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Production and Product Recovery for Complete Tree Utilization in the Northern Rockies

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John M. Mandzak, Kelsey S. Milner, and John Host

I

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This study could not have been undertaken without the help and cooperation of Hahn Machinery, Incorporated, of Two Harbors, Minn., and Strong Manufacturing Company of Remus, Mich. Both manufacturers provided new test machines, competent operators, and more than adequate support.

St Onge Logging Company of Missoula, Mont., provided skidding and loading equipment, with skilled and conscientious operators. Midnight Logging Company of Huson, Mont., provided a Melroe Bobcat feller-buncher and a skilled operator.

RESEARCH SUMMARY

Profitable management of second-growth timber in the Northern Rockies will be influenced by the economics of small timber harvesting. The small average stem size of second-growth stands coupled with low product values tends to make current logging systems uneconomical in many areas.

In this study, a whole-tree harvesting system designed to produce logs and chips was evaluated on four sites, each with a different silvicultural prescription. The system consisted of: feller-bunchers, grapple-equipped rubber-tired skidders, a tree processor, a whole-tree chipper, and a hydraulic log loader. Production rates for the overall system and for its various components were developed with time-motion study techniques. Variation in productivity between study areas was analyzed with respect to stand and site characteristics.

Results of this study indicated: (1) The system can produce chips and logs at acceptable rates for a range of site and stand conditions. Daily production ranged from 89 to 193 tons (81 to 176 tonnes) of logs and 119 to 178 tons (108 to 162 tonnes) of chips. (2) The proportions of chippable and sawable material available in the stand affect overall system productivity and productivity of system components. (3) The complete utilization of slash by the system provided additional forest management benefits. These included: reduction in bark beetle hazard, reduction of future site preparation activities (especially burning), and improved appearance of harvested stands.

II

CONTENTS

TABLES

FIGURES

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INTRODUCTION

The harvest of small timber of commercial size has historically been a problem due to relatively high logging costs per unit coupled with low product values. Small logs are typically processed into studs (8-ft 2″ × 4″, 2″ × 6″, etc.). Because demand and price constantly fluctuate, the process of harvesting and conversion of small timber to studs is difficult and marginally profitable. Nevertheless, small timber represents a relatively large percentage of the volume of timber available in the Rocky Mountain area, and this percentage will increase in the coming decades as old-growth timber stands are converted to managed stands. If costs of logging small trees were reduced, the ultimate profitability of the production of framing material could be improved dramatically.

Stands of small timber are of two basic types. There is the relatively old stand, with small-diameter trees that have little potential for further net growth. Such stands occupy valuable growing space yet contribute little to site productivity. Stagnant old-growth lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and stands of true fir (*Abies* spp.) are common examples. The harvesting and subsequent regeneration of these stands, usually by clearcutting, would bring these areas back into production.

The second type of small-timber stand is the relatively young, overstocked stand with some stems of small commercial size. Partial cutting, such as a commercial thinning, would permit added growth on the remaining stems and prevent the stagnation of the first type of stand. Such partial cuts in young ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands would also help prevent buildup of bark beetle populations by maintaining tree vigor. These young, overstocked stands are of critical importance because a shortage of merchantable timber is expected after the old-growth has been harvested. The faster these young stands are brought to merchantable sizes the shorter will be the time interval with a lower harvesting rate. It is, therefore, highly desirable that young stands are managed so as to fully utilize the growth potential of the site.

Management of small timber is also affected by the demand for wood fiber suited to the manufacture of paper, fiberboard, particleboard, or hog fuel. Historically, mill trimmings and waste have been the source of such material. However, during slack market periods when lumber and veneer production is reduced, the supply of such waste material is also reduced. Small-sized timber could help satisfy the raw material shortfall during these intervals.

This study was undertaken to explore one alternative for utilizing postlogging residues and to determine the feasibility of generating boiler fuel from thinning operations for the Forest Service and Champion Timberlands, respectively. The study took place during August 1980. It is one of a series of studies dealing with utilizing material from thinning operations in western Montana.

Study Objectives

The objective of this study was to test the feasibility of a mechanical harvesting system designed to process small logs and produce chips suitable for hog fuel and pulp and paper. The logging system is shown schematically in figure 1. Specific goals were:

1. Compare the productivity and advantages of falling and prebunching turns for grapple skidders by a feller-buncher (tree shear) relative to conventional sawyer falling, choker-skidding logging methods.
2. Compare the quality of logs manufactured by a tree processor to that for logs produced by conventional methods. Also, determine production rates for the tree processor.
3. Compare the loading time for small logs delimbed and bucked by a tree processor to those for logs decked in a conventional system.
4. Evaluate the tree processor-chipper logging system as a forest management tool. Specific tasks to be considered include:
   a. Thinning stands on a commercial basis.
   b. Clearing stands of small trees for regeneration on a commercial basis.
   c. Reducing insect damage potential in ponderosa pine stands.

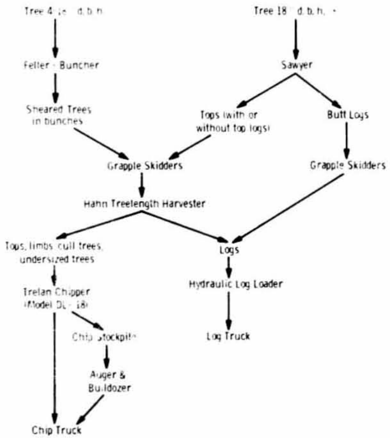

Figure 1.—Flow diagram of a harvesting system for logs and whole-tree chips (hog fuel), using a Hahn Treelength Harvester in conjunction with a Trelan Model DL-18 whole-tree chipper.

d. Eliminating slash disposal costs through 100 percent tree utilization.
e. Maintaining air quality by eliminating slash burning.
f. Improving stand access and recovering greater volume.
g. Improving esthetics of harvested areas.

STUDY METHODS

Study Area Description

Figure 2 shows the location of the four cutting blocks near Missoula, Mont. The blocks varied with respect to timber type, terrain, and cutting method, reflecting the diversity of conditions on which the logging system might be applied.

Marking, Cruising, and Block Layout

The Gold Creek lodgepole pine block was clearcut. Therefore, only the boundaries were marked. Leave trees on the remaining blocks were marked with blue paint. Rings were painted around the tree at about breast height and also just above the groundline so tree shear operators could identify the leave trees from all directions (conventional leave marking for Champion Timberlands consists of vertical blue stripes). Blocks were cruised to ensure that the stands were carefully characterized, especially with regard to stem size distribution.

