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Cover: Cutter using chainsaw with felling frame attachment. Note bunch being formed at right.

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The observations herein were made and are published in English units to facilitate application by foresters and logging contractors in the northeastern U.S. To convert to metric units:

1 acre = 0.4 hectares
1 foot = 0.3 meters
1 pound = 0.45 kilograms
1 inch = 2.54 centimeters
1 foot^2 = 0.093 meter^2
1 ton = 0.907 metric ton

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ABSTRACT

This study evaluated precommercial, full-tree thinning of saplings and small poletimber (1-8 inches dbh) using chainsaws and modified farm tractors for skidders. To facilitate cutting large numbers of small trees (1-5 inches), the chainsaw was fitted with a felling frame. The cutter felled and manually bunched up to 145 trees/2.7 tons per productive man-hour. Average production, assuming 73% efficiency, was 90 trees/1.8 tons per scheduled hour at a cost of $6.22/ton. Skidding was done by a two-wheel drive grapple skidder and a four-wheel drive farm tractor with double-drum winch. The grapple skidder produced 3.8 tons per scheduled hour at a cost of $8.25 per ton, assuming a 75% utilization rate. The cable skidder produced 4 tons per scheduled hour at a cost of $7.00/ton; preset chokers increased production to 4.7 tons/hour at a cost of $5.96. The key to production was a modified herringbone pattern of corridors which facilitated skidder access to the wood. The weakest link in the operation was the difficult, labor-intensive work of felling and bunching.

INTRODUCTION

The spruce-fir forests of Maine are characterized by prolific regeneration from advance growth and, consequently, by overstocking. A major part of the fiber produced by these stands is lost to suppression mortality as most trees die from competition before they become merchantable. Because of spruce budworm infestations early in this century, the area of dense, small-diameter stands is quite large.

As a result of natural stand development, exacerbated by budworm, Maine's foresters face the problem of managing thousands of acres of spruce-fir forests which are cluttered with small trees, living and dead. Densities of 2,000 to 6,000 trees per acre with mean stand diameters of 2-4 inches are common. While it is desirable to salvage this prospective mortality early in the rotation, these small trees cannot be economically harvested with conventional logging equipment. Further, given tree rooting habits and shallow, often poorly drained soils, such machinery may damage the soil and residual trees.

Silvicultural research has repeatedly shown the superiority of selection over strip thinning. Selection permits fairly consistent spacing of better quality, more vigorous trees for future growth. This is difficult in dense stands because of the lack of suitable harvesting equipment, hence more costly manual logging methods are required. With mechanical methods, access strips for harvesting equipment must be cut. Many good trees are taken from the strips, many poor ones are left between, spacing is variable, and future yields and quality are not maximized.

Based upon experience in Maine using winches, economic removal of small trees seemed feasible by widening corridors to permit a skidder to back part of the way into the stand. With selection between corridors, acceptable thinning could be effected. Though trees less than five inches in dbh have not been salable, projected demands for biomass fuel in Maine indicate that markets will develop within three to five years. The ability to harvest small trees would add to available fiber and improve the potential for managing problem stands.

Literature Review

Ten softwood stands in eastern Maine ranging in density from 800 to 4400 stems per acre were thinned in order to study the effects of density on harvesting productivity (Hoffman 1982b). First, all trees less than four inches dbh were cut and bunched for extraction by a portable winch. In the denser stands, this submerchantable, often dead material amounted to as much as 46.5 green tons (roughly 23 cord equivalents) per acre. By the time these stands matured, about 41 tons of this biomass would be lost to mortality.

Aside from the value of the biomass in the 10 stands cited above, reducing obstacles to logging lowered the commercial thinning cost by $89.33 per acre (Hoffman 1985) in one stand. Such small material has been shown to reduce feller-buncher productivity by up to 20% (Granskog and Anderson 1981), and "preharvest" of small trees for fuel has been used to reduce costs of clearcutting merchantable wood in the South (Ford 1982).

Lehtonen (1976) described the Jaaranen-Rantapuu felling frame (cover photo) which permits a chainsaw operator to control the saw at ground level using a metal frame held at waist height. The device allows control of the saw with the right hand while using the left to direct the fall of the severed tree. One can also set the saw aside and use both hands to push or drag the tree into a bunch. Hakkila et al. (1977, 1979) described the felling frame use in early thinning and determined that it increased chainsaw productivity by 20-30% in trees up to four inches in dbh. A small feller-buncher was more economical in larger diameters. In 1984 there were about 200 felling frames in use in Finland.[1]

Schaafsma and Hoksbergen (1980) compared production of felling frames, chainsaws and spacing saws in stands of different densities and species. At densities of 2200-2600 trees per acre, the felling frame was most productive. The spacing saw was faster in higher densities, but trees cut with spacing saws cannot be readily piled for extraction.

Use of the felling frame in Maine was described by Sarna (1978) and production rates of 2.12 tons per worked hour were reported by Hoffman (1982b). A technique for using the tool in northeastern softwood stands is described by Hoffman and Mills (1983).

In Finland, bundles of small trees cut with the felling frame are extracted by winch or long-reach booms, followed by forwarding (Hakkila 1982). Forwarding of full trees in Scandinavia is facilitated by the use of grapple saws to cut them to suitable lengths.

Hoffman (1982b, 1983b) reported on the winching of small trees to trailside. His analysis suggests that winching costs are too high for such low-valued products and need to be eliminated.

