REMOVAL INTENSITY AND TREE SIZE EFFECTSON HARVESTINGCOST AND PROFITABILITY

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ABSTRACT

Sixteen stands were harvested at intensities (proportion of basal area removed) ranging from 0.27 to 1.00. Logging contractors used chain saws and rubber-tired skidders. Harvested sites were similar in slope and tree size. Harvest cost per hundred cubic feet of wood (CCF) was' inversely related to harvest intensity and tree size. Harvesting profitability per CCF was near zero when removing trees averaging less than 8 inches diameter at breast height (DBH). Harvest intensity had the greatest influence on profitability in small-diameter timber. Harvest profitability was greatest when removing large trees at high levels of harvesting intensity. Because of the differences in averagetreesizeremoved by different harvesting prescriptions, some prescriptions were more profitable than others. Most profitable for harvesting contractors in our study was single-tree selection in an uneven-aged stand. Less profitable were selection in an even-aged stand, clear cutting, and shelterwood harvests, in that order. Selection at low removal intensities with small trees removed would always be the least favored harvest method with the equipment spreads we observed. Average removed tree size needed to be at least 8 inches DBH to break even.

Profitability of harvesting operations is of prime concern to harvesting contractors, mill operators, and forest managers. Con&actors are concerned with meeting payrolls, paying banknotes, and securing the long-term health of their businesses. Mill operators wrestle with providing an adequate supply ofraw material into mills at reasonable costs. Landowners desire maximum returns for stumpage, the value ofwhich is often calculated as the residual of mill average cost, minus cut-and-haul price. This study focuses on the position of the independent harvesting contractors who must successfully negotiate with a mill representative regarding the delivered price for his products, cover all harvesting and transport costs, and also purchase stumpage to harvest.

Harvesting contractors participate as suppliers in a purely competitive market. Their products are purchased by mills that frequently display oligopsonistic purchasing power because of low value-to-weight ratios inherent to harvested roundwood. Because of high hauling Costs, contractors are often effectively limited in the number of markets to which they may deliver their products. In most cases, mills are price makers; contractors, having limited negotiating power, are price takers. However, for the astute contractor, cut-and-haul margins arc generally sufficient to cover all fixed and variable costs of production as well as realize an adequate return on capital to prompt reinvestment.

The first two papers in this three-part series outlined the forest stand and operational characteristics that influence process cycle time and productivity for manual felling and mechanical skidding." Both of those studies verified the importance of the traditionally accepted variables of diameter at breast height (DBH) and inter-tree distance for felling; and, skidding distance, DBH, and number of stems pulled per cycle for skidding. Additionally, those studies investigated the effect of harvesting intensity (proportion of the stand basal area removed), on process cycle time and productivity. These studies also found that for moderately mechanized harvesting operations, those where felling was performed manually with a chain saw, three distinct operational types were present: 1) grapple skidders; 2) cable skidders operating in the presence of grapple skidders; and

[1] Kluender, K.. D. Lortz, W. McCoy, B. Stokes, and J. Klepac. 1997. Productivity of rubber-tired skidders in southern pine forests. Forest Prod. J. 47(11/12): 53-58.

[2] Lortz, D., R. Kluender, W. McCoy, B. Stokes, and J. Klepac. 1997. Manual felling time and productivity in southern pine forests. Forest Prod. J. 47(10):59-63.

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TABLE 1. — Descriptive information for the 16 stands studied.

Stand no. and year	Harvest method	Proportion of basal area removed	Average DBH removed
			(in.)
91-01	Clearcut	1.00	11.4
92-04	Clearcut	1.00	10.4
92-05	Shelterwood	0.71	10.6
91-02	Shelterwood	0.57	10.4
93-08	Group selection	0.62	10.9
93-07	Group selection	0.4s	11.7
93-09	Single-tree	0.45	13.5
92-06	Single-tree	0.43	13.7
93-10	Single-We	0.32	13.9
91-03	Single-tree	0.31	10.7
93-11	Single-tree	0.31	11.8
93-12	Single-tree	0.30	12.2
93-13	Single-tree	0.27	12.3
94-14[a]	Single-tree, uneven-age	0.36	15.5
94-15[a]	Single-tree, uneven-age	0.32	15.5
94-16[a]	Single-tree, uneven-age	0.27	16.0

[a] These three stands were well-balanced uneven-aged stands. All others were even-aged.