Arkansas Creek block.—This 20-acre (8.1-ha) logging block was established in a young-growth stand of approximately 80 percent ponderosa pine, 15 percent Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), and 5 percent western larch (*Larix occidentalis* Nutt.). The cutting was designated a shelterwood cut. Leave trees were identified. The terrain was a flat bench with about a 5 percent slope. This stand was chosen to represent a relatively light harvest volume shelterwood cut.

The cruise summary for the block was:

Item[1]	Per acre	Per block
Basal area (ft^2)	99	1,980
Number – chippable stems < 9" d.b.h.[2]	278	5,560
– saw log stems > 9" d.b.h.	85	1,700
Total trees	363	7,260
Volume – chippable trees (ft^3)	579	11,580
– saw log trees (ft^3)	1,418	28,360
– total (ft^3)	1,997	39,940
– tops of saw log trees[3] (ft^3)	112	2,240
– Scribner – 6" top d.b.h. (bd.ft.)	4,280	85,600
– per tree (bd.ft.)	50	
Area (acres)		20

[1]See whole-tree chipping section for discussion of utilization.
[2]Except for occasional cull trees > 9" d.b.h.
[3]Does not include limbs and needles harvested for hog fuel, not quantified due to losses during harvesting.

Gold Creek block.—This 12.7-acre (5.1-ha) logging block was established in a 70-year-old lodgepole pine stand. The species mix was approximately 98 percent lodgepole pine and 2 percent ponderosa pine. The stand was clearcut with the exception of scattered, large old-growth ponderosa pine, larch, and a few young-growth ponderosa pine of good form. The terrain was relatively flat, ranging from 5 to 25 percent on small areas of steeper ground. This block is representative of stagnant lodgepole pine stands in the Northern Rockies.

The cruise summary for the block was:

Item[1]	Per acre	Per block
Basal area (ft^2)	137	1,740
Number – chippable stems < 9" d.b.h.	265	3,365
– saw log stems > 9" d.b.h.	187	2,375
Total trees	452	5,740
Volume – chippable trees (ft^3)	1,531	19,444
– saw log trees (ft^3)	3,583	45,504
– total (ft^3)	5,114	64,948
– tops of saw log trees (ft^3)	945	12,001
– Scribner – 6" top d.b.h. (bd.ft.)	11,504	146,101
– per tree (bd.ft.)	62	
Area (acres)		12.7

Sunflower Road block.—This 4.5-acre (1.8-ha) logging block was established in a young western larch stand. The species mix was estimated to be 80 percent western larch, 10 percent lodgepole pine, and 10 percent Douglas-fir. The terrain consisted of a smooth slope of about 25 percent grade throughout. The block represented a commercial thinning of fairly light log volume on slopes near the maximum capability for conventional tree shears and rubber-tired skidders. The area also had a restricted landing area and provided an opportunity to gain experience and data on the processing of western larch.

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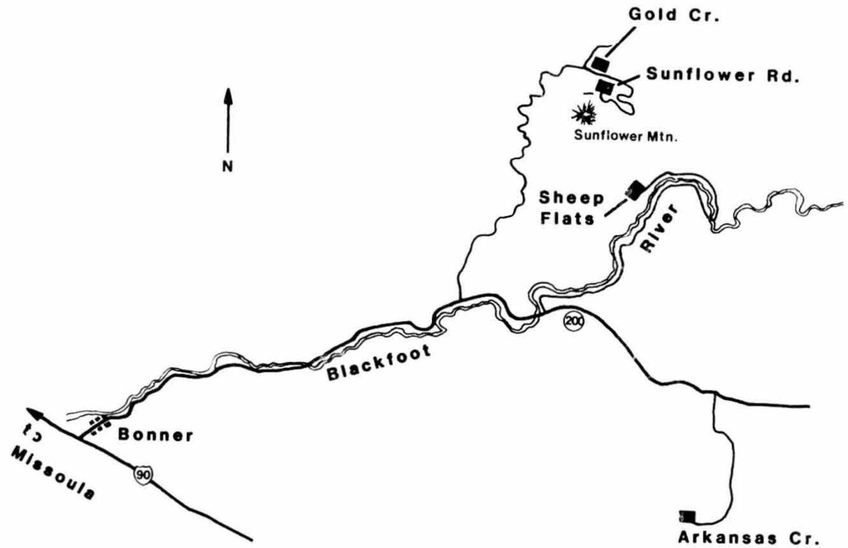


Figure 2.—Location of study blocks on Champion International lands in western Montana.

The cruise summary was:

Item[1]	Per acre	Per block
Basal area (ft^2)	147	661
Number – chippable stems < 9" d.b.h.	441	1,984
– saw log stems > 9" d.b.h.	117	526
Total trees	558	2,511
Volume – chippable trees (ft^3)	1,610	7,245
– saw log trees (ft^3)	2,830	12,735
– total (ft^3)	4,440	19,980
– tops of saw log trees (ft^3)	496	2,232
– Scribner – 6" top d.b.h. (bd.ft.)	11,441	51,484
– per tree (bd.ft.)	97	
Area (acres)		4.5

Sheep Flats blocks.—Three blocks were established of 17.5, 5.6, and 20 acres (7.1, 2.3, and 8.1 ha), respectively. The species mix was approximately 80 percent ponderosa pine and 20 percent Douglas-fir. Slopes were generally less than 5 percent, with the exception of about 2 acres (0.8 ha) with slopes up to 15 percent. Leave trees were marked and the dominant cutting practice was the shelterwood method with some commercial thinning. These blocks were representative of a stand with large harvestable trees that would also be attractive to conventional logging operations.

The cruise summary was:[4]

Item[1]	Per acre	Per block
Basal area (ft^2)	155	2,961
Number – chippable stems < 9" d.b.h.	161	3,075
– saw log stems > 9" d.b.h.	129	2,464
Total trees	290	5,539
Volume – chippable trees (ft^3)	687	13,122
– saw log trees (ft^3)	2,969	56,708
– total (ft^3)	3,656	69,830
– Scribner – 6" top d.b.h. (bd.ft.)	10,676	203,912
– per tree (bd.ft.)	84	
Area (acres)		19.1

[4]The cruise summary was for 13.5- and 5.6-acre (5.5- and 2.3-ha) units initially set up; 4 acres (1.6 ha) were added to the 13.5-acre (5.5-ha) unit. The additional areas of 4 and 20 acres (1.6 and 8.1 ha) were similar to the cruised units.

Logging Equipment and Methods

Feller-bunchers.—An International track-mounted feller-buncher (Model 3966-B) did most of the felling and bunching for the study. A Melroe Bobcat (Model 1079) feller-buncher was also used on the Gold Creek lodgepole pine and on the Sheep Flats blocks. The Bobcat shear had an accumulator to hold two or more cut stems, while the International did not. Conventional powersaws were used to fall trees 18 inches (45.7 cm) d.b.h. and larger that were too large for the feller-bunchers. Sawyers also limbed and bucked the first log out of very large trees. The bunches were not sorted according to merchantability. Bunches were oriented butt first toward the landing to facilitate skidding as shown in figure 3. Unmarked trees were sheared to a 6-inch (15.2-cm) lower d.b.h. limit.