Seymour and Gadzik (1985), studying commercial thinning in northern Maine, compared production, cost and stand damage for a rubber-tired skidder in both bunched (by winch) and unbunched wood. Though the skidder moved loads of up to three cords of prebunched stems, prebunching was not clearly better than skidding properly felled wood from the stump on preplanned trails. Further, skidding damage to residual trees was minimal.

Hoffman (1982a) studied the productivity of a small, two-wheel drive grapple skidder in Maine and Louisiana. Its low cost, high speed, light weight and small size seemed promising for thinning.

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[1] Hakkila, Pentti. 1984. Personal communication.

METHODS

An overstocked softwood stand on the Northern Experimental Forest of International Paper Company, in Edinburg Township, was selected for this study. The site was level but very poorly drained, best operated in winter when the soil was frozen and snow-covered. The only obstacles to equipment operation were occasional boulders and large pine stumps.

The stand was about 6 acres in size and had been harvested in the early 1950's to remove white pine. It was composed largely of spruce-fir with an overstory of pine which was too small to harvest three decades earlier. Species composition was 96% softwood, ranging in size from one to 15 inches in dbh.

One section of the stand, about an acre in size, was selected for study and all trees one inch in dbh and larger were inventoried. As trees were tallied, they were marked with a paint code so that their sizes could be identified during time studies of cutting. Since dead conifers are suitable for wood pulp and fuel (Chase and Young, 1976), they were included. Such trees have the added value of higher BTU values for fuel than do green stems.

Stand Characteristics

The data in Table 1 portray the stand before and after cut. The cut removed 46.7 green tons of biomass per acre, corresponding closely with the 46.5 tons of "submerchantable and dead material in the more dense stands" reported by Hoffman (1982).

Several points relative to logging productivity bear emphasis:

1) One-inch trees comprised 20.4% of the total number; dead trees in this class constituted 19.8 % of the trees in the stand.
2) One-inch trees comprised 28% of the number of trees cut, but contributed only 3% of the biomass removed.
3) If the dead tree biomass is reduced by needle mass, the one-inch trees contribute only 2.6% of the total weight.

Although only the intermediate and suppressed crown classes were removed, the crown release of remaining trees and the effects on increasing

Table 1. Stand structure before and after cut, showing cutting yields.

DBH (In.)	NUMBER OF TREES PER ACRE							CUMULATIVE CUT		BIOMASS REMOVED[1]	
	LIVING		DEAD		TOTAL						
	Precut	Postcut	Precut	Postcut	Precut	Postcut	Cut	No.	%	LBS.	%
1	22.4	7.1	706.1	10.2	728.5	17.3	711.2	711.2	28	2845	3.0
2	291.8	19.4	716.3	7.1	1008.1	26.5	981.6	1692.8	67	20221	21.6
3	510.2	132.7	277.6	16.3	787.8	149.0	638.8	2331.6	92	34623	37.1
4	364.3	284.7	73.5	18.4	437.8	303.1	134.7	2466.3	97	14494	36.8
5	252.0	225.5	25.5	9.2	277.5	234.7	42.8	2509.1	99	7850	8.4
6	129.6	126.5	9.2	2.0	138.8	128.5	10.3	2519.4	99	2905	3.1
7	69.4	55.1	0	1.0	69.4	56.1	13.3	2530.7	99	5426	5.8
8	34.7	26.5	4.1	5.1	38.8	31.6	7.2	2537.9	100	4093	4.4
9	14.3	16.3	2.0	0	16.3	16.3	0	-	-	0	0
10	15.3	16.3	1.0	1.0	16.3	17.3	1.0	2538.9	100	954	1.0
11+	45.9	46.9	2.0	1.0	47.9	47.9	0	-	-	0	0
TOTAL	1749.9	957.0	1817.3	71.3	3567.2	1028.3	2538.9	2538.9	100	93411	

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[1] Green weight, 50% spruce - 50% fir (Young et al., 1980).

light to the litter layer were dramatic. Sample plots were installed in the stand and an adjacent control area in order to monitor response to the cut.

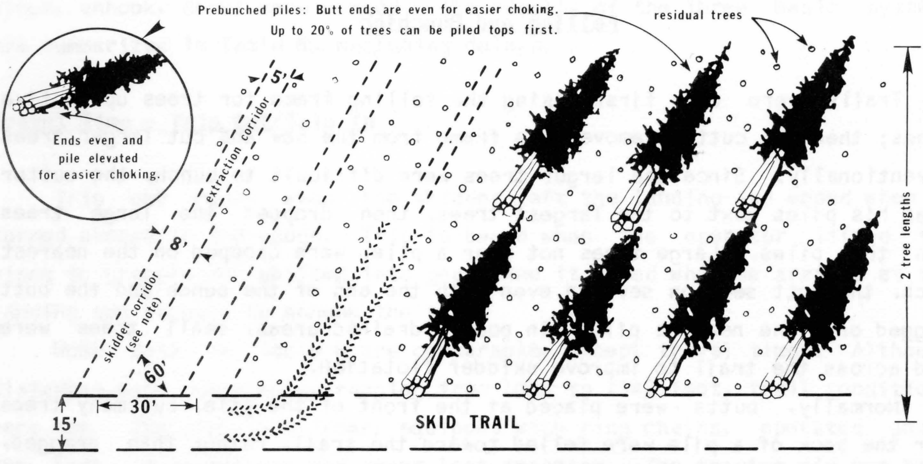
Basal area of all trees before cut was 260 square feet per acre, with a mean stand diameter of 3.65 inches. After cutting, the basal area still exceeded desirable silvicultural limits - 208 square feet per acre - but mean stand diameter was 6.09 inches. Since the residual pine overstory was considerably above the spruce and fir, there was no crowding of the spruce-fir crowns. Considering only the spruce/fir canopy, basal area was about 140 square feet. The high residual basal area and number of trees attests to the small crowns which resulted from overstocking. Spacing was determined by the fallers, who tried to release trees without creating large openings in the canopy; their judgement was far better than armchair analysis of the data would suggest.

