HARVESTING ECONOMICS AND WOOD FIBER UTILIZATION IN A FUELS REDUCTION PROJECT: A CASE STUDY IN EASTERN OREGON

CAMERON G. BROWN
LOREN D. KELLOGG

ABSTRACT

A single-grip harvester and a small skyline system were combined to salvage log and thin a 40-acre (16.2-ha) site on flat terrain in eastern Oregon. The objectives were to reduce fuel loading, improve growing conditions for trees, and minimize soil impacts from logging. A total of 403 thousand board feet (MBF) (813 cunits, or 2301 m^3) of small sawlogs and pulpwood were harvested, 14 percent of which came from dead and standing material; 44 percent from dead and down material; and 42 percent from live material. Live stems with a minimum diameter of 5 inches (12.7 cm) were utilized as sawlogs; all other material was utilized for pulpwood. Of the total volume, 29 percent was sawlogs and 71 percent was pulpwood. Sawlogs were profitable to log based on their value of $515/MBF, whereas pulpwood was logged at a loss based on its value of $36/ton in log form. Sawlog revenues compensated for pulpwood losses, resulting in a profit of $611/acre ($1,505/ha) from revenues of $2,581/acre ($6,374/ha) and costs of $1,970/acre ($4,869/ha).

Almost every pioneer journal describing the Blue Mountains portion of the Oregon Trail in the 1850s marveled at the "tall magnificent pines, large grassy openings, and the lack of underbrush" (6). These forests currently bear little resemblance to their earlier descriptions, due in part to a combination of management practices and natural occurrences. Wickman (22) characterized the present-day stands as "thickets of sapling and pole-sized fir severely defoliated by western spruce budworm, scattered Douglas-fir (*Pseudotsuga menziesii* var *glauca*) and grand fir (*Abies grandis*) being killed by bark beetles, pockets of root disease killing fir, and scattered second growth stands of ponderosa pine that often are infected with dwarf mistletoe." Many stands are overstocked, contain standing dead or dying trees, and have medium to heavy levels of surface fuels. Where frequent, low-intensity fires once reduced the natural understory regeneration and eliminated buildup of woody debris on the forest floor, fire suppression has allowed the stands to become dense and accumulate excessive downed woody debris (1,10). Frequent insect infestations, pathogens of coniferous trees, and severe droughts have also contributed to the deterioration of the stands (20,22). The possibility of highly destructive wildfires now seriously threatens the forests and surrounding areas. Thinning overstocked stands and salvage logging merchantable standing dead or down timber would help reduce the fuel loading and improve tree vigor.

Although many acres in this condition were salvage-logged during the 1980s, markets for fiber were limited. Today, higher demand for small sawlogs and wood fiber has increased their market value and provided opportunities for economic treatment of these stands. The fiber obtained from salvage logging and thinning may generate enough revenue to completely offset the cost of management and provide an economical supply of wood fiber, while improving stand conditions and reducing the risk of catastrophic fire.

Logging systems on gentle terrain in the Blue Mountains of eastern Oregon traditionally have utilized rubber-tired skidders, crawler tractors and, more re-

The authors are, respectively, Research Assistant and Professor, Dept. of Forest Eng., Oregon State Univ. (OSU), Corvallis, OR 97331. The authors would like to thank the logging contractors involved in the Deerhorn study for their cooperation during the project. The harvester contractor was Forest Recovery Systems of Baker City, OR; the yarding contractor was McCaulley, Inc., of Port Angeles, WA. The Louisiana-Pacific employees of Pilot Rock, OR, and Walla Walla, WA, and USDA Forest Service personnel on the La Grande Ranger District also deserve our thanks for their help with this project. This research was supported by the USDA Wood Util. Special Grant Pro., by a USDA Forest Service PNW Res. Sta. Coop. Agreement and by the OSU Strachan Res. Fund. This is Paper No. 3126, Forest Res. Lab., OSU. Mention of a brand name does not imply endorsement by the authors or by OSU. This paper was received for publication in October 1995. Reprint No. 8447.

Forest Prod. J. 46(9):45-52.

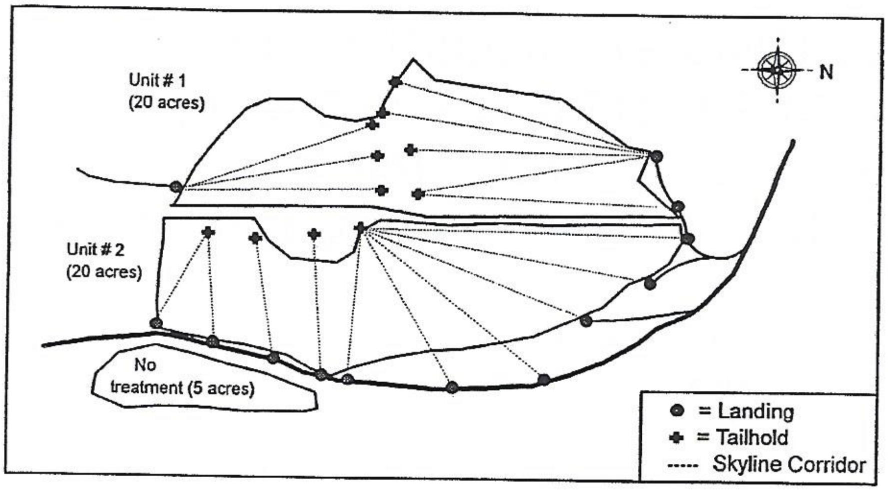

Figure 1. — Study unit layout.

cently, forwarders. With careful planning and quality control, such systems have proven economically feasible and environmentally sensitive on flat to moderate terrain (3,4,7-9,11). However, forest operations on some sites must be approached extremely carefully, particularly with respect to soil disturbance and compaction. Such is the case for several watersheds in eastern Oregon that provide the water supply for urban areas, critical habitat for endangered fish species, or both. Severely burned areas with erosive soils and nearby riparian areas also require minimal soil impacts during salvage logging.