Figure 3.—Bunched trees oriented toward landing.

Skidding machines.—Two John Deere Model 640 rubber-tired skidders were used to do the skidding. One skidder was equipped with a grapple and the other with chokers. The grapple machine operated primarily on and close to the landing, while the choker machine was used to forward bunches from the back of the units. This separation of the skidders eliminated the hazardous unhooking of chokers. Also, there was less delay with the grapple skidder at the machine-crowded landing.

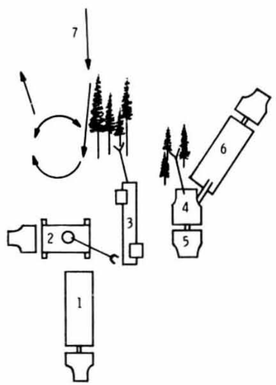
Tree processor.—The machine used was a new Hahn Tree-length Harvester equipped with two control cabs. One operator controlled the log processing while the other operator controlled the grapple, which fed trees to the processor and also helped sort bunches and feed the chipper.

Whole-tree chipper.—A Trelan Model DL-18 whole-tree chipper manufactured by Strong Manufacturing Company chipped tops and cull trees for hog fuel. This model was also equipped with a grapple loader.

Log loading.—A truck-mounted Husky Brute hydraulic loader loaded the logs produced. The loader was normally stationed next to the tree processor and sorted logs when a truck was not available.

Chip vans.—Chip vans were used to transport hog fuel chips. The vans were not disconnected from the tractors when they were filled, although this would be an option. Four types of vans were used in the study, described in appendix A. Figure 4 shows the landing on Sheep Flats block; figure 5 illustrates the landing schematically. The landing could be (and was) split up if either the tree processor or the chipper was unavailable, or if landings were too small to accommodate all of the equipment.

Figure 4.—Landing at the Sheep Flats block.



1. Log Truck
2. Hydraulic Loader
3. Hahn Harvester
4. Whole Tree Chipper
5. Truck Tractor used to move Chipper
6. Chip Van
7. Path of Skidder(s)

Figure 5.—Orientation of equipment on the landing as used in the study.

Crew Members and Organizations

Hahn Manufacturing Co. supplied two operators who had some experience with the tree processing machine. We trained the operator responsible for cutting out logs to recognize the tree species and the corresponding log lengths desired. Strong Manufacturing Co. also supplied an experienced operator for the chipper. A logger under hourly contract provided the two rubber-tired skidders, hydraulic loader, sawyer, and an operator for the International feller-buncher. The International tree shear was rented from a local equipment dealer. The Melroe Bobcat feller-buncher and operator were provided by a local contract logger. Champion Timberlands furnished data collectors, who were trained and supervised by the USDA Forest Service study coordinator. Crew supervision for the landing and woods operation was cooperative and flexible to take advantage of various ideas and skills. Most crew members were highly motivated and production conscious.

Data Collection

Time study methods.—Detailed time data were collected at each study area for the shearing, skidding, tree processing, and chipping phases of the logging system. For a sampling period the activity of each machine was timed with a stop watch to the nearest 0.01 minute and the production of each machine tallied. The sampled time for each machine was broken into two parts: that spent in active production and that spent in nonproductive activities, termed downtime. Downtime was further subdivided into categories so that causes of lost production could be identified. The data collected for each machine are described below.

Feller-bunchers.—Feller-buncher production for the tree shears was in trees cut per minute for the sample period. Merchantable and unmerchantable stems were tallied separately. The time spent cutting, the time spent moving, and the downtime were recorded. Periodically, the time spent actually cutting a given stem was recorded for a range of basal diameters. The estimated distance covered moving from stump to tree was also recorded.

Skidders.—Two persons were needed to collect skidder data, a landing observer and a field observer. At the landing the turn number, lapsed downtime, and time spent at several landing activities were recorded. Landing activities recorded included unhook time, time spent clearing the area, and time spent moving stockpiled turns closer to the tree processor and chipper. The field observer recorded lapsed time, turn number, number of trees per turn, hook time, round trip time, downtime, and skid distance. These observations were then combined on a per-turn basis to yield production rates of stems per day and time per turn.

Tree processing.—A single observer recorded lapsed clock-time, number of trees handled, number of logs produced, and downtime for the tree processor. Periodically, processing time per tree was recorded for a range of diameters and species. Production was in produced logs per minute.

Chipping.—A single observer recorded lapsed time, number of merchantable stems, number of unmerchantable stems, and downtime for the chipper by van load produced during the sample period. Tops and limbs were not counted. Production was in number of stems processed per minute or units of chips produced per unit of time. The observers also recorded arrival and departure of chip vans and log trucks and noted other activities or characteristics of the operation that affected production.

Miscellaneous.—The data collection was carried out in such a manner that:

1. Safety of all personnel was ensured.
2. Production personnel did not have to worry about the safety of study personnel.
3. The production process was not affected by the study process.

Production tallies.—Each load of logs received a receipt or "ticket book" number according to Champion Timberlands' practice. Every load of logs was weight scaled at the mill log yard. Scaling frequency (number of loads scaled versus total number of loads) varied from block to block, depending on the number of loads expected. The scaling frequency was 50 percent on the larger blocks and 100 percent on the smaller blocks. Log volume in Scribner board feet was obtained from the scaling data.

Each van load of hog fuel also received a "ticket." Net weights, gross weights, and number of "hog fuel units" were determined by standard accounting and sampling procedures at the unloading facility of a Champion International pulpmill.

Log quality.—Log quality reports were prepared in accordance with standard company procedures. Data were, therefore, available to compare logs manufactured with a tree processor to normally processed logs. Log lengths, broken ends, unsquare bucking, limbs, etc., were evaluated in such reports.

Chip quality.—Samples of chips were analyzed for properties important to papermaking. The percentage of bark content and the percentage of chips over and under a desired size range were determined. Such properties are not critical if the product is used for hog fuel.

RESULTS

System Productivity

Table 1 shows the overall production of hog fuel and logs realized from each cutting block. On a per-acre basis, production of hog fuel (tons/acre) and logs (M bd.ft./acre) varied considerably among the cutting blocks. The clearcut operation in lodgepole pine (Gold Creek) generated the highest per-acre yields of both logs and hog fuel. The partial cutting operations at Sunflower Road and Arkansas Creek generated the next highest per-acre production of hog fuel followed by the shelterwood cutting at Sheep Flats. The order of log production in the partial cuts is reversed. The Sheep Flats operation produced 50 percent more log volume than did the other partial cutting operations at Sunflower Road and Arkansas Creek.