In order to drive the skidder directly to the bunched wood, yet minimize soil and stand disturbance, a herringbone corridor pattern (Figure 1) was designed based upon the following criteria:

1) Corridors angled 60 degrees from the trail permitted skidding full trees into the trail with minimal damage to residual trees. A 45-degree angle would be better but would reduce trail spacing.
2) Trail spacing was four times the average height of harvested stems, thus each corridor would have two treelength bunches. The skidder needed to back only to the beginning of the second bunch.
3) Based on the estimated number, size and weight of trees to be cut, corridor spacing was set at 30 feet and trail spacing at 160 feet.

A two-acre training area was laid out and used to train personnel in cutting and skidding techniques.

Half of the one-acre study area was laid out, cut and skidded with the pattern described above. In the other half, the herringbone pattern was modified as shown in Figure 2. Corridors three to five feet wide are adequate for piling bunches, but skidder access required at least eight feet. Herringbone corridors every 30 feet on both sides of the trail often created large openings in the canopy, but the modified herringbone, with alternating corridors every 60 feet, reduced the total amount of cutting, the number of large trees cut and the size of openings.



Note: Skidder corridor length is slightly more than one tree length, but adequate to reach wood piled in the extraction corridors.

Figure 1. Details of herringbone pattern for skidding.

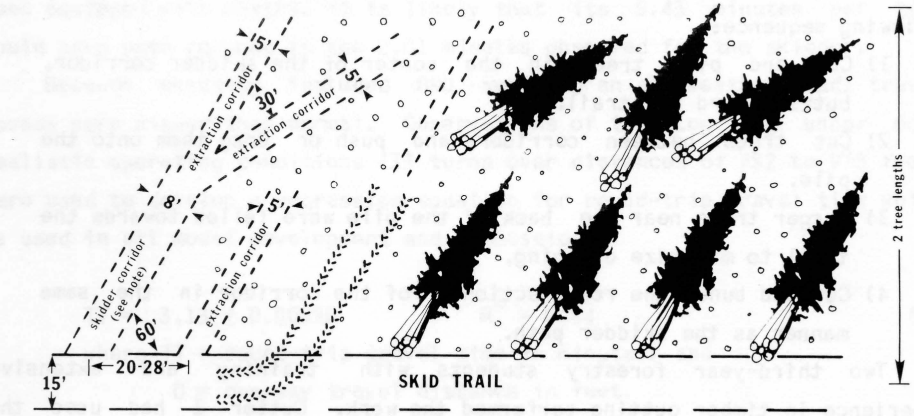


Figure 2. Details of modified herringbone pattern for skidding.

Job layout consisted of flagging skid trail boundaries and the center line between trails. Though straight, parallel trails are desirable, large boulders and stumps should be skirted with gentle curves.

Felling and Bunching

Trails were cut first, using the felling frame for trees up to five inches; then the cutter removed the frame from the saw and cut larger trees conventionally. Since the larger trees were difficult to bunch, the cutter began his piles next to the largest trees, then dropped the large trees onto the piles. Large trees not near a pile, were dropped on the nearest bunch, the butt section severed even with the end of the bunch and the butt dragged onto the nearest pile. In poorly drained areas, small trees were laid across the trail to improve skidder flotation.

Normally, butts were placed at the front of the pile, but many trees near the back of a pile were felled toward the trail, rather than dragged, and the tops trimmed even with the lead end of the bunch.

When cutting corridors, the cutter paced from the previous corridor, estimated the 60 degree angle, and established the new corridor by felling one or more trees on the center line. Cutting usually proceeded in the following sequence:

1) Cut and pile trees in the center of the skidder corridor, butts toward the trail.
2) Cut trees between corridors and push or drag them onto the pile.
3) Larger trees near the back of the pile were felled towards the trail to minimize dragging.
4) Cut and bunch the rear section(s) of the corridor in the same manner as the skidder path.

Two third-year forestry students with training and extensive experience in timber cutting performed the work. Cutter I had used the felling frame in 1981 and helped develop the technique. Cutter II had never used the frame but was taught the newest techniques and given several days of practice before being timed.

Skidding

Skidding was carried out over two field seasons. The first year, a Dunham 660 Log Hog, two-wheel drive, grapple skidder equipped with ring chains was used. The Log Hog (Figure 3) is a modified farm tractor with a heavy-duty, high flotation front end. It has the advantage of a narrow front end and independent steering brakes for maneuverability, and its maximum width of 83 inches permitted easy access to the corridors. With a total weight of 8,900 pounds and positive traction assured by chains, it never broke through the surface soil/root mat. The operator was experienced with farm tractors but not with grapples.

Skidding in 1984 used a Kubota 4500DT, four-wheel drive tractor with a hydraulic blade and Farmi JL 2-45 double-drum winch. The Kubota was lighter and slightly narrower than the Log Hog and was not equipped with chains. The modified herringbone corridors were ideal for a 2-drum winch and enabled the tractor to move double the payload of the grapple skidder. The tractor operator was experienced with the machine and the winch.

In cable skidding, eight turns were observed using preset chokers and 15 with operator-set chokers. Preset chokers were 1/4-inch cable, suitable for carrying and setting by the cutter. For these turns, the tractor operator merely attached his winch cables to the chokers, winched them in and skidded them to the landing. When setting chokers, the operator had to pull the winch cable under each bunch using a steel rod with a hook in one end.