3) cable skidders operating solo. These three different operating groups not only displayed significantly different production characteristics, but also gave rise to widely differing cost and profitability structures.

This study utilizes the results of the productivity studies. With those, we use constant costs for loading and hauling to investigate the relationship between the identified operational and stand factors and total cost and profit per unit volume.

METHODS

STAND TREATMENTS

A wide range of harvest intensities was examined. Clearcutting and single-tree selection methods represented extremes in harvest intensity, while shelterwood and group selection harvests represented intermediate treatments. Table 1 shows the method of harvest, harvest date, harvest intensity, and average DBH removed. The proportion of basal area removed was used as an index of harvesting intensity for each stand. The stands were composed primarily of shortleaf pine (*Pinus echinata* Mill.) and loblolly pine (*Pinus taeda* L.). There was a small hardwood component in all stands that was judged to have no effect on cycle time or productivity. The three stands harvested in 1994 were of uneven-aged structure, while the other 13, harvested in 1991 to 1993, were even-aged.

ESTIMATED TIME AND PRODUCTIVITY TO FELL AND SKID

Equations for estimating operational cycle time and productivity for felling and skidding are reproduced here from the previous reports in this series. All productivity estimates are in CCF per productive machine hour.

The key variables for predicting both total cycle time and productivity for felling were: DBH, harvest intensity, and inter-tree distance. Skidding operations were grouped by the way in which skidders were used: 1) grapple skidders; 2) cable skidders operating with grapple skidders; and 3) cable skidders operating independently. Grapple skidders tended to have higher productivity rates than cable skidders, but cable skidders operating in the presence of grapple skidders tended to have higher productivity than cable skidders operating alone. For grapple skidders and cable skidders operating with grapple skidders, round-trip skid distance, number of stems hauled, and harvest intensity were important in predicting total cycle time. One additional variable, DBH, was added to predict productivity for these machines. For the low-productivity operations, which included only cable skidders operating alone, key variables for prediction of process cycle time were total round-trip skid distance, number of stems per load; and skidder horsepower. These same variables, with the addition of DBH, were most important in predicting productivity for this class of skidder operation. A more complete description of the differences in the two groups was presented in the report on skidding factors.[2]

Felling

$$Total\ Cycle\ Time = 0.049 \times DBH^{1.338} \times DISTANCE^{0.083} \times INTENSITY^{-0.196}$$

$$\frac{CCF}{HR} = 1.959 \times DBH^{0.668} \times DISTANCE^{-0.083} \times INTENSITY^{0.196}$$

$r^2 = 0.55$ $\quad n = 1145$

All Grapple Skidders

$$Total\ Cycle\ Time = 1.415 \times TDIST^{0.574} \times STEMS^{0.100} \times INTENSITY^{-0.113}$$

$$\frac{CCF}{HR} = 0.077 \times TDIST^{-0.574} \times DBH^{2.002} \times STEMS^{0.865} \times INTENSITY^{0.113}$$

$r^2 = 0.50$ $\quad n = 542$

Cable Skidders Operating With Grapple Skidders

$$Total\ Cycle\ Time = 2.140 \times TDIST^{0.399} \times STEMS^{0.190} \times INTENSITY^{-0.325}$$

$$\frac{CCF}{HR} = 0.046 \times TDIST^{-0.399} \times DBH^{2.041} \times STEMS^{0.766} \times INTENSITY^{0.325}$$

$r^2 = 0.61$ $\quad n = 315$

Cable Skidders Operating Solo

$$Total\ Cycle\ Time = 83.626 \times TDIST^{0.453} \times STEMS^{0.295} \times HP^{-0.758}$$

$$\frac{CCF}{HR} = 0.002 \times TDIST^{-0.453} \times DBH^{1.814} \times STEMS^{0.471} \times HP^{0.758}$$

$r^2 = 0.64$ $\quad n = 240$

where:

Total Cycle Time = process cycle time (min.)

