relatively low levels of soil disturbance and residual stand damage can be achieved with skyline yarding.

INTRODUCTION

Public concern about the clearcutting of eastern hardwoods, combined with contemporary forest management issues such as ecosystem management have encouraged forest-land managers to consider alternative silvicultural practices and harvesting systems. Alternatives for even-age management include shelterwood and group selection, while irregular shelterwood (deferment) cuts can be used to initiate two-age management. In sawtimber stands, thinning can yield the volumes of sawlogs required for commercial operations. While often criticized, diameter-limit cuts are perhaps the most popular option on private forestland.

The adverse visual impact of large clearcuts has been a major source of public concern. Forested landscapes are affected by the size of clearcut units and the percentage of the viewing area that has been harvested (Palmer and others 1993). Interior views of harvested stands were evaluated for six silvicultural methods ranging from clearcutting to single-tree selection. Scenic beauty increased with residual basal area and years elapsed since harvesting, and decreased with amounts of logging slash (Pings and Hollenhorst 1993). Modifying the size and spatial relationships of harvest units and/or using silvicultural practices other than clearcutting can ease public concerns about timber harvesting.

The growing emphasis on maintaining the productivity and sustainability of forested ecosystems makes protection of soil and water resources an increasingly important issue. Efforts to reduce environmental impacts are primarly responsible for the reintroduction of cable yarding to the eastern hardwood region (Patrick 1980). Using a skyline yarder versus rubber-tired skidders can greatly reduce the need for truck roads and skid trails. (Kochenderfer and Wendel 1978) and significantly reduce the amount of bare or compacted soil within harvest units (Swanston and Dyrness 1973).

Until recently, commercial application of skyline yarding in the Appalachian hardwood region was confined largely to relatively large clearcut units. However, case studies in Pennsylvania (Fairweather 1991) and West Virginia (Wendel and Kochenderfer 1978) indicate that light to moderate residual stand damage is possible with cable yarding in partial cuts of hardwood stands on steep slopes.

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[1]Research Forest Products Technologist, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505.

[2]Supervisory Industrial Engineer, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505.

To reduce the environmental and visual impacts of harvesting timber on steep slopes in the Appalachian hardwood region, unconventional applications of cable yarding technology will be required to implement the silvicultural practices that the public now demands. Although harvesting revenue is not the sole consideration in forest management decisions, commercial timber sales are needed to meet goals related to ecosystems management objectives on public lands. And because cash flows remain critical to harvesting decisions on private lands, harvesting economics is an important consideration in selecting harvesting systems and silvicultural practices for steep-slope hardwood sites.

METHODS

Computer simulation was used in a sensitivity analysis of harvesting costs and revenues for 13 silvicultural treatments. Simulation allowed standardized production assumptions to be applied to all treatments and provided estimates of cost and revenue for hypothetical treatments.

The information required to simulate specific harvesting operations was obtained through field studies of skyline yarding operations. A conventional shelterwood harvest, an irregular shelterwood harvest (deferment cut), and a thinning were monitored at a study site on the Nantahala National Forest near Franklin, North Carolina. The three 6- to 8-acre units were located in a yellow-poplar, red oak, and white oak stand, with a site index of 80 (50-year basis for northern red oak) on slopes of 30 to 50 percent. All units were yarded with an inexpensive shop-built yarder rigged with a 30-foot tower and a gravity outhaul carriage. Also studied was the use of a commercial skyline yarder in four group-selection units at a site on the Pisgah National Forest near Asheville, North Carolina (LeDoux and others 1991). Loggers at both study sites harvested pulpwood and sawlogs from trees 8 inches and larger in dbh. Cycle-time equations were developed and additional data obtained on yarding delay times and causes and times to rig skylines and change landings. We also developed stand tables for both the initial and cut stands.

Because of important differences between study sites and among harvesting units at each site with respect to equipment, unit dimensions, crew size, and delay times unrelated to silvicultural treatments, observed production rates and costs were not directly comparable. As a result, comparison of yarding production and costs for silvicultural alternatives was standardized using simulation models calibrated on observed production rates (using cycle-time equations) and delay times obtained from field data.