Upon arrival at the landing, the skidder/tractor operator released/unhooked the turn, decked the material and returned for the next trip. Since many operators habitually deck each turn, whether needed or not, the operator was instructed to deck only when necessary.

Data Collection

All cutting and skidding operations were timed by an observer with a digital watch, and times, tree size, load size, and distance were recorded, as appropriate, for each event. Both cutters were observed over several days and were timed continuously to determine the extent of work, rest, and

Figure 3. Two-wheel drive grapple skidder with load of biomass.

other activities, but work elements were timed 15 minutes of each hour throughout the day. The field data were edited promptly and processed by computer (cutting) or desktop calculator (skidding).

Before skidding, all prebunched piles were numbered and their weights estimated by applying weight tables (Young et al. 1980) to the cutting tally for each pile. In 1983, after all cutting was completed and skidding of the westerly half of the area was completed, a 100% inventory was made of the residual stands and of damage to residual trees in the westerly half. Wood in the easterly section was not moved until 1984.

Delays

Most delays in experimental operations result from trying new techniques. Because of the relatively short time span of the observations, there are a large number and variety of delays, and many are difficult to identify correctly. As a result, delays were ignored in this analysis by arbitrarily assuming a utilization or efficiency level.

Skidders were considered to be available for 1700 hours per year, the equivalent of 42.5 weeks, leaving nine and one-half weeks for vacation, mud season, overhaul and other periods of non-use. During the 42.5 weeks that such machines work, they were assumed to be utilized 75 percent of the time, leaving two hours per day for fueling, lubricating, maintenance, repair and other delays.

For a man with chainsaw, utilization is based upon 40 hours per week. He actually works about six hours daily, devoting two hours (exclusive of lunch breaks) to saw refueling and maintenance, rest, planning, and other factors which vary with the individual. In this study, one cutter worked 86 percent of the time, the other 60 percent. In practice, these production rates should be surpassed in several weeks.

RESULTS and DISCUSSION

Cutting

The productivity of Cutter I was clearly superior to that of Cutter II

(Table 2) and he worked 86% of scheduled time compared with 60% for Cutter II (Table 3); there is a striking difference in their output (Table 4). Differences in productivity between cutters are difficult to explain. No

Table 2. Felling and bunching production of two cutters using a chainsaw and felling frame, 1983.

			MEAN TIME IN MINUTES			
	DBH (In.)	No. of Trees	Prepare	Fell/Bunch	Total Effective Time	Delays
CUTTER I	1	75	0.135 ± 0.107[a]	0.126 ± 0.074	0.261	0.023
	2	237	0.145 ± 0.118	0.198 ± 0.093	0.343	0.044
	3	174	0.187 ± 0.159	0.335 ± 0.175	0.522	0.074
	4	32	0.178 ± 0.106	0.372 ± 0.178	0.550	0.134
	5	4	0.233 ± 0.067	0.330 ± 0.127	0.560	0.158
CUTTER II	1	85	0.209 ± 0.159	0.215 ± 0.125	0.424	0.006
	2	248	0.214 ± 0.172	0.356 ± 0.293	0.570	0.047
	3	138	0.228 ± 0.137	0.481 ± 0.249	0.769	0.056
	4	69	0.314 ± 0.248	0.688 ± 0.429	1.002	0.383
	5	22	0.299 ± 0.214	0.699 ± 0.388	0.998	0.261

[a] Standard deviation.

Table 3. Proportion of time spent at different work activities by two cutters with chainsaw and felling frame, 1983.

	PERCENTAGE OF TIME DEVOTED TO WORK ACTIVITIES			
Cutter	Felling/ Bunching	Chainsaw Maintenance and Fueling	Rest	Planning Work
I	86	7	3	4
II	60	12	27	1
Mean	73	10	15	2

Table 4. Production and efficiency of two cutters using chainsaw and felling frame, 1983.

		CUTTING PRODUCTION						
	Hours	Number of Trees		Tons of Biomass		Util.	Productivity per Shift Hr.	
Cutter	Worked	Total	Per Hour	Total	Per Hour	Rate	Trees	Tons
I	3.60	529	145.3	9.77	2.71	86	124.9	2.33
II	6.27	570	90.9	13.50	2.15	60	54.5	1.29
Mean	-	-	118.1	-	2.43	73	89.7	1.81

doubt motivation was a major factor, for Cutter II was high a producer with a spacing saw when motivated by piece-rate payment.

Cutter I was athletic, in excellent physical condition, and highly motivated. He was employed for two weeks to develop new techniques and to train others, after which he left for a highly desirable summer job.

Cutter II was in good physical condition and had nothing to look forward to but more of the same strenuous effort. His performance casts a sobering outlook on the productivity to be expected in such labor-intensive work.

From this and previous studies of cutting efficiency, it is likely that the average of the productivity of the two cutters is a reasonable level to expect. Because of the strenuous physical effort involved, it is desirable to mix felling with other activities which are less demanding.

Improving Productivity

Cutter I used the same chainsaw and felling frame in 1981 and 1983 under similar conditions, but changed technique in 1983. The improved technique consisted of falling trees near the back of the pile toward the trail rather than dragging butts to the front of the pile. This improved both preparation and felling times by reducing the amount of walking (Table 5).

Table 5. The effects of technique improvement on total cutting time, by dbh class, 1981-1983, using chainsaw and felling frame.