$\frac{CCF}{HR}$ = productivity in *CCF* per hour

DBH = stem diameter breast height (4.5 ft. above ground) (in.)

Distance = inter-tree distance (ft.)

INTENSITY = proportion *BA* removed

TDIST = skidding distance (100 ft. stations)

STEMS = number of stems in load

HP = skidder horsepower

HARVESTING COSTS

Harvesting costs, expressed in dollars per CCF, for both felling and skidding were developed by the general formula:

$$\frac{\$}{CCF} = \frac{\frac{\$}{Hour}}{\frac{CCF}{Hour}}$$

where:

$\frac{\$}{CCF}$ = cost in dollars to produce one CCF of wood

$\frac{\$}{Hour}$ = cost in dollars to operate a machine 1 hour

$\frac{CCF}{Hour}$ = productivity of a machine or phase

This relationship is customarily used as an expression of cost per unit of wood produced and is dependent on machine productivity and cost to operate. Machine operational costs were developed for a representative chain saw ($17.55/hr.), and skidder (95-hp, grapple, $46.20; 95-hp\cable, $44.75; 79-hp cable, $35.56) by using a machine rate calculation method.[3] The following assumptions were used to complete the estimated productivity equations (except for DBH and Intensity). For felling, 78 feet inter-tree distance (DISTANCE) was assumed. All skidders were assumed to have a 13.1 100-foot-station round-trip skidding distance (TDIST). For grapple skidders, an average load size of 4.19 STEMS pulled per cycle was assumed. Cable skidders in the presence of grapple skidders were assumed to be 95 hp and pulled 3.7 STEMS per cycle. Cable skidders operating independently were assumed to have 79 hp and pulled 2.677 STEMS per load. Cost to load was assumed to be $4.75/CCF and hauling (for a simulated 45-mile one-way trip to deliver logs to a mill) was assumed to be $7.45/CCF for all three systems. The estimated cost per CCF for these two phases was assumed constant since neither loading nor hauling were influenced by stand parameters or the harvest prescription.

PROFITABILITY

The nonlinear cost models for skidding and felling were combined with calculated estimates for loading and hauling costs to give total harvesting cost. Loading costs and hauling costs were held constant across all diameters and harvest intensities. Delivered market price and stumpage values by product class were estimated from proprietary market information for the harvest region and are shown in Table 2. Total logging cost added to stumpage value produced total harvest cost. Delivered market price minus cut-and-haul costs and stumpage value yielded profit.

RESULTS

HARVESTING PRESCRIPTIONS

Productivity of a harvesting operation is determined by several factors including the harvesting prescription and the harvest equipment to be employed. The harvesting prescription is derived from the silvicultural prescription that specifies the trees to be removed from the stand. This, in turn, determines the average DBH of the harvested trees and the proportion of the stand to be removed. Both tree size and harvest intensity directly influence productivity of the harvesting operation.

In addition to the stand factors, productivity is a function of the harvesting machinery selected and the way it is operated on the harvesting site. Equipment and operational factors that affect productivity include horsepower, grapple or choker capacity, and average skid distance for skidders, and saw weight and power for chain saw operations.

The previous two papers in this series detailed the relationship of stand, equipment, and operational factors on felling and skidding productivity. The following analysis combines these and demonstrates their effect on harvesting cost and profitability.