To more accurately assess the differences in system productivity, it is useful to consider production per unit of labor rather than production per acre. Table 2 shows production rates in tons per net man-hour (net time = total time - delay time) for hog fuel and logs for each cutting block.

When productivity is based on time rather than acres, the rankings change. This is because table 2 data indicate how well the system processed the flow of raw materials per unit of labor rather than what was available per acre for the system to process.

The results in table 2 suggest that the system is most productive, in terms of total tons per man-hour, when logs are produced at a rate equal to or greater than that for hog fuel. Two factors that logically affect these rates of production are (1) raw material characteristics and (2) system component interactions.

Table 1.—Summary of study areas and production volumes

Area	Description	Species mix		Production: Hog fuel	Production: Logs
		Percent			
Arkansas Creek	20 acr. (8.1 ha) Slope 4% Shelterwood Maximum skid 800 ft (0.24 km) Haul distance 65 mi (104.6 km) 5 days	PP WL DF	82 15 3	333 units 1 load/acre 25 tons/acre (56.3 t/ha)	71.1 M bd.ft. .9 load/acre 3.6 M bd.ft./acre
Gold Creek	12.7 acres (5.1 ha) Slope 4%-25% Clearcut Maximum skid 800 ft (0.24 km) Haul distance 55 mi (88.5 km) 4 days	PP LLP	2 98	426 units 1.9 loads/acre 44.4 tons/acre (99.9 t/ha)	94.9 M bd.ft. 1.8 loads/acre 7.5 M bd.ft./acre
Sunflower Road	4.5 acres (1.8 ha) Slope 25% Commercial thin Maximum skid 500 ft (0.15 km) Haul distance 55 mi (88.5 km) 2 days	WL LPP DF	90 7 3	142 units 2 loads/acre 43 tons/acre (96.8 t/ha)	17.4 M bd.ft. .9 load/acre 3.2 M bd.ft./acre
Sheep Flats	43.1 acres (17.4 ha) Slope 5% Shelterwood Max. skid 1,000 ft (0.30 km) Haul distance 70 mi (112.6 km) 9 days	PP DF	80 20	607 units 0.9 load/acre 19.4 tons/acre (43.7 t/ha)	224.9 M bd.ft. 1.2 loads/acre 5.2 M bd.ft./acre

Table 2.—Comparison of labor productivity for different logging blocks

Harvest block	Production: Fuel	Production: Logs	Production: Total	Manhours	Production rates: Fuel	Production rates: Logs	Production rates: Total
	Tons				Tons/man-hour		
Arkansas Creek	495	471	966	339	1.5	1.4	2.9
Gold Creek	564	608	1,172	313	1.8	1.9	3.7
Sunflower Road	193	108	300	107	1.8	1.0	2.8
Sheep Flats	903	1,349	2,252	530	1.7	2.6	4.3

With respect to the first item, table 3 shows that the most productive blocks (Sheep Flats and Gold Creek) had roughly 70 percent of the take volume in trees ≥9 inches (22.9 cm) d.b.h., and these trees accounted for 33 percent and 41 percent of the total take stems, respectively. In contrast the least productive blocks had roughly 60 percent of the take volume in trees ≥9 inches (22.9 cm) d.b.h., but these stems were only 17 percent of the total take stems. Thus, the system was least productive where the supply of saw log material was low relative to the supply of chippable material. As with other logging systems, stem size is an important productivity parameter.

Table 3.—Distribution of harvested cubic volume by size class

Harvest block	Percent of take volume: ≥9" d.b.h.	Percent of take volume: <9" d.b.h.	Percent of take stems: ≥9" d.b.h.	Percent of take stems: <9" d.b.h.
Arkansas Creek	64	36	17	83
Gold Creek	70	30	41	59
Sunflower Road	60	40	17	83
Sheep Flats	72	28	33	67

The distribution of volume by size class also appeared to affect productivity of the system through its effect on the system operation. For example, the feller-bunchers could cut 5- to 15-inch (12.7- to 38.1-cm) diameter trees in approximately the same time. Thus, shearing time per cubic foot of production is higher in stands with a large proportion of small stems than in stands with mostly large stems.

The log processor and chipper were also affected by the relative proportion of large and small stems. Table 4 shows the utilization rates for both machines. In the most productive blocks (Sheep Flats and Gold Creek) the processor and chipper had utilization rates of about 70 percent. In the Sunflower block the utilization rate for the processor was only 36 percent.

Table 4.—Machine utilization[1] rates for the tree processor and chipper

Harvest block	Processor	Chipper
	Percent	Percent
Arkansas Creek	65	63
Gold Creek	70	72
Sunflower Road	36	71
Sheep Flats	72	70

[1]Computed from study data:

$$\frac{\text{Net time}}{\text{Gross time}} = \frac{\text{Gross time} - \text{Downtime}}{\text{Gross time}}$$

Gross time = Time under observation

While a portion of this low rate was due to lack of sawable material, a sizeable portion was due to an overabundance of chippable material. That is, the chipper could not chip the small stems fast enough to keep the landing from becoming clogged with this material. The tree processor, as a result, was forced to help feed the chipper and to spend an excessive amount of time sorting sawable and chippable material. Thus, the mix of size classes affects how efficiently the system operates and therefore affects overall productivity.

Component Productivity

Felling, bunching and skidding.—Skidding production data are shown in table 5. The lowest total daily net production was in the Arkansas Creek block, which may have been due to inexperience with the harvest system. Bunches of trees were not properly oriented with respect to the landing in this block. Total daily net production at the Sunflower block was next lowest. This may have been due to the steeper slopes (25 percent) and a relatively large percentage of small trees chipped for hog fuel.

Table 5.—Felling and skidding production

Area	Item	Tons/day[1]-block average: Hog fuel	Tons/day[1]-block average: Logs	Total
Arkansas Creek	Shears	52.7	50.1	102.8
	Skidders	120.8	114.7	235.5
Gold Creek	Shears	67.2	72.5	139.7
	Skidders	148.5	160.2	308.7
Sunflower Road	Shears	49.6	24.9	74.5
	Skidders	177.8	89.3	267.1
Sheep Flats	Shears	83.1	134.2	217.3
	Skidders	119.4	192.8	312.2

[1]Operational days = (total hours-unnecessary downtime)/8 hours.

Two different kinds of feller-bunchers were employed. An International tracked (Model No. 3966-B) feller-buncher accounted for most of the volume logged in the study. The remainder of the felling was accomplished with a Melroe Bobcat (Model No. 1079) feller-buncher. Average production rates for each machine are presented in table 6. They ranged from 343 to 511 trees per day for the International and from 511 to 562 trees per day for the Bobcat.