DBH Inches	MEAN TIME IN MINUTES 1981[1]	 1983	Productivity Increase, %
1	0.33	0.26	27
2	0.38	0.34	12
3	0.56	0.52	8

[1] Data from Hoffman (1982b). Only 1-3 inch trees cut.

From Table 1, the number of trees cut was multiplied by the time per tree (Cutter I) for the one- to five-inch dbh classes to determine the total time required to cut each size class. Production time was then compared with biomass production by size class (Table 6).

Table 6. Comparison of work effort and biomass yields per acre by dbh class for trees cut with chainsaw and felling frame, 1983.

DBH (Inches)	Number of Trees Per Acre	Time per Tree (Minutes)	Total Cutting Time (Minutes)	Percent of Work Effort	Percent of Biomass Produced
1	711.2	0.261	185.6	19.5	3.6
2	981.6	0.343	336.7	35.3	25.3
3	638.8	0.522	333.5	35.0	43.3
4	134.7	0.550	74.1	7.8	18.1
5	42.8	0.560	24.0	2.5	9.8
Total	-	-	953.9	100.1	100.1

Work and yield are considerably out of balance for the one-inch class -- 19.5% of the work produced only 3.6% of the biomass. Since leaving one-inch trees should improve productivity and reduce costs, two corridors were cut in 1984 by Cutter I, removing only those one-inch trees which interfered with work. The improvement in productivity is detailed in Table 7.

Production and Cost

Production per shift hour ranged from 1.29 to 2.33 tons (Table 5), depending upon the cutter. The mean of the two -- 1.81 tons per shift hour -- is based upon their average production rate and efficiency. Efficiency at 73 percent is realistic and attainable. If the cost of a man equipped with chainsaw and felling frame is $12.05 per scheduled hour, including overhead, then cutting would cost $6.65 per ton.

Table 7. The effects of not cutting one-inch trees on the productivity of Cutter I with chainsaw and felling frame, 1983-1984.

Year	Hours Worked	NUMBER OF TREES CUT Total	NUMBER OF TREES CUT Per Hour	TONS OF BIOMASS CUT Total	TONS OF BIOMASS CUT Per Hour	Weight per Tree, Lbs.
1983	3.63	523	145.3	9.77	2.71	37.3
1984	0.63	82	131.0	1.95	3.17	48.4

Using the 1984 technique (not cutting one-inch trees), 2.31 tons per scheduled hour could be expected; at $12.05 per scheduled hour, cost per ton would be $5.22. Because of the small amount of data obtained in 1984, the lower cost figure is not reliable.

A more accurate method of predicting cost would be to apply average production times (Table 2) by diameter class to a stand table for any stand in question. Multiplying the number of trees per class by the cutting time per tree yields an estimate of total productive time per acre. This is adjusted by a utilization factor (or average efficiency of 73 percent) to predict cost on a scheduled-hour basis. Biomass yields could be estimated from the same stand table using a weight table similar to Young et al. (1980). Divide total cost by total yield for an estimate of cost per ton.

Since the study dealt only with felling trees up to five inches dbh with a chainsaw and felling frame, costs for larger trees must be estimated from other production studies. A study for northern species (Hoffman 1983a) includes prediction equations for felling larger trees found in trails and corridors.

Skidding

Skidding utilized a two-wheel drive grapple skidder (58 turns) and a four-wheel drive tractor with double-drum winch (23 turns). Further, skidding used two corridor patterns (herringbone and modified herringbone) and tractor operations used two methods of choking (preset and operator-set). Because of the variations in tractor skidding, each work element was analyzed for each method, then those that could be combined (position, winch, unhook, deck) were merged. The results of the three basic systems are summarized in Table 8, excluding delays.

Travel Time - Trip Out/Trip In

Trip out began when the skidder left the landing and ended when it turned around in the woods. Trip in began when the operator lifted the winch or grapple and shifted into gear, and it ended when he arrived at the landing and stopped to unhook the turn.

Most data in Table 8 are comparable, except travel times. Although distances were comparable, ranging from 1032 to 1342 feet, trail conditions were not. The grapple skidder, equipped with ring chains, operated under the best of conditions and never lost traction. The tractor did not have chains; its wheels slipped frequently, tearing up the trail surface, and it often became stuck. Traction problems are the chief reason for the difference in trip-in times between skidder and tractor. Had the tractor been equipped with chains, it is likely that its 5.43 minutes per trip could have been reduced to the 2.01 minutes observed for the skidder.

Because skidding included 890 feet on an all-weather road, travel speeds were higher than normal. Observations of the Log Hog under more realistic operating conditions (33 turns over distances of 752 to 978 feet) were used to develop a regression equation for round-trip travel time which is used in all model development and discussion.

$$TT = 3.13 + 0.0033D \qquad R^2 = 0.44 \qquad (1)$$

where TT = round-trip travel time in minutes, and
D = one-way travel distance in feet.

Two features of the rigid-frame tractors used in this study were the narrow front end and independent rear wheel braking. These permitted easy turning in a minimum of space without damaging the adjacent stand.

Table 8. Effective working time for three skidding methods.