HARVESTING COSTS

Figure 1 shows the operational cost (including felling, skidding, loading, and hauling cost in $/CCF) for a 95-hp grapple-skidder operation at three intensities of harvest. Note that operational cost varies little for harvesting stems above about 12 inches DBH. Cost is relatively flat through a broad range of diameters (above 12 in. DBH); there is very little difference across the three harvesting intensities. Only in the smaller diameter classes (below 10 in. DBH) does intensity play an important role in determining cost for this type of operation.

Figure 2 shows the operational cost for a cable skidder (95-hp) operating in the presence of grapple skidders. Harvest intensity plays a much more important role, compared to the grapple-skidder operation, especially in smaller diameters, where costs decrease with increasing harvest intensity.

Operational cost for cable skidders not in the presence of grapple skidders (79-hp), is displayed in Figure 3. The operational pattern of these skidders was significantly different from cable skidders operating in the presence of grapple skidders. These skidders were smaller than those used with grapple skidders and they tended to haul not more than four stems, and then only smaller DBH stems. Although cost per CCF decreased exponentially as diameter increased for the other operational groups, harvest intensity was not a significant factor in determining operational productivity or cost for this type of operation. The number of stems hauled per turn, however, was a major factor in determining productivity and cost.

The cost of stumpage, by product class, is outlined in **Table 2.** These product stumpage and mill delivered prices were obtained in an informal proprietary survey in 1994, concurrent with the final harvesting operations. They represent regional averages during the period that our 16 study stands were being harvested, and thus, representative stumpage costs and mill delivered prices that contractors would confront in making operational and business decisions.

Contractors purchasing their own stumpage to harvest must deal with landowners to procure an adequate supply of timber. These operators are faced with a more complex cost structure than those contractors who perform cut-and-haul operations. **Figure 4** depicts the total cost (operational cost + stumpage) per CCF

TABLE 2. — Assumed product specifications, stumpage, and delivered prices.[a]

Product	DBH range	Stumpage price	Mill delivered price	Margin
	(in.)	($/CCF)		
Pulpwood	6 to 9	17	57	39
Chip and saw	10 to 13	72	113	41
Sawlogs	14 to 21	98	145	47
Veneer logs	22 to 26	111	162	51

[a] Stumpage and mill delivered prices used here were obtained from a proprietary survey conducted in 1994 concurrent with the final harvesting operations.

[3] Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. Gen. Tech. Rept. NC-55. USDA Forest Serv., North Central Expt. Sta., St. Paul, MN. 16 pp.

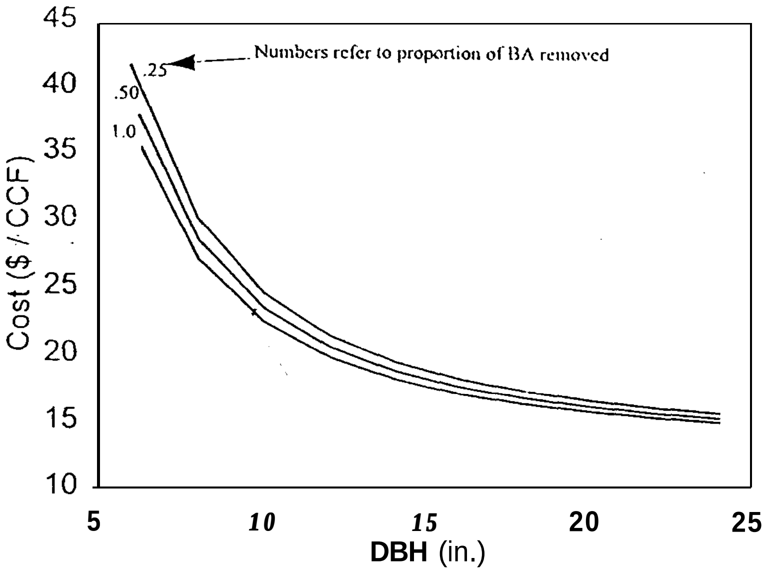

Figure 1. — Harvest operational cost per CCF for a 95-hp grapple-skidder operation by harvest intensity and DBH. Cost includes felling, skidding, loading, and hauling.