Table 6.—Production rates for feller-bunchers (block average)

Area	Machine	Trees/day[1]	Utilization[1]
			Percent
Arkansas Creek	International	343	85
Gold Creek[3]	International	511	88
	Bobcat	612	85
Sunflower Road	International	470	86
Sheep Flats[4]	International	386	85
	Bobcat	562	81

[1]Based on the time study samples expanded to an 8-hour shift, downtime included.
[2]Utilization = (total time-downtime)/total time.
[3]The Bobcat worked on slopes less than 10 percent; the International, slopes up to 30 percent.
[4]The Bobcat was used mainly in thicker, smaller diameter portions of the stand.

Several factors affected the International tree shear production. The operator was new to this kind of work and gained experience on the Arkansas Creek block. There was a decided improvement in the orderliness and efficiency of his work in the remaining three blocks. The spacing of leave trees also was a factor, with the operator having greatest freedom in the clearcut situation. Heavy branches, which lodged in adjacent tree crowns, affected handling of the sheared trees. The size of the trees cut had little effect on the shearing and bunching time, unless the stand was so thick that several small stems could be sheared at once. Also, the International feller-buncher did not have an accumulator, so it had to lay down each tree as it was sheared.

The International shear easily felled and bunched trees up to the capacity of the shear opening; i.e., 18 inches (45.7 cm) at the ground level. The Bobcat shear had trouble with the taller trees over 14 inches (35.6 cm) d.b.h. The International shear seemed quite adequate for trees up to 18 inches (45.7 cm) at ground level, on slopes up to 30 percent. Because of its small size, the Bobcat had trouble with large trees on slopes over 10 percent. Under favorable conditions (flat ground, small stems, etc.), the Bobcat was slightly more productive than the International machine. Because the Bobcat could travel fast with a sheared stem, the operator made larger bunches, which raised skidding production.

Skidding was done by two John Deere Model 640 rubber-tired skidders. One machine was equipped with a grapple, the other with standard chokers and winch. The machines generally performed different functions, so direct comparisons of production were not possible. Time study data, however, did contain information on hook/unhook time, which provided a basis for comparison with respect to one of the factors that influences production. Table 7 gives hook/unhook times for the two skidders.

The table shows that hook time for the grapple machine was considerably less than that for the choker machine. Unhook time was more similar, though the grapple machine still required less time.

Table 7.—Hook/unhook times for John Deere skidders

Date	Location	Average hook time/turn: Grapple	Average hook time/turn: Choker	Average unhook time/turn: Grapple	Average unhook time/turn: Choker
		Minutes			
8/06	Arkansas Creek	0.8	3.9	0.63	0.67
8/08	Arkansas Creek	.4		.44	
8/11	Gold Creek			.40	
8/12	Gold Creek	.99		.37	
8/15	Sunflower Road				
8/22	Sheep Flats	.24	4.72	.46	.78
8/27	Sheep Flats	.59		.33	

Tree processing.—Average production rates for the tree processor are given in table 8. Daily production rates are given in appendix B. In terms of tons of logs produced per day, the greatest average rate was attained at the Sheep Flats block, nearly 200 tons (182 tonnes)/day, and the least at the Sunflower block, less than 90 tons (82 tonnes)/day. The difference was probably due to the supply and size of saw log and chippable stems and their effect on the system balance. Based on total observed time of the tree processor, production in logs/minute ranged from 0.7 to 1.0, a difference of 144 logs in an 8-hour shift. Because of the extent and type of downtime included in the total time, these figures are difficult to compare. When all downtime is removed, however, only processing times remain and comparisons become more meaningful. Table 8 indicates that logs were processed considerably faster in the Sunflower and Gold Creek blocks than in the Arkansas Sheep Flats blocks. These differences are largely because larch and lodgepole pine can be processed faster than limby "bull pine" (ponderosa).

Table 8.—Tree processor production rates

Area	Tree processor: Tons/day[1]	Tree processor: Logs/min[2] Total time	Tree processor: Logs/min[2] Net time	Whole-tree chipped: Tons/acre
Arkansas Creek	114.7	0.7	1.0	120.8
Gold Creek	160.2	1.0	1.4	148.5
Sunflower Road	89.3	.7	2.1	177.8
Sheep Flats	192.9	.8	1.1	119.4

[1]The operational hours (total time – unnecessary downtime) were divided into total tons of logs produced (scale tickets).
[2]Based on time study data. Total time is full observation period; net time is total time minus all downtime. Appendix A details the tree processor productivity.

The Hahn Harvester representative said our production was low. He considered one load of logs per hour a reasonable goal. At an average of 90 logs per load, this translates to 1.5 logs per minute. While the net processing rate exceeded this figure in two blocks, the gross rate was only about half that value for the rest of the blocks. The chipping operation may have slowed down the log processor. This happened in the Sunflower block, where the tree processor had to be shut down on several occasions to allow the chipper to catch up. It also happened on the other blocks when the tree processor grapple was used to segregate saw log and chippable material in the turns rather than maintaining a steady supply of tree lengths to the processor. These events were not recorded; however, a low production rate may be expected when the machine is part of a system that produces both logs and hog fuel. Appendix B presents daily tree processor productivity on both gross and net time basis. Utilization percentage is also shown. These daily figures reflect block differences, daily production problems, and the learning process during the study.

Of 99 loads of logs produced in the study, about 56 were scaled and inspected under the Champion Timberlands log quality program. Two loads produced in the first harvest block showed total log defects of 36 and 23 percent, respectively. After these two adverse reports were received, a concentrated effort was made to improve log quality by instructing the processor crew in species bucking specifications. The remaining log quality reports averaged 9.3 percent total defect. During the month of the study, log quality reports from the Champion Timberlands operations averaged 12 percent defect. Figure 6 shows the quality of delimbed logs.

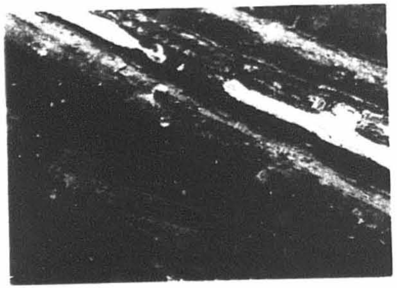


Figure 6.—Deck of delimbed study logs.

Initially, some loggers said that shearing would cause massive defects through "butt shatter" or stem crushing. Such damage was less than one-half inch on most logs. Figure 7 shows butt ends of some sheared trees. The tree butts that were substandard were trimmed by the tree processor's hydraulic chainsaw. Stem crushing might have been more severe if frozen trees were being harvested.