	ELEMENT	TRIP OUT	POSITION	GRAPPLE/ CHOKE	WINCH	RAISE WINCH	TRIP IN	UNHOOK	DECK[3]	TOTAL PER TURN
GRAPPLE[1]	Mean time/ turn, mins.	2.06	2.14	.89	-	-	2.01	-[4]	.484	7.58
	Percent of total time	27.2	28.2	11.7	-	-	26.5	-	6.3	100.0
CABLE PRESET	Mean time/ turn, mins.	2.68	2.47	.268[5]	3.28	.484	5.43	2.27	1.39	18.27
	Percent of total time	14.7	13.5	1.5	18.0	2.7	29.8	12.4	7.6	100.2
CABLE NORMAL[2]	Mean time/ turn, mins.	2.68	2.47	2.94[5]	3.28	.484	5.43	2.27	1.39	20.94
	Percent of total time	12.8	11.8	14.0	15.7	2.3	25.9	10.8	6.6	99.9

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[1] Average load was 1200 pounds, 1221 foot skidding distance.
[2] Average load was 2400 pounds, 1172 foot skidding distance.
[3] Normally performed once every two turns.
[4] Unhooking grapple was a barely perceptible pause.
[5] Normally performed twice each turn.

Positioning

Positioning reflects the time spent backing the skidder or tractor into position to grasp (grapple) or choke (cable) bundles of wood. Positioning the skidder was difficult, as the operator had to back the small (42-inch) grapple directly over the end of the bunch. If he missed, it was necessary to drive ahead and try again. With an articulated skidder, "crabbing" the grapple to one side with the steering cylinder could correct positioning.

A further problem was that the grapple size was inadequate for the large bundles of small stems. This was often corrected by grasping and compressing part of the bundle, then opening and grasping the entire bunch. On most turns in which all stems could not be contained in the grapple, the branches of trees felled tops-ahead held the bundles together.

The small grapple may be the result of scaling equipment down. For thinning, one expects small payloads, hence a small grapple, but the contrary is true. With smaller trees, load length (tree height) is reduced, hence for any given payload size, a larger cross-section area of stems must be taken. The manufacturer has increased the grapple size.

Positioning the tractor and winch for cable skidding was similar to grapple-skidding, but precision was not necessary. The operation was the same for both preset and operator-set chokers. Unfortunately, due to poor planning by the cutters, the tractor could not be backed into all corridors, necessitating winching as much as 50 feet.

Positioning time began when the operator completed turning the machine (after trip out) and began backing to the wood. Time ended when the skidder stopped and the grapple was lowered, or when the tractor stopped, the winch was lowered and the operator began to dismount.

Positioning, one of the most critical elements of skidding, affected all aspects of loading, whether by grapple or cable. Personnel involved in cutting must understand the effects of their work on positioning and loading the skidder. Many aborted positioning attempts with the grapple were caused by poor cutting practices.

The following practices are essential to efficient skidder operations:

1) Corridor width must permit the skidder to back to the second

pile(s) of wood.

2) Stumps must be cut flush with the ground in the corridors. High stumps can cause the grapple skidder to slip sideways and miss the pile.
3) Piles must be placed where they are accessible to either grapple or winch, never behind obstacles or in terrain depressions.
4) Piling crosswise on a log improves both grapple and cable choking.
5) With the modified herringbone, the piling pattern must be followed so that the skidder operator can acquire two bundles at each position with minimal winching.

Grapple/Choke and Winch

Grapple time began when the operator stopped the skidder and began lowering the grapple to acquire the turn, ending when the grapple was fully raised and forward motion began. Many aborted attempts were abnormal delays caused by improper cutting and/or piling.

Choke and winch consisted of five separate operations:

1) Pull cable - began when operator dismounted and ended when he finished pulling cable and began to choke the turn.
2) Choke - began when the operator began choking the bundle, ending when the choker was hooked and he started back to the winch.
3) Walk to tractor - time walking from pile until operator grasped winch control.
4) Winching - began when winch control was grasped, ended when the turn was hooked in the notched beam of the winch.
5) Raise winch - time from completion of winching second turn until operator mounted tractor and raised winch to travel position.

Evaluating the three systems requires comparing total loading and unloading times, including positioning, and the effect of doubling payloads with the double-drum winch.

Note that of five work elements in cable choking, three -- pull cable, walk, winch -- are distance-related. Because poor cutting practices made winching of 30 feet a common occurrence, these three elements were grouped and subjected to regression analysis. Although the R^2 value and the standard deviation of the mean are very low, it is logical to adjust for the effects of distance when constructing models.

The equation for predicting winching time is:

$$W = 1.184 + 0.023D \qquad (R^2 = 0.1030) \qquad (2)$$

where W = winching time in minutes

D = distance in feet from pile to winch

In a production mode, the mean winching distance of 20 feet observed in these trials would be unacceptable. Layout and cutting must permit backing the winch to within 6-8 feet of the two piles.

Unhook and Deck

Unhook consisted of unloading the skidders at the landing. With the grapple skidder, the operator simply slowed, released the grapple, and drove on -- a barely perceptible pause in forward motion. With cable, time began when the tractor stopped and resumed when the operator completed unhooking, hung the chokers on the winch, mounted the tractor and commenced the return trip, an average of 2.27 minutes per turn.

Decking consisted of pushing the bundles into a pile at the landing. Timing began when the operator completed unhooking and mounted the tractor. After turning, if he did not proceed to the woods, he pushed the unpiled bundles into the deck, usually with one or two attempts. Timing ended when he backed out and shifted into gear for the trip to the woods.

The differences between the Log Hog and tractor -- 0.48 vs. 1.39 minutes per turn -- are most likely the result of a better blade on the Log Hog and the larger piles faced by the Kubota.

One factor which improved productivity was that both operators decked an average of once every two turns, while most skidder operators routinely deck each turn. In unpublished data from an earlier Log Hog study, decking averaged 0.99 minutes per turn when each turn was decked.