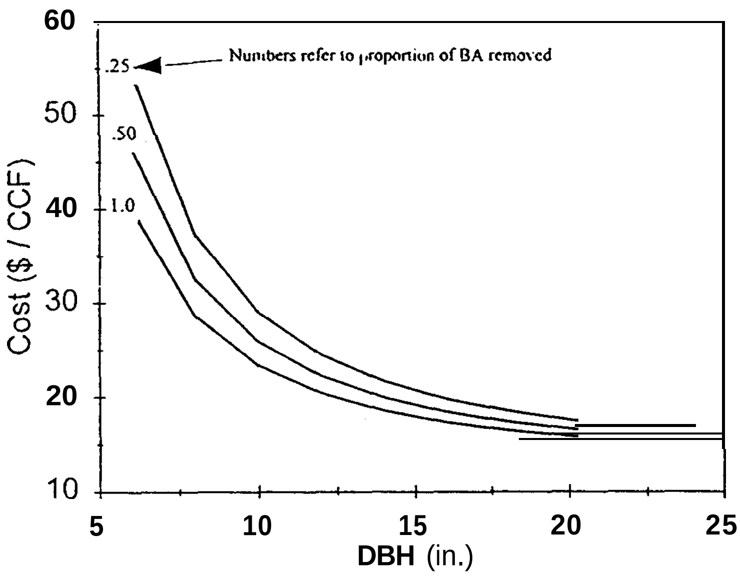

Figure 2. — Harvest operational cost per CCF for a 95-hp cable-skidder operating in the presence of grapple skidders, by harvest intensity and DBH. Cost includes felling, skidding, loading, and hauling.

for a 95-hp skidder operation for three levels of harvest intensity. Note that major cost jumps come with increases in DBH. These jumps are attributable to differing stumpage cost by product class. Thus, total cost increases dramatically when moving to the next higher product class: but then slowly declines within that class due to the effect of decreasing operational costs as DBH increases (small declines within product classes). This general pattern existed for all operational types. Harvest intensity had almost no effect on total harvesting cost across all product classes. The marginal effect of harvesting intensity on total harvest costs was apparent only below 8 inches DBH.

Harvesting profitability

For a cut-and-haul contract, title to the timber never passes to the contractor, who is customarily paid a flat amount per CCF to fell, process, and deliver stems to mill specifications. Figure 5 depicts the estimated profit conditions for an assumed cut-and-haul contract price of $30/CCF ($70/MBF). Note that profit is the inverse of the operations cost structure shown in Figure 1. Profit rises exponentially with increasing DBH, but increases at a decreasing rate after the 12-inch DBH class. Harvesting intensity has only a minor effect, with profit increasing with increasing intensity. Cut and haul contractors who process and deliver small diameter stems with an average harvested DBH less than 8 inches could not profitably operate within the $30/CCF contract price, and would require a higher cut-and-haul allowance. For independent contractors who purchase their own stumpage and sell it processed at mill delivered prices, the question of profitability is more complex.

Profitability for harvesting contractors who purchased stumpage and sold finished logs to a mill is depicted in Figure 6 (95-hp grapple-skidder operation). Profit is the difference between total harvesting costs (Fig. 4) and the delivered market price (Table 2). Harvesting profit per CCF always increased within a product class due to decreasing cost with tree size. Relative profitability across product classes was a function of the market demand by product. Higher value product classes tended to have higher profit margins. Stem diameter was critical to harvesting profitability in that it determined the product class as well as harvest cost. The relative importance of diameter on profit within a product class was greater for the small-diameter products than for the large-diameter products. The effect of harvest intensity generally diminished with increasing average harvested tree size (DBH). These results are highly dependent on the market structure (stumpage and delivered prices) at any given time and the operational cost of harvesting.