Some machine damage to logs can result if too much pressure is placed on the delimber knives of the tree processor. This pressure is controllable by the machine operator and should not be a problem with an experienced crew. Some "limb pull" defect was noted during the first part of the study. This defect was caused by a slow delimber knife speed that produced more of a pulling than a shearing action. A change to a high-speed sprocket drive on the delimber unit reduced the problem.

Figure 8 shows accumulated tops and limbs from the tree processor. An overaccumulation of this material plugs up the landing and requires the tree processor grapple to be used to feed the chipper.

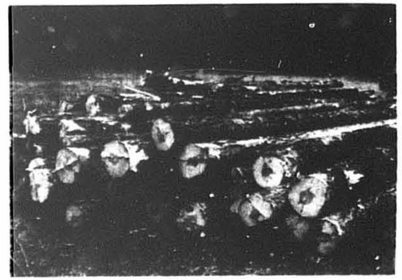


Figure 7.—Sheared logs decked for loading.

Figure 8.—An accumulation of tops and limbs from the tree processor.

Whole-tree chipping.—The average production rates in tons per day are given in table 8. A high of nearly 180 tons (164 tonnes)/day was achieved in the Sunflower block and a low of about 120 tons (109 tonnes)/day at the Sheep Flats block. Although the average utilization rates of the chipper are similar in all blocks (table 4), production rates varied considerably. (See also appendix C for daily productivity utilization.) Much of the variation was due to the kind of material chipped. In the Sunflower block and the Gold Creek block, many of the stems skidded to the landing were just under saw log size, were quite tall, and had few limbs (larch and lodgepole pine). This material produced more chips at a faster rate than the limbs and tops, which provided a greater proportion of the input of the Arkansas and Sheep Flats block.

Saw log recovery (M bd.ft./acre) was less than the preharvest cruise indicated. We attribute this to the difficulty of judging whether a small (marginal) tree will produce the minimum-sized log, especially from the cabs of the tree processor or whole-tree chipper. Apparently, the marginal trees looked smaller than they really were. For example, the Gold Creek block contained many marginal saw log stems. The cruise estimated a recovery of 11.5 M bd.ft./acre. The actual recovery was 7.5 M bd.ft./acre. Identification of marginal saw log trees may or may not be a problem, depending on the relative values of marginal logs and whole-tree chips.

The chipper used in this study was set up to produce 3/4- to 1-inch chips. Hog fuel specifications, however, allow chip thicknesses up to 2 inches (5.1 cm). The chipper operator suggested that if his machine were modified (a standard factory procedure) to produce 2-inch (5.1-cm) chips, chipping rate would be increased by 25 percent. Such an increase in chipping rate would be highly desirable in areas like the Sunflower block, where chipper capacity limited log production by the tree processor. Production of large chips could cause increased wear on the chip vans, especially on tarps or other areas that receive the full impact of blown chips.

Chip vans.—The chip vans used in this study were designed for highway use. The investigators had thought that off-highway use would require van reinforcement and that the tractors should be geared the same as log trucks. An inquiry was made as to the types of chip vans and tractors used in the Upper Peninsula of Michigan.[5] In that region, special tractor gearing or chip van reinforcement **is not** considered necessary. Apparently, there is also little significant difference in gearing systems between highway and log trucks. Log trucks utilize a slightly lower gear ratio to help them start loads moving on steep grades or soft ground. Even in the Rocky Mountains, whole-tree chipping operations would probably be conducted on reasonably gentle terrain. Also with a whole-tree logging system, skidders would be available to assist trucks. Normally, log loading occurs after skidders have stopped working in an area.

During the study, chip vans were loaded by blowing chips through the rear door. This often resulted in illegal loads due to poor weight distribution. A possible solution would be to load over the top of the van, using a U-shaped spout that would distribute the chips more evenly. Top filling would also eliminate the unfavorable orientation of the chip vans on the landing (see fig. 2). For landings of limited size without adequate turnaround space, this modification would be essential. Figure 9 shows a landing that required much less area than the landings shown in figure 4. Steep terrain limited the landing size.

[5]Personal communication with Mike Coffman, silviculturist with Champion Timberlands, Lake States Operation, Norway, Mich.

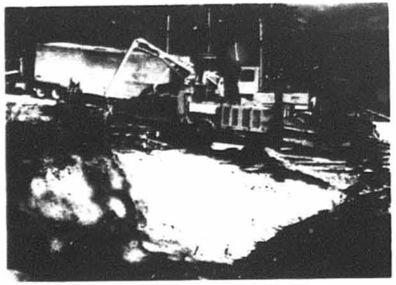


Figure 9.—Landing operation on restricted steep terrain.

Log loading.—The use of a tree processor was expected to reduce the log loading time. In a conventional system, decked logs are seldom completely limbed and a landing sawyer or "knotbumper" is required to finish delimbing the logs. Loading times for logs from stands similar to those harvested in this study are typically 1 to 1.5 hours per load. Loading times for three of the study areas are given in table 9.

The table shows that load times in all areas were well under the 1 to 1.5 hours required in conventional systems. The few logs that had limbs after processing by the tree processor were delimbed by the loader operator.

Table 9.—Loading times for Hahn Harvester processed logs

Area	No. of loads	Average logs/load	Average load time
			Minutes
Gold Creek	12	84	28
Sunflower Road	4	95	31
Sheep Flats	54	55	24

Fuel consumption.—Fuel consumption data for the tree processor, chipper, and feller-bunchers are shown in table 10. These data are given because of the relative newness of this logging equipment.

Table 10.—Fuel consumption rates

Machine	Operating hours	Diesel fuel	Consumption Rate	
		Gallons	*Gal/h*	*Tons/gal*
Hahn Harvester	111.6	439	3.9	5.8
Trelan chipper (Model DL-18)	111.6	884	7.9	2.4
International (Model 3966-B feller-buncher)	142.7	387	2.7	6.9
Bobcat feller-buncher (Model 1075)	77	84.7	1.1	23.8

Evaluation as a Forest Management Tool

The potential of the system to accomplish various forest management tasks was evaluated in this study. Accomplishment is evaluated in the following section.

Two tasks were: (1) feasibility of thinning stands and (2) clearing stands of small timber for regeneration on a commercial basis. Silvicultural method has little effect on the economics of this logging system. Profitability is more closely related to the balance between saw log and hog fuel production. In stands where the supply of hog fuel material was large, log production was reduced. Unfortunately, saw logs are the higher valued product, and idling of the tree processor increased costs and decreased profits.