Total Time, Productivity and Cost

The purpose of studying the skidding alternatives was to determine which is best and to identify methods of improving performance. The data in Table 8 can be used to predict productivity, including the effects of improving some aspects of work. Several assumptions must be made:

1) Assuming maximum skidding distances of 1800 feet (Jacobs et al. 1978), average distance would be 900 feet, not the 1172-1221 feet observed. From equation (1) (Log Hog skidding model):

   $$TT = 3.13 + 0.0033D = 6.1 \text{ minutes.}$$

2) Excessive positioning times caused by poor cutting, piling and trail layout are eliminated, reducing grapple positioning time from 2.14 to 1.98 minutes. Improved cutting and tire chains on the Kubota reduce its positioning time to 1.98 minutes.
3) No change in grapple and choke times, though a larger grapple should improve Log Hog performance.
4) Winching times assume proper planning and cutting reduce average distance from 20 to 7 feet. The model previously described in equation (2) is used for both cable systems, thus:

   $$W = 1.184 + 0.023D = 1.345 \text{ minutes/bunch or } 2.69\text{/turn}$$

5) Unhook and deck times unchanged, though improved blades would raise productivity.
6) Load size remains at 1200 pounds per bunch.

Using these assumptions, observed and predicted costs and production rates are compared in Table 9.

The least expensive skidding method uses a farm tractor and winch with preset chokers, with the cutter setting chokers. At an average production rate of two bunches per hour, the cutter must carry and set 16 chokers per day. The chokers (1/4-inch steel cable) are easy to carry and set, requiring less work than placing a small log under the bunch to elevate it for choking or grappling. However, normal choker setting by the operator cost $1.05 per ton, or $0.63 per bunch, and the costs of lost and broken preset chokers could exceed this in the long run, thus conventional choking

Table 9. Observed and predicted productivity and cost for three biomass skidding methods (excluding delays).

System	Turn time, minutes		Production tons/hour[1]		Cost per ton[2]	
	observed[3]	predicted[4]	observed	predicted	observed	predicted
Grapple	7.58	9.45	4.75	3.81	6.62	8.25
Cable, preset	18.24	15.18	3.95	4.74	7.16	5.96
Cable, normal	20.94	17.85	3.44	4.03	8.22	7.00

[1] Based on 1200 lbs/turn for grapple, 2400 for cable.

[2] Based on machine rates (75% utilization) of $31.43 for grapple, $28.23 for cable.

[3] Observed, no adjustments for distance or improved performance.

[4] Standardized for 900' average skidding distance, plus improved performance as outlined in text.

appears to be a better choice.

Grapple skidding was more expensive, at $8.25 per ton, but if a larger grapple reduced positioning and grappling time by 25 percent, total cost would be $7.87 per ton. The simplest method of raising productivity is to increase payloads with larger bunches of wood, which requires wider corridor spacing and more work for the cutter.

With herringbone corridor spacing increased from 30 to 40 feet, average pile weight could be raised to 1500 pounds. If the larger grapple permitted, this would reduce costs to $6.27 for the grapple skidder and $5.61 for the cable system with conventional choking.

When estimating production, allowances must be made for skidding losses of foliage, branches and twigs. According to a Swedish study (Anon. 1977), 30 percent of the branches and needles are lost in whole-tree winching and skidding. Since needles and branches constitute about 26 percent of the aboveground weight of spruce and fir (Young et al. 1980) as much as 8 percent of the total biomass may be lost in skidding. Either yields must be reduced by this amount or costs increased by a factor of 1.087 to account for this loss.

The nature of woods work affects labor availability and cost, in many cases through the quality rather than the amount of available labor. Improving working conditions by providing skidders with mechanized wood acquisition features, which eliminates leaving the cab to crawl around in snow and mud with chokers, is one means of attracting better workers. The Log Hog's popularity in the South resulted from not having to dismount and face snakes when setting chokers. This study, conducted over a short period under good working conditions, is not representative of year-round performance under more adverse conditions. The safety and desirability of an all-weather cab are important.

Larger grapple size would improve positioning, loading and decking times, as well as load capability. Improving operator vision to the rear would also improve performance, as would a powershift transmission. One possible cost saving might be to reduce horsepower; the Log Hog's 75 horsepower was less efficient for moving 1200-pounds than the Kubota's 55 horsepower moving 2400 pounds. Note, however, that the difference in cost between the two was only $3.00/productive hour, and had the Kubota been equipped with the superior operator protection and hydraulics of the Log Hog, its cost would have been higher.

Stem damage was limited to trees adjacent to the trails and corridors and consisted principally of roots and butts scraped by skidding. A total of 30 trees per acre, 4.43 square ft. of basal area, was damaged; six of these were trailside and 24 were along skidder corridors. Most injuries were minor and the trees would be removed in the next thinning.

APPLICATION

A number of logical assumptions can be extracted from the data and applied, with caution, to harvesting small stems.

Estimating Cutting Production and Cost

No prediction equations were developed from cutting, but an estimation table (Table 10), based upon observations of mean times for felling and bunching can be used to predict production and cost. The user must supply his own stand data, weight tables, wage rates and utilization estimates. If he wishes to modify cutting rates by eliminating one-inch trees, an appropriate change can be made in the number of such trees cut.

Table 10. Tabulation form for computing felling and bunching production and cost using a chainsaw and felling frame.

COLUMN	(1)	(2)	(3)	(4)	(5)
dbh	Trees/Acre (number)	Time/Tree[1] (minutes)	Time/Acre[2] (minutes)	Weight/Tree[3] (pounds)	Biomass per Acre[4] (pounds)
1		0.3425		4.0	
2		0.4565		20.6	
3		0.6455		54.2	
4		0.766		107.6	
5		0.779		183.4	
Total					

[1] Average for 2 cutters, 1048 trees, 1983

[2] Col. (1) x Col. (2)

[3] Fresh aboveground biomass in pounds, from suitable weight tables. In this case Young et al. (1980) for spruce (50 percent) and fir (50 percent).