Discussion

Harvest cost

Harvest cost is determined by the harvesting prescription (silvicultural objectives) and the operational limitations of the equipment selected. For the 16 operations observed, tree size (DBH) was the significant single determination factor when other factors, such as skid distance and load size, were held constant. As productivity increased with

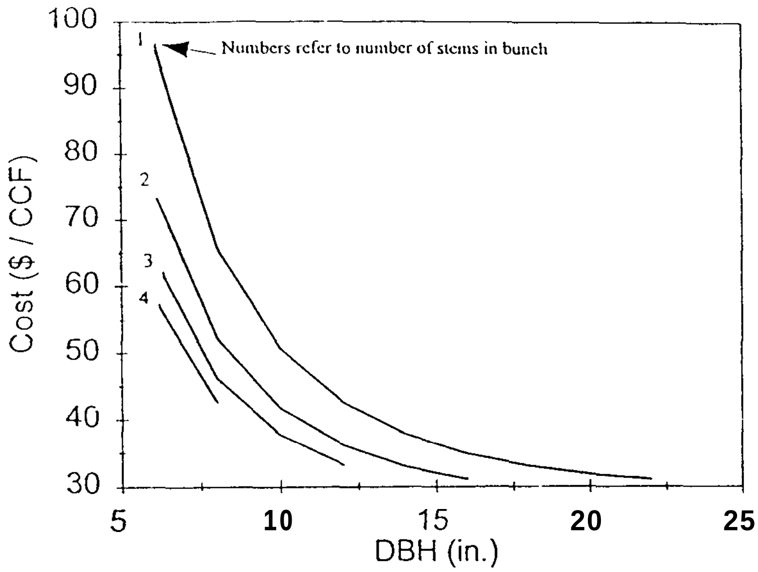

Figure 3. — Harvest operational cost per CCF for a 79-hp cable-skidder operating solo, by harvest intensity and DBH. Cost includes felling, skidding, loading, and hauling.

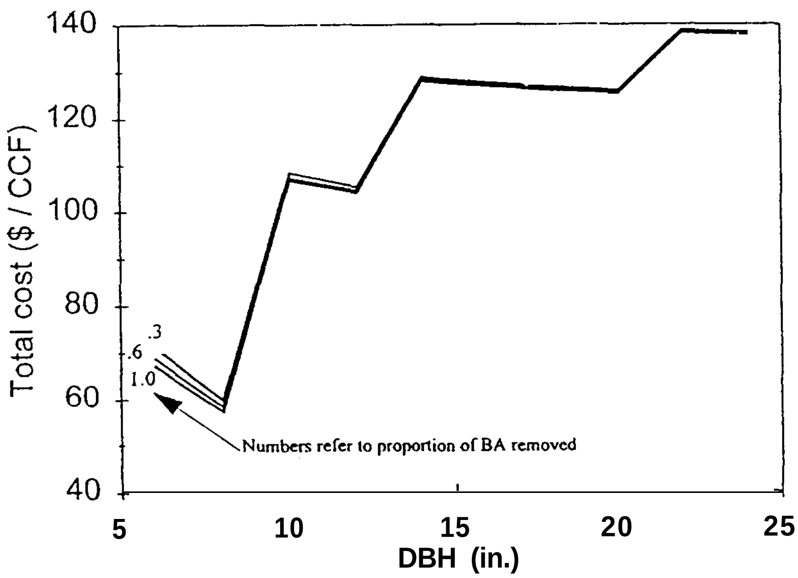

Figure 4. — Total cost (stumpage + operational cost) for a 95-hp grapple skidder operation, by harvest intensity and DBH.

DBH, cost per unit volume ($/CCF) decreased. For the grapple skidders and the cable skidders operating in the presence of grapple skidders, cost changed little above an average tree size of 12 inches DBH. The principal reason for this is that fewer stems were required to build a bunch when larger stems were hauled.