Commercial thinning treatment is of little value if residual stand damage is high. When cutting and skidding were properly laid out, stand damage was minor and much less than conventional logging in the same stands. Where stand regeneration is desired, such as in clearcutting and seed tree cutting, the system works very well since there are few standing trees to hinder the skidding operation. In some cases, a good job of scarification to encourage natural regeneration can be achieved in the process of skidding bunches of tree-length stems. The effectiveness of the scarification will depend on several factors. We observed that skidding of coarse-limbed ponderosa pine was more effective than skidding of finer branched species. Also, soil conditions can be critical. Certainly, skidding on frozen or snow-covered soils will produce little scarification. The Arkansas Creek block was harvested in August during a Douglas-fir seed year. Scarification was excellent. The following growing season was moist. Due to this fortunate combination of events, it appears that adequate natural regeneration has occurred. Figure 10 provides a comparison of before and after harvesting conditions on some of the harvest blocks. Slash treatment was not necessary on any of the blocks harvested.

It is a well-known fact that risk of insect attack is increased when partial cutting ponderosa pine stands, due to the improved breeding conditions for *Ips* bark beetles (*Ips pini*) in the accumulation of green slash. Whole-tree utilization definitely eliminates this problem. Only minor amounts of slash consisting of fine branches that quickly dry and become unsuitable habitat for bark beetles are left in the stand.

Whole-tree utilization eliminates piling and burning. On the experimental logging blocks, one or two slash piles on landings were burned. These were made up of fine branches, soil, and stones. It was not considered worth the damage to chipper knives to process the material.

Air pollution due to slash burning is of concern in the study area. Air temperature inversions in the mountain valleys often limit the number of days when burning can be accomplished. Therefore, reduction in the total amount of material to be burned is a definite advantage for this harvest system because it reduces the cost of burning dependency on suitable weather and fuel conditions.

Stand access for current and future harvests was definitely improved by the use of feller-bunchers. The low stumps greatly reduced skidding problems. Also, smaller material that is normally pushed over during skidding was chipped for hog fuel. Elimination of the small trees also facilitated the skidding

Visual impact of logged areas, especially along heavily traveled routes, is often a major concern. The appearance of all the blocks harvested by this system was esthetically satisfactory. This harvest system could probably be used in visually sensitive areas.


ARKANSAS

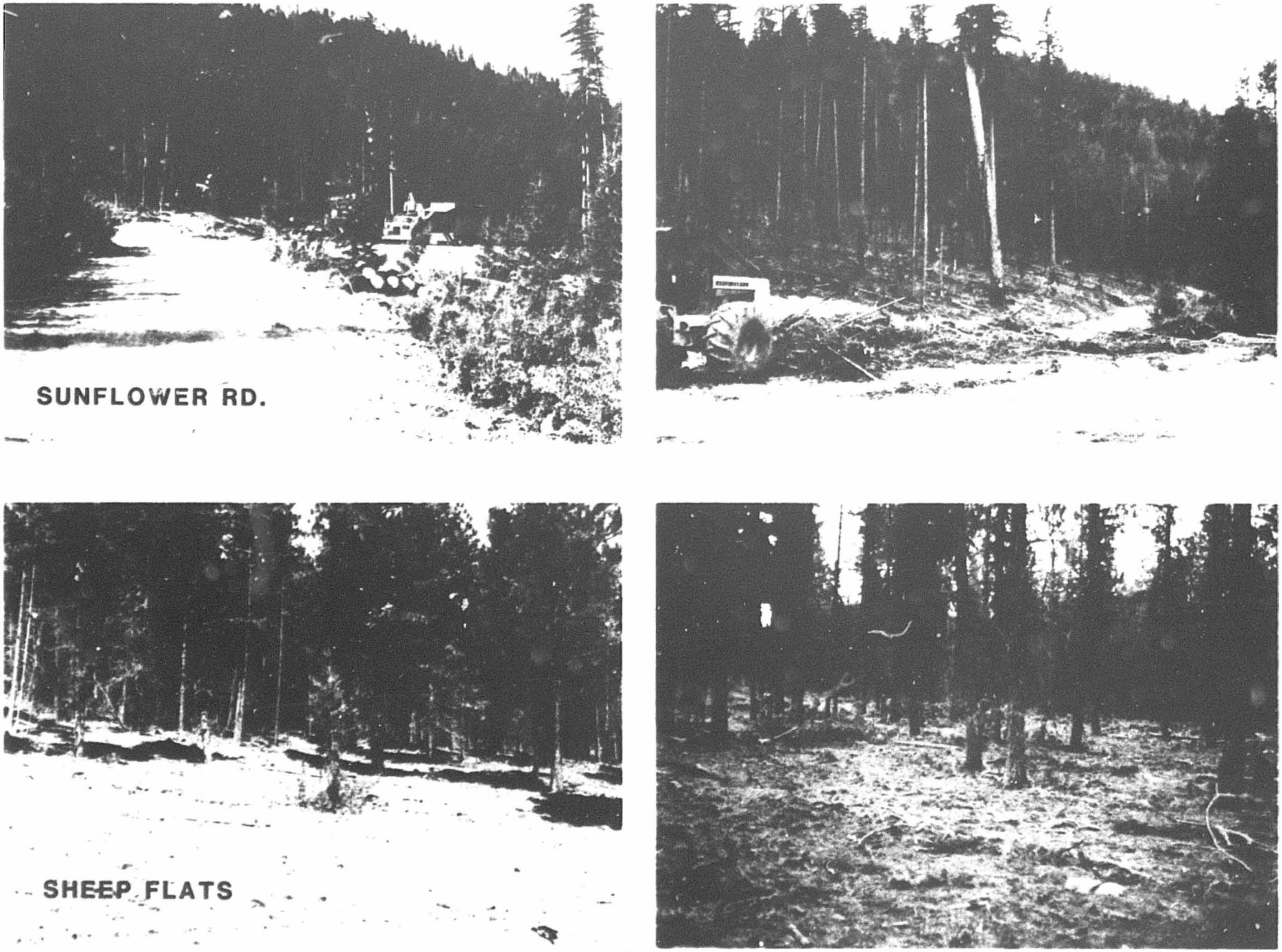


Figure 10.—Before (left and after (right) logging views of study blocks.

13

SUMMARY AND RECOMMENDATIONS

The major reasons for this study were:

1. "Second-growth" and "small-log" harvesting costs are currently high; and new logging systems are urgently needed to handle this material efficiently and economically.
2. Methods to harvest biomass fuels and fiber efficiently and economically are also urgently needed.
3. Highly mechanized and specialized logging systems often prove to be necessary in managed stands. In the past, construction equipment with only minor modifications was sufficient to log large, high-value old growth.

The results of this study indicate that the harvest systems studied can produce a mix of hog fuel and logs at acceptable rates over a range of stand and site conditions under a variety of silvicultural prescriptions. Generally, the system is most productive (tons/man-hour) on gentle terrain in stands where the supply of sawable material is equal to or greater than the supply of chippable material. The results suggested that the system studied can operate profitably in stands where conventional systems would be uneconomical. This competitive advantage will increase as the value of small diameter material rises.