Silvicultural Treatments

The 13 treatments evaluated include the three treatments observed at the Franklin site: conventional shelterwood (stand 1), irregular shelterwood (stand 2), and thinning (stand 3). The initial attributes of these stands were similar (Table 1). The scope of the sensitivity analysis was broadened to include treatments that were not observed at the Franklin site but could be implemented to satisfy alternative ownership or ecosystem management objectives. These hypothetical treatments were developed using initial stand tables from the Franklin site and modifying the cut-stand tables from the observed treatments.

The conventional shelterwood harvest observed at the Franklin site removed approximately 70 percent of the initial basal area of trees 7.5 inches and larger in dbh. Alternatives that removed approximately 30 and 50 percent of initial basal area from the smaller diameter classes represent treatments required to obtain oak regeneration on medium to good sites (Schlesinger and others 1993). For the three conventional shelterwood treatments, the mean dbh of harvested trees ranged from 11.9 to 17.1 inches (Table 2).

The irregular shelterwood or deferment cut was applied to initiate two-age management. The observed harvest of stand 2 (Table 1) removed all but 20 ft^2/acre of basal area, leaving mostly trees that were 8 to 18 inches in dbh. Two variations of the observed treatment were developed by modifying the diameter distribution of the residual basal area, leaving trees 12 to 22 and 20 to 30 inches in dbh, respectively (Table 2). For these three treatments, the mean dbh of trees harvested ranged from 15.3 to 17.1 inches. The different treatments could affect the visual quality of the residual stand, or reflect the scheduled harvest of residual trees. If the residual stand were to remain until the next crop matures, residual trees would be smaller than trees left to be harvested in the next 20 to 40 years.

Table 1.--Initial attributes of timber stands at the Franklin study site

Stand	No. trees/ per acre[a]	Basal area[a]	Mean dbh	Merchantable volume[b]
		ft^2/acre	inches	ft^3/acre
1	76	117	16.8	3,669
2	77	111	16.3	3,378
3	73	119	17.2	3,773

[a]Trees ≥ 7.5 inches in dbh.
[b]Volume of wood and bark to merchantable top ≥ 4.0 inches diameter (inside bark).

Equal amounts of basal area also were removed in all three thinnings. The observed thinning (essentially a thinning from above) removed 47 ft^2/acre of basal area in trees with an average dbh of 17.8 inches (Table 2). Modifying the diameter distribution of trees removed from stand 3 (Table 1) produced thinnings with cut trees averaging 13.7 and 15.1 inches in dbh (Table 2). These two alternatives would concentrate growth on the largest trees and help create an "old growth" or park-like appearance. Thinning trees with a mean dbh of 13.7 inches also produced a cut stand similar to that resulting from thinning in younger sawtimber stands.

Two types of silvicultural treatments not observed at the Franklin site--group-selection and diameter-limit harvests--also were evaluated using the initial stand tables for stands 1, 2, and 3. Because results were similar, only those from stand 1 are presented. The diameter-limit cuts were evaluated with dbh limits of 12, 15, and 18 inches. The group selection harvested all trees 7.5 inches and larger in dbh. Management alternatives for applying group selection include the size of openings created and the spatial relationships between units. For this analysis, openings of 0.23, 0.92, and 2.75 acres were evaluated; the 0.23- and 0.92-acre openings were located at varying distances from the yarder landing.

Economic Analysis

Production rates for cable yarding were estimated with THIN, a computer simulation model (LeDoux and Butler 1981). The simulations applied the yarder cycle-time equation developed for the shop-built yarder observed at the Franklin site, as well as delay times that included a standardized component for all silvicultural treatments and a delay component unique to each treatment. The yarding corridor was standardized at 150 ft by 800 feet (2.75 acres). In addition, group-selection cuts also were simulated for openings of 100 by 100 feet and 200 by 200 feet. These openings were located 100 to 700 feet from the yarder landing. The times to move the yarder to a landing and to change corridors at each landing were standardized using the average of times recorded on all units at the Franklin site. The log populations required for each THIN simulation were obtained from cut-stand tables unique to each treatment; it was assumed that stems were bucked to a maximum log length of 32 feet as observed at the Franklin site.

Felling and limbing production rates, log populations for the THIN simulations, and yields of roundwood products were estimated with GB-SIM, a harvesting simulation model developed for ground-based harvesting systems (Baumgras and others 1993). Because felling and limbing generally are completed before yarding begins, felling and yarding production can be simulated independently. Inputs to these simulations include the cut-stand tables specified for each silvicultural treatment. GB-SIM uses tree-taper equations developed for Appalachian hardwoods to estimate log lengths and volumes. Equations for estimating percentages of trees by tree grades, and sawlog volumes by log grade also are used by GB-SIM to estimate sawlog yields by species and grade.