Differences in harvesting cost for grapple skidders and cable skidders operating with grapple skidders were obvious, especially in the smaller diameters. This was primarily due to the time spent in building bunches. For example, a grapple skidder could build a bunch relatively rapidly by moving each stem to a collection point, and then picking up the multistem bunch. However, cable-skidder operators tended to not drop the stems that they had picked up, but relied on the flexibility of the fairlead to allow hooking of additional stems to build a bunch. This activity required getting off the skidder and pulling the choker to the logs, thus, increasing time per **cycle,** decreasing **productivity, and** increasing **cost.**

HARVEST PROFITABILITY

Harvest profitability will, by definition, be governed by market conditions. Specifically, the spread between stumpage and mill delivered price is extremely important to the contractor who purchases his own stumpage. Profit **will also** be influenced **by** the same factors that increase or decrease harvesting cost, including size of trees being removed and the harvest intensity of the logging prescription. At times, market conditions will favor certain products over others. It is possible for the difference between stumpage and delivered price (Margin ($/CCF) in **Table 2) to** be higher in a middle product size class than in a high product size. The prices used in this study, however, showed a steady increase in margin with product class.

Removing larger trees within a product class will reduce logging costs per unit of volume and therefore increase profit. When this is coupled with product class price jumps, profit can increase significantly, since the change in logging costs across the larger diameter classes is relatively small **(Fig. 1).**

High harvest intensities produced higher levels of profitability in all product classes and for all diameters. The marginal profit gain by harvest intensity was higher in the small-diameter classes than for larger stems. For example, the zero profit line cuts the profit lines **in Figure 6** at about 6 inches. But, profit was positive only at the higher intensities. Thus, in the pulpwood class, harvest intensity determined whether the operation made or lost profit. Finally, independent contractors engaged in cut-and-haul operations, are not faced with managing procurement functions, but rather act as independent agents of a mill to perform a service. Larger profit margins for these individuals are the reward for judicious cost management rather than the vagaries of the market.

THE EFFECT OF HARVESTING PRESCRIPTION

Profitability for four harvesting prescriptions is shown in Figure 6. In harvests where the average tree size removed is 12 inches DBH, clearcutting (Fig. 6, A) is more profitable than selec-

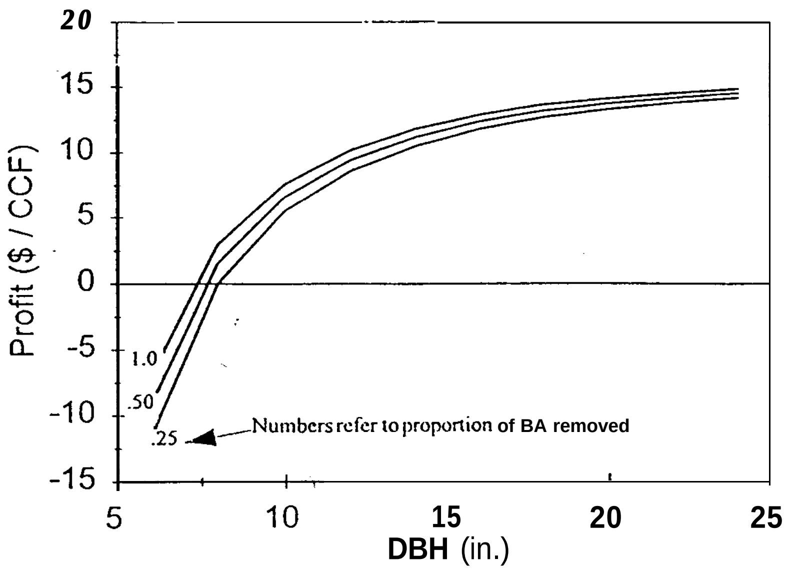

Figure 5. — Estimated profit **for a cut-and-haul contractor using a 95-hp grapple-skidder operation, by harvest intensity and DBH.**