Recommendations for inclusion of this system in Champion Timberlands operation are based on:

1. Relative economics of this harvesting system compared to conventional methods.
2. The current need for wood as an alternative fuel source.
3. The place of this harvest system in overall logging programs.
4. Potential uses and abuses of the logging system.

We recommended that Champion Timberlands equip at least one crew with a tree processor, whole-tree chipper, two feller-bunchers, and two grapple skidders for a truly operational test of this harvest system. This crew should produce in excess of 15,000 units of hog fuel and 3 million board feet of logs in a 200-working-day year. Approximately 1,000 acres (404.7 ha) would be treated, yielding an average log volume of 4 M bd.ft./acre. The recommendation is assumed to be economically sound because the experimental harvest system produced logs at a favorable production rate relative to conventional logging. Also, hog fuel was produced at a cost about equal to current market prices. Within modest hauling distances, hog fuel can be produced more cheaply than hauling it from remote mill sites.

Because of terrain and weather in the Rocky Mountains, woods operations must be scheduled for areas that are suitable for summer-fall, winter, and spring logging conditions. Winter logging opportunities are confined to relatively low elevations and gentle slopes. The harvest system described in this report is limited to the same type of ground and might compete with conventional logging equipment for winter ground. This can be avoided by using the whole-tree system in stands where it has an advantage. For example, in the summer and fall, lodgepole and true fir could be clearcut on high elevation, gentle slopes. In the winter and spring, commercial thinning of ponderosa pine could be a specialty. The whole-tree harvest system has several advantages in such sites over conventional logging systems. Visually sensitive areas could also be a specialty of whole-tree logging.

Potential abuses include overthinning of stands that are being commercially thinned. Also winter game ranges could be temporarily stripped of storm shelter and forage during a commercial thinning. Perhaps whole-tree logging should be limited, as are clearcuts, to blocks under 40 acres unless large clearcuts are justified.

APPENDIX A

VOLUME AND LEGAL LOADS FOR STANDARD CHIP VAN AND TRACTOR COMBINATIONS

Trailer type	Volume	Montana legal gross weight (lb) including tractor	Estimated net weight (lb of hog fuel)	Approximate number of hog fuel units
	Ft³			
40-foot "flat bottom"	2,600 (73.6 m³)	78,600 (35.8 t)	49,700 (22.6 t)	17.7
45-foot "flat bottom"	3,200 (90.6 m³)	78,600 (35.8 t)	49,700 (22.6 t)	17.7
45-foot "drop belly-tandem axle"	3,500 (99.0 m³)	78,600 (35.8 t)	49,700 (22.6 t)	17.7
45-foot "drop belly-spread axle"	3,500 (99.0 m³)	79,400 (36.2 t)	50,100 (22.8 t)	17.9

APPENDIX B

TREE PROCESSOR PRODUCTIVITY

Date	Location	Logs/day[1]		M bd.ft./day[1]		Utilization
		Gross time	Net time	Gross time	Net time	
						Percent
08/04	Arkansas Creek	211	312	15.4	22.7	68
08/05	Arkansas Creek	316	456	23.0	33.2	69
08/07	Arkansas Creek	417	552	30.4	40.1	76
08/08	Arkansas Creek	278	561	20.2	40.8	50
	Average	*311*	*475*	*22.6*	*34.7*	*65*
08/11	Gold Creek	581	682	28.1	32.9	85
08/12	Gold Creek	523	658	25.3	31.8	80
08/13	Gold Greek	364	619	17.6	29.9	59
	Average	*461*	*658*	*22.3*	*31.8*	*70*
08/15	Sunflower Road	278	1,334	12.7	60.8	21
08/18	Sunflower Road	360	695	30.5	58.9	52
	Average	*319*	*1,014*	*21.6*	*59.0*	*36*
08/19	Sheep Flats	576	662	48.8	56.1	87
08/20	Sheep Flats	370	504	31.4	42.7	73
08/25	Sheep Flats	389	576	33.0	48.8	68
08/26	Sheep Flats	264	451	22.4	38.2	59
08/27	Sheep Flats	370	499	31.4	42.3	74
	Average	*393*	*538*	*33.3*	*42.3*	*72*

[1] A day consists of 8 hours of production per shift.

APPENDIX C

WHOLE-TREE CHIPPER PRODUCTIVITY

Date	Location	Average minutes per HF[1] unit		Average minutes per load		Utilization
		Gross	Net[1]	Gross	Net	
						Percent
				Mean Load = 16.6 HF Units		
08/04	Arkansas Creek	7.6	5.4	127.0	90.0	71
08/05	Arkansas Creek	4.5	3.9	74.4	64.6	87
08/07	Arkansas Creek	3.3	3.1	55.0	50.9	93
	Average	*4.7*	*4.1*	*78.7*	*64.5*	*84*
				Mean Load = 17.0 HF Units		
08/11	Gold Creek	4.5	3.7	76.8	62.2	81
08/12	Gold Creek	4.6	3.4	78.0	58.0	74
08/14	Gold Creek	4.2	3.6	71.3	44.1	61
	Average	*4.4*	*3.2*	*75.4*	*54.8*	*72*
				Mean Load = 14.2 HF Units		
08/18	Sunflower Road	4.0	2.8	56.8	40.1	71
				Mean Load = 16.4 HF Units		
08/20	Sheep Flats	4.9	3.4	80.2	56.2	71
08/21	Sheep Flats	5.5	4.6	90.6	74.8	82
08/25	Sheep Flats	4.9	2.8	80.8	45.7	56
08/26	Sheep Flats	6.2	3.8	101.9	62.9	62
08/27	Sheep Flats	4.4	3.2	72.8	51.9	71
08/28	Sheep Flats	4.9	3.4	79.6	56.0	70
	Average	*5.1*	*3.5*	*84.3*	*57.9*	*69*

[1] HF = hog fuel.
[2] Net time = gross time – delay time

Mandzak, John; Milner, Kelsey S.; Host, John. Production and product recovery for complete tree utilization in the Northern Rockies. Res. Pap. INT-306. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 17 p.

Thinning operations on four different cutting blocks were monitored. The logging system consisted of feller-bunchers, grapple and choker skidders, and on the landing a whole-tree processor, chipper, and hydraulic loader. Variation in productivity among study areas was analyzed with respect to stand and site characteristics. Product alternatives and volumes were evaluated. Results indicated that (1) logs and chips can be produced at acceptable daily rates of 89 to 193 tons of logs and 119 to 178 tons of chips, (2) the proportions of saw logs and chippable material in the stand affect system productivity, and (3) complete utilization of slash provided additional benefits compatible with public and private forest management goals.

KEYWORDS: logging productivity, commercial thinning operations, product recovery

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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