Table 2.--Attributes of cut stands resulting from conventional shelterwood, group selection, and diameter limit applied to stand 1, irregular shelterwood applied to stand 2, and thinnings applied to stand 3.

Treatment	No. trees per acre	Basal area	Mean dbh	Volume per acre	Average volume per tree
		ft^2/ac.	inches	---------ft^3----------	
Conventional Shelterwood[a]					
Cut 70%	50	80	17.1	2,519	50.4
Cut 50%	44	53	14.9	1,614	36.7
Cut 30%	36	28	11.9	817	22.7
Irregular Shelterwood[b]					
Lv. trees 8-18 inches	58	91	17.1	2,852	49.2
Lv. trees 12-22 inches	63	91	16.3	2,728	44.0
Lv. trees 20-30 inches	71	91	15.3	2,711	39.3
Thinning[c]					
17.8 inches $\bar{X}$ dbh	27	47	17.8	1,556	57.6
15.1 inches $\bar{X}$ dbh	38	47	15.1	1,493	41.5
13.7 inches $\bar{X}$ dbh	46	47	13.7	1,327	32.3
Group Selection[d]	76	117	16.8	3,669	48.3
Diameter Limit[e]					
12 inches dbh	52	99	18.6	3,311	63.7
15 inches dbh	38	86	20.2	2,911	76.6
18 inches dbh	25	67	22.2	2,299	91.9

[a]Percentage of initial basal area.
[b]Dbh of residual trees.
[c]Mean dbh of cut trees.
[d]Volume/acre from groups harvested, not entire stand.
[e]Minimum tree dbh harvested.

Production rates for log bucking and loading estimated from results of production studies (Baumgras and LeDoux 1989) indicate that these rates would greatly exceed simulated yarder production for all treatments. Since bucking and loading production would be constrained by yarding production, fixed costs and wages for yarding, bucking, and loading were allocated to production at the rate estimated for yarding. Felling and limbing costs were based on production rates simulated for these functions. Rates for wages and equipment costs were obtained from USDA Forest Service appraisal guides and published rates for chain saws, loaders, and trucking. All rates were inflated to 1994 levels using the Producer Price Index for all commodities.

Estimated logging costs represent the sum of felling, limbing, yarding, bucking, and loading costs. Net revenue represents the gross value of roundwood products delivered to the mill minus logging and hauling costs. Delivered prices for sawlogs and pulpwood represent median prices obtained from published price reports (Pa. State Univ. 1990-93; Tenn. Div. For. 1990-93) (Table 3). The estimates of haul cost assume a 40-mile haul distance.

Table 3.--Roundwood product prices applied to economic analysis

	Sawlogs[a]			
Species	Grade 1	Grade 2	Grade 3	Pulpwood[b]
		Dollars/mbf		Dollars/100 ft^3
White oak	325	185	100	45
Red oak	485	285	125	45
Yellow-poplar	175	125	85	45
Other hardwoods	190	140	85	45

[a]Factory grade sawlogs, USDA Forest Service grades 3 or better, scaling diameter ≥ 10 inches.
[b]Roundwood with diameter inside bark ≥ 4 inches, not meeting the quality or dimension requirements for sawlogs.

Environmental Impacts

Environmental impacts were monitored on the shelterwood and thinning units harvested at the Franklin site. Soil disturbance was surveyed by sampling disturbance classes (Dyrness 1965) at 5-foot intervals along 50-foot random azimuth transects. Residual stand damage was sampled by recording damage to trees located on 1/10-acre plots after felling, and again after yarding. To assess visual quality before and after harvesting, oblique aerial photographs were taken of each harvest unit.

RESULTS

Stand Attributes

Because the three initial stands in Table 1 are similar and 7 of the 13 treatments evaluated were applied to stand 1, differences between stands harvested were largely a function of the silvicultural treatments. For the diverse array of treatments estimates of volume harvested ranged from 817 ft^3/acre for the 30-percent shelterwood harvest to 3,669 ft^3/acre for the group selection (Table 2). Average volume per tree harvested ranged from 22.7 ft^3 for the 30 percent shelterwood to 91.9 ft^3 for the 18-inch diameter-limit cut.