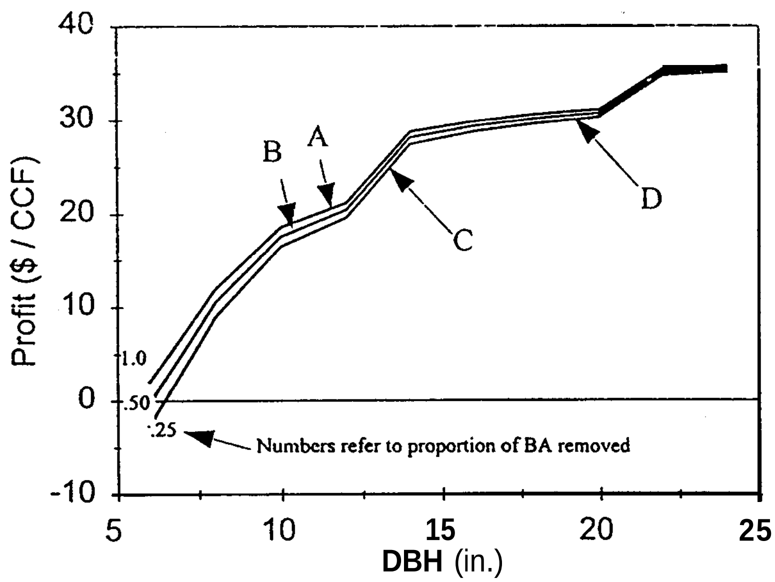

Figure 6. — Estimated profit for an independent contractor who purchases stumpage, harvests, and delivers logs to a mill, by harvest **intensity and DBH. A= clearcut; B = shelterwood;** C = even-aged selection; D = uneven-aged selection harvests.

tion harvests (1 .0 vs. .25 proportion **of** basal area removed). Above about 12 inches average DBH, however, this advantage is very minimal (i.e., the lines get closer together). In shelterwood harvests (Fig. 6, B), which remove about .70 of basal area, and average 10 to 11 inches DBH, profit would be less than clearcutting. Shelterwood harvests are characterized by a substantial number of dominant trees left on the site. The remaining overstory can be as much as 40 percent of the pre-harvest basal area.

For selection harvest (.33 of basal area removed) in an even-aged stand (Fig. 6, C), with an average harvested DBH of 13 inches, profit was higher than for clearcutting or for shelterwood. Selection harvests in even-aged stands are performed to reduce basal area, as thinnings from above to remove crop trees and to release co-dominant trees. Generally, when thinning from above, the average DBH of the harvest is greater than the average DBH of all trees in the stand. This is reflected by the DBH of the harvested stems being slightly larger than those of the clearcut. Selection harvest of an uneven-aged stand (Fig. 6, D) would take only the largest of the trees present (.33 proportion of basal area removed). Thus, an 18-inch average DBH of harvested stems is reasonable. This type of harvest is clearly the most profitable of the four examples depicted **here.**

CONCLUSIONS

Central to the long-running discussion of even-aged vs. uneven-aged management has been the question of how well harvesting contractors will fare if pressured into harvesting solely on a selection basis. The results of this study show that, with the exception of low intensity thinnings of small trees, harvesting cost and profit are within normal ranges and quite acceptable for a broad range of harvesting conditions. While it is obvious that harvest layout is easier for a clearcut prescription, other factors in selection harvests (especially tree size) may more than make up for any losses due to reduced harvest intensity.

The harvesting operations that we observed were all outfitted similarly. They utilized one or two chain saws to fell the trees, one or two skidders to pull the stems to the deck, a loader, and sufficient trucking to keep the operation fluid. Had the operation been configured differently, for example, with a feller buncher of high capital cost that bunched the stems for skidding, the economics and profitability of the harvest might have been significantly different. Analysis of the effect of stand and harvesting prescription clearly needs to continue with different equipment mixes and in a broader variety of stand conditions. Only with a much broader set of observations can all questions be answered definitively.