[4] Col (1) x Col (4)

To compute production and cost from Table 10, use the formulae below:

$$\text{Production (tons/scheduled hour)} = \frac{(\Sigma\ \text{Col. (5)}/2000)}{(\Sigma\ \text{Col. (3)}/60)} \times \text{Utilization}$$

Cost per ton (\$) = (Hourly rate)/Production (tons/sched. hr.)

Estimating Skidding Production and Cost

Skidding is composed of fixed-time work elements, such as choking, unhooking, decking, and variable-time elements related to distance and load weight, such as travel time and winching. In this study, load size was below tractor capacity and is ignored, so most variable time is taken up by round-trip travel, described by equation (1);

$$TT = 3.13 + 0.0033D \quad (1)$$

where TT = round-trip travel time in minutes

D = one-way distance in feet

The fixed elements of grapple skidding can be represented by the sum of all other work elements - position, grapple, unhook, deck - whose average total time per turn is 3.35 minutes. Therefore, grapple skidding time per turn can be expressed by summing the fixed time, including the fixed (3.13 minutes) and distance-related portions of travel time, as follows:

$$GST = 6.48 + 0.0033D \quad (3)$$

where GST = grapple skidding turn time in minutes, and

D = average one-way skidding distance in feet.

In a similar manner, the cost of cable skidding can be predicted from travel time plus fixed times of position, choke, raise winch, unhook, and deck, plus the fixed and variable times of winching. Incorporating the winching equation,

$$W = 1.184 + 0.023WD \quad (2)$$

where W = winching time in minutes

WD = winching distance in feet

with two winching cycles per turn, the prediction equation becomes:

$$CST = 14.56 + 0.0033D + 0.046WD \quad (4)$$

where CST = cable skidding time in minutes

D = one-way travel distance in feet

WD = average winching distance in feet

Caution: these equations are based upon limited observations under good operating conditions and several logical but unproven assumptions.

Also, approximately 8 percent of the biomass will be lost in skidding, increasing costs by a factor of 1.087/ton delivered to the landing.

A Recommended Operating System

Based upon experience gained in the study, a viable harvesting system is possible using these techniques, but the strenuous physical work makes it doubtful if the felling frame can be used on a full-time basis. The cutter is the key to successful operation of this system. He must plan, lay out and cut the corridors for efficient skidding. A person with the intelligence to do this well is not likely to tolerate the physical hardship of cutting on a continuous basis.

Given a choice, the grapple skidder is preferred because of its operator safety and comfort. The lower cost of four-wheel drive farm tractors suggests that cable skidding might be more prevalent, but the high initial cost of double-drum winches ($4600) is a negative factor.

Wider cutting strips will increase skidder payloads, but as cutting strips are widened, the cutter's work becomes more strenuous, for he must carry stems a longer distance. This aspect of the system needs more study.

One method that was not tried is a single-drum winch. With a herringbone system, the trailside pile could be winched to the tractor and secured, then the in-stand bunch could be winched. However, while winching full-tree bunches works well with a high lead angle, problems occur when winching long distances with virtually horizontal leads. One option is to reduce trail spacing to two tree lengths and eliminate backing a single drum winch into the stand.

Felling frame cutting should be limited to trees of two to four inches dbh, except for larger trees in skidder corridors. One-inch trees should be cut only when they interfere with the removal of other trees.

To minimize bundle diameter for choker or grapple, only three-inch and larger tree butts should be placed at the lead end of the bunch. Pile smaller trees with the butts several feet back; interlocking branches will hold the bundles together.

Considering the success of two-wheel drive with chains in adverse operating conditions, there is little reason to insist on four-wheel drive.

In either case, chains improve traction and reduce trail damage. Given the Scandinavian experience with two-wheel drive tractors in winter, the Log Hog is suited to the northeastern forest. The key to success is good trail planning and layout.

CONCLUSIONS

A feasible system for thinning dense, small-diameter softwood stands was demonstrated using a chainsaw and felling frame in combination with small cable and grapple skidders.

Felling and bunching production rates of 1.81 tons of fresh biomass per scheduled hour were achieved at a cost of $6.22 per ton. Higher rates and lower costs seem attainable through the application of improved cutting methods.

Two trail systems were devised which enable skidders to back to prebunched wood with minimal damage to the soil and residual stand. With grapple skidders, a herringbone corridor system works well, whereas a modified herringbone is efficient for cable skidding with a double-drum winch.

For mean skidding distances of 900 feet, predicted grapple and cable skidding productivity ranged from 3.8 to 4.7 tons per scheduled hour at costs of $8.25 to $7.00, respectively. Cable skidding with preset chokers was more productive than having the operator set chokers, but the uncertain expense of preset chokers would likely offset savings.

A two-wheel drive grapple skidder equipped with ring chains operated in poorly drained "winter logging" sites without damaging the soil or becoming stuck. A four-wheel drive tractor without chains damaged the soil and frequently became stuck.

The weakest link in the system is the strenuous physical work required of the cutter. Satisfactory performance of this job requires a person who can plan, lay out and cut corridors so as to avoid skidding problems and maintain a high level of physical effort to meet production goals.

Until better data become available, biomass yields should be reduced by 8%, or costs increased by 1.087, to account for needles and branches lost in skidding.

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