Differences among the three treatment levels evaluated for each of four silvicultural methods were most pronounced for the conventional shelterwood cuts: volume harvested ranged from 817 to 2,519 ft^3/acre, and average volume per tree ranged from 22.7 to 50.4 ft^3 (Table 2). The three diameter-limits also had a large impact on attributes of the cut stand. Increasing the diameter limit from 12 to 18 inches dbh reduced the volume harvested by 30 percent, but increased average tree volume by 44 percent. The three irregular shelterwood cuts showed the least amount of variation. With only 20 ft^2/acre of basal area, the diameter distribution of the residual trees had minimal impact on volume harvested (2,711 to 2,852 ft^3/acre) and average volume per tree (39.3 to 49.2 ft^3).

Cost and Revenue

The results in Table 2 show how the selection and application of silvicultural methods can affect critical attributes of the harvested stand component. These attributes, especially volume per acre and volume per tree, are closely correlated with harvesting system production and costs, and with product yields and revenue.

The sensitivity of cost and revenue to silvicultural treatments is most evident from estimates of net revenue that range from $58 to $2,809/acre (Table 4). The 12-inch diameter-limit, group-selection, and 15-inch diameter-limit cuts produced the largest estimates of net revenue, $2,809/acre, $2,789/acre, and $2,712/acre, respectively. The two lowest estimates resulted from the 30-percent removal shelterwood ($58/acre), and the thinning of trees averaging 13.7 inches dbh ($382/acre).

The heavy stocking of large trees and the substantial component of high-value oaks contributed to relatively low harvesting costs and high revenue per unit of volume. Given the assumptions of the analysis, estimated revenue generally exceeded costs by such a wide margin that the economic feasibility of 11 of 13 options tested was not a critical issue. Four of the 5 silvicultural methods and 7 of the 13 specific treatments yielded more than $2,000/acre.

The key attributes of logging-machine production cycles form the link between harvesting conditions and harvesting-system production. Although machine cycle times generally increase with average tree volume and/or numbers of trees per cycle, the relative gains in volume exceed the increases in cycle times. Consequently, production rates generally increase with trees/acre, volume/acre, and volume/tree. These relationships are modeled by the THIN and GB-SIM programs.

The lowest harvesting costs are associated with the highest volumes per acre. In the case of the three conventional shelterwood cuts, reducing volume per acre from 2,519 to 817 ft^3 and average volume per tree from 50.4 ft^3 to 22.7 ft^3 (Table 2) more than doubled harvesting costs (Table 4). When only the diameter distribution of basal area removed in thinning was altered, the changes in volume/acre and volume/tree caused logging cost to increase by 46 percent, from $21.50 to $31.45/100 ft^3.

Another important element in the net revenue equation is the value per unit of production, represented by gross revenue in Table 4. Because larger diameter trees generally yield higher proportions of merchantable volume in grade 1 or 2 sawlogs, gross revenue is highly correlated with the mean dbh or average volume of trees harvested. Although the tree and log-grade estimates incorporated in this analysis are not completely site specific, they represent observed stand attributes and well-documented relationships among tree species, dbh, and sawlog quality. Estimated gross revenue ranged from $59 to $131/100 ft^3 (Table 4), reflecting the estimated grade distribution of sawlogs and the proportions of sawlog and pulpwood volume. The percentage of sawlog volume in grade 1 logs ranged from 10 to 38. The percentage of merchantable volume in pulpwood ranged from 13 to 59.

Estimates of cost and revenue for the group-selection cut (Table 4) represent a 150- by 800-foot (2.75-acre) opening adjacent to the landing. Because the cost of changing landings or rigging the skyline to yard each unit is largely independent of unit area, smaller units result in higher costs per unit volume for moving the yarder and changing corridors. Depending on the location of the unit (100 to 700 feet from the landing), yarding a 100- by 100-foot (0.23-acre) unit increased costs by $14 to $22/100 ft^3 over those for the 2.75-acre unit. In this comparison, net

Table 4.--Simulated yarding production, estimated logging costs, gross revenue, and net revenue

Treatment	Yarder production[a]	Logging cost[b]	Gross revenue[c]	Net revenue[d]
	$ft^3/hr.$	Dollars/100 ft^3		Dollars/acre
Conventional Shelterwood				
Cut 70%	416	20.55	113	2,069
Cut 50%	336	25.48	98	1,004
Cut 30%	193	42.22	59	58
Irregular Shelterwood				
Lv. trees 8-18 inches	465	19.01	116	2,481
Lv. trees 12-22 inches	400	21.14	114	2,245
Lv. trees 20-30 inches	347	23.37	99	1,788
Thinning				
17.8 inches $\bar{X}$ dbh	426	21.50	124	1,441
15.1 inches $\bar{X}$ dbh	332	25.72	98	927
13.7 inches $\bar{X}$ dbh	257	31.45	70	382
Group Selection	454	18.77	105	2,789
Diameter Limit				
12 inches dbh	504	16.84	111	2,809
15 inches dbh	555	16.41	120	2,712
18 inches dbh	608	15.97	131	2,407

[a]Delay-free production rate.
[b]Total cost to fell, limb, yard, buck, and load.
[c]Average value of sawlogs and pulpwood delivered to mill.
[d]Gross revenue - logging cost - haul cost x volume/acre.

revenue is reduced by $513 to $789/acre. Compared to the 2.75-acre unit, a 200- by 200-foot (0.92-acre) unit located 300 to 600 feet from the landing increased costs by $5 to $8/100 ft^3 and reduced estimated net revenue by $163 to $174/acre. These comparisons do not include the additional cost of locating harvest units, planning yarding corridors, or locating the landings required to harvest numerous small units scattered throughout a larger harvest area. Also, the estimates of net revenue reported for group-selection cuts represent dollars from each acre actually harvested. Because the entire stand would not be harvested with each entry, net revenue per acre for the entire stand would be much lower than net revenue per acre harvested. For example, given a 20-year cutting cycle and a 100-year rotation such that 20 percent of the stand is cut each entry, net revenue per entry for the entire stand would be 20 percent of that estimated for each acre actually harvested.

The values in Table 4 for the group-selection cut represent harvesting the entire 2.75 acre-corridor. With respect to estimated costs and revenue per acre harvested, this is equivalent to a conventional clearcut. Expressing net revenue as a percentage of that estimated for this group selection cut illustrates the relative impacts of silvicultural alternatives to large-opening group selections or clearcuts (Fig. 1). Five of the 12 alternatives evaluated yield more than 80 percent of the revenue available from clearcutting. However, four alternatives yield less than half of the net revenue available from clearcutting, two less than 15 percent, and one only 2 percent.

Environmental Impacts

Analysis of data on soil disturbance at the Franklin site revealed no difference between the observed shelterwood and thinning treatments with respect to percentage of area in each soil-disturbance class. Deep soil disturbance and deep disturbance combined with visible soil compaction was found on 10 percent of the area. Most of this occurred within the yarding corridors, the extraction path between the tailhold and the yarder. Seventy-one percent of the area showed no disturbance.

The results of the stand damage surveys indicate that logging damage was significantly greater on the two shelterwood units than on the thinning unit. Sixteen percent of the residual trees were destroyed on the conventional and irregular shelterwood units compared to only 5 percent on the thinning unit. On the two shelterwood units, 13 percent of the trees received bark wounds larger than 100 square inches, versus only 1 percent on the thinning unit. Other damage, small bark wounds and abrasions and broken limbs, affected 51 percent of trees on the shelterwood units versus 36 percent on the thinning units.

Trees destroyed were uprooted or broken off, generally during felling operations. Most of the large bark wounds occurred during yarding operations, with frequency increasing with proximity to yarding corridors. Much of the difference between damage on the shelterwood and thinning units can be attributed to the heavier removals on the shelterwood units (Table 2). It is important to note that trees on the thinning unit were felled by an experienced crew while the felling crew on the two shelterwood units included relatively inexperienced chain-saw operators.

From the oblique aerial photos of the three harvested units at the Franklin site it is difficult to distinguish the thinning unit from the adjacent uncut area. The observed conventional shelterwood cut and the irregular shelterwood cut were visible on the photos, though there was much less contrast between the cut and adjacent uncut areas than would be apparent with a clearcut.

DISCUSSION

Each of the 13 silvicultural treatments evaluated represent different forest management objectives or desired future conditions. Consequently, the estimated cash flows are not intended for ranking or selecting treatments. Nonetheless, efficient management requires an understanding of the relationships between silvicultural prescriptions and harvesting revenue. Whether timber sales represent an important source of revenue or a means of managing vegetation, costs and revenue from harvesting operations play an important role in forest operations.

Results of the cash-flow analysis demonstrate the sensitivity of cost and revenue to silvicultural treatments: logging costs ranged from \$15.97 to \$42.22/100 ft^3, gross revenues from \$59 to \$131/100 ft^3, and net revenues from \$58 to \$2,809/acre. Due to the composition of the initial stands, the group-selection, diameter-limit, and heavy shelterwood cuts all yielded large cash flows. However, treatments requiring significant reductions in harvested volume per acre and/or volume per tree resulted in large reductions in estimated net revenue--as much as \$2,011/acre for the conventional shelterwood cuts and \$1,059/acre for thinnings. There also were significant variations in net revenue resulting from location and dimensions of the group-selection units. The estimates of harvesting cost and net revenue reflect the relatively low cost of a shop-built yarder, which is commonly used in southern Appalachia.

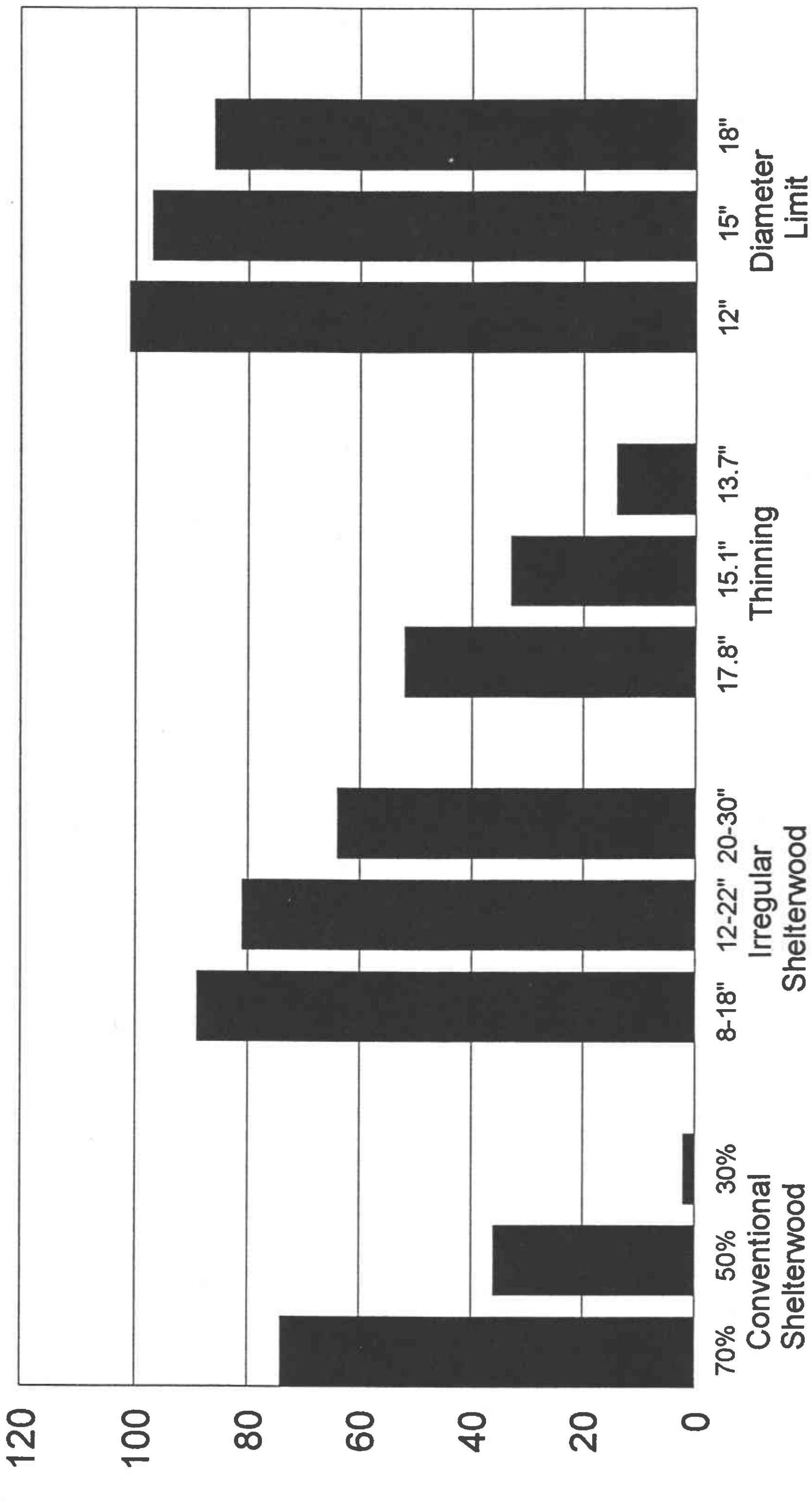

Figure 1. Percentage of net revenue available from the 2.75-acre group-selection cut; for conventional shelterwood removing 30, 50, and 70 percent of basal area; irreguar shelterwood leaving trees 8 to 18, 12 to 22, and 20 to 30 inches dbh; thinning removing trees averaging 17.8, 15.1, and 13.7 inches dbh; and diameter-limit cuts to 12, 15, and 18 inches dbh..

Compared to conventional ground-based harvesting systems operating in large clearcut units, the harvesting system and silvicultural treatments evaluated in this study provide an opportunity for significant reductions in environmental impacts associated with harvesting timber on steep slopes. Levels of soil disturbance and compaction sampled on observed shelterwood and thinning units were similar to those reported for western skyline operations (Swanston and Dryness 1973), less than those reported for ground-based systems (Hatchell and others 1970), and considerably less than those reported for mechanized whole-tree harvesting systems (Martin 1988). Observations at the Franklin site also indicated that soil disturbance on specific yarding corridors could have been reduced further by rigging the skyline for more lift and bucking large stems to lighten payloads. Effective application of cable yarding requires expert sale layout skills to locate yarder landings and yarding corridors that provide the skyline deflection required to allow the yarder to operate and to minimize soil disturbance.

Harvesting damage to residual trees can affect the health and value of future stands. The light damage on the observed thinning unit was similar to that reported for partial cuts in hardwoods harvested with rubber-tired skidders (Nyland and Gabriel 1971) and skyline yarders (Fairweather 1991). The heavier damage on both observed shelterwood units was comparable to that reported for conventional ground-based systems used in heavy shelterwood cuts in hardwoods (Nichols and others 1993).

Cable yarding in a variety of silvicultural treatments in Appalachian hardwoods (Wendel and Kochenderfer 1978) resulted in less stand damage than was observed for the thinning or shelterwood units at the Franklin site. These low levels of damage resulted from wide yarding corridors being felled before yarding, and directional felling to minimize felling damage and facilitate yarding stems through standing timber. Yarding damage also can be moderated by logging during the dormant season, or allowing for damage when marking the cut trees and then harvesting heavily damaged trees before moving the yarder to the next corridor. Radio-controlled carriages can be positioned to select the best extraction path to laterally yard logs to the skyline corridor. Forest managers also need to recognize the potential for stand damage when prescribing silvicultural treatments, especially where large-diameter trees or trees with large tops are harvested. Although residual stand damage is unavoidable, attaining acceptable levels of damage requires only that the condition of the residual stand satisfies silvicultural objectives.

Visual quality is one of the more important reasons why many forest managers are seeking alternatives to clearcutting. Compared to clearcut units, aerial photos of the Franklin site indicate an enhanced visual quality of harvested units, especially the thinning unit. Although interior views were not evaluated at the Franklin site, results reported by Pings and Hollenhorst (1993) contrast scenic values of interior views for similar silvicultural treatments. On a scale of 1 to 10, uncut areas rated 7.17 versus 5.12 for clearcuts. Ratings for other silvicultural treatments were 6.28 for thinnings, 6.22 for shelterwood, and 5.55 for irregular shelterwood. Cable yarding also improves the visual quality of harvest sites by eliminating the highly visible network of skid trails on steep hillsides.

As increasingly stringent constraints are imposed on harvesting practices, the more important it will be to recognize the implications of these constraints with respect to the economic feasibility of specific treatments and the tradeoffs among management alternatives. Skillful planning of timber sales and effective control of harvesting operations will allow forest managers to meet both environmental and silvicultural objectives.

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