The extreme tree mortality and high fuel levels in many of these sensitive watersheds led the La Grande Ranger District of the Wallowa-Whitman National Forest to explore management of the stands within environmental constraints. Potential alternative harvesting systems were assessed for their ability to reduce fuel loading and improve stand structure while minimizing soil impacts. A relatively new combination of conventional logging equipment—a single-grip harvester and a small skyline yarder—was identified for a pilot study of salvage logging and thinning on flat terrain. The study, referred to as the Deerhorn Project, was designed and conducted as a collaborative effort among the USDA Forest Service, Louisiana-Pacific Corporation, the PNW Research Station, the Blue Mountain Natural Resources Institute, and Oregon State University.

Both the single-grip harvester and the skyline yarder produce minimal soil impacts. A harvester generally passes over the soil in a harvest unit only once, often traveling on a mat of slash produced by delimbing trees in front of the machine. A skyline cable system eliminates the repetitive passes of ground-based vehicles such as skidders or forwarders over the forest soil; logs are transported to landings by cables suspended above the forest floor. Use of a similar system in a South African study of clearcutting eucalyptus resulted in "insignificant soil impacts" (13).

The objectives of the Deerhorn Project were to address the following questions about treatment with the harvester/yarder combination: 1. Is harvesting fiber material and small sawlogs on flat terrain with such a system economically feasible? 2. Can fuel loads be reduced to acceptable levels? 3. How much soil disturbance and compaction can be expected? 4. How does the treatment affect small mammals and log-dwelling ants?

This paper focuses on the first objective: assessment of the productivity and economic feasibility of the logging system. Fuel reduction and soil impact results have been presented elsewhere (19), and animal studies are in progress.

Study Site and Silvicultural Strategy

The study was conducted on 40 acres (16.2 ha) of Louisiana-Pacific Corporation land on Deerhorn Ridge, southwest of Pendleton, Oreg. The site consisted of two adjacent units that were generally flat with undulating terrain at a maximum slope of 10 percent. Soils were deep, well-drained silty loam formed from volcanic ash.

The overstory consisted of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), grand fir (*Abies grandis*), western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), and lodgepole pine (*Pinus contorta*). The lodgepole pine, which had been severely damaged by mountain pine beetle (*Dendroctonus ponderosae*) in the 1970s, was mostly dead and lying on the forest floor. Other stand health concerns included defoliation of grand fir and Douglas-fir by western spruce budworm (*Choristoneura occidentalis*), dwarf mistletoe (*Arceuthbium douglasii*) in the Douglas-fir, and scattered grand fir with dead tops.

The study area varied considerably in structure and represented typical mixed conifer stand conditions in much of the Blue Mountains of eastern Oregon. The average diameter at breast height (DBH) was approximately 9 inches (23 cm), and there were over 1,000 stems per acre (2,471/ha) in some areas of the unit. Tree heights and down-log lengths ranged from approximately 20 feet (6.1 m) to 80 feet (24.4 m). The silvicultural objectives prepared by the La Grande Ranger District were to: 1) reduce fuel loading in the area; 2) increase stand vigor by eliminating diseased trees and thinning the green trees to 80 to 90 trees per acre (198 to 222/ha); and 3) provide some late forest structure in a landscape dominated by younger pine stands. The prescription also required that 50 pieces of woody debris be left on each acre (124/ha) to provide habitat for ants and small mammals. The pieces were to be at least 5 inches (12.7 cm) in diameter and 6 feet (1.8 m) long. Accomplishing these silviculture objectives with harvesting operations means that logging is primarily salvaging dead or dying trees and down wood as pulplogs. An additional sawlog component is added when some needed thinning of overcrowded green trees is conducted.

Logging Layout, Equipment, and Operations

The existing road into the study units required some improvement. Additional roads were not constructed inside the unit boundaries, requiring the yarder to set up at locations around the perimeter of the units (**Fig. 1**). Several short spur roads were built to gain access to the unit boundaries.

LAYOUT

Logging layout for this study included the design and field work associated with identifying road locations, landings, and skyline corridors. Unit boundaries had been located and residual standing trees had been marked by the USDA Forest Service before the study began. Logging layout work was completed by an experienced timber consultant with direction from the yarding contractor and Louisiana-Pacific.

Skyline corridor layout for the cable system was crucial in achieving productive operations and environmental protection. Skyline roads were flagged before felling began, and potential intermediate support trees and tailtrees were marked to prevent their removal by the harvester operator. Each skyline road had a designated landing and tailtree, along with at least one potential intermediate support location if the span was longer than 450 feet (137 m). Preference was given to double-tree intermediate supports; however, both single-tree and double-tree supports were identified, depending on the availability of suitable trees. Where possible, intermediate supports were placed so as to provide the most benefit (i.e., at midspan or terrain breaks), but the small trees and patchy nature of the stand provided few options. Skyline corridors were spaced approximately 150 to 250 feet (46 to 76 m) apart, depending on the orientation of the corridors. Skyline deflection analysis was helpful in skyline road planning for determining intermediate support and tailtree locations and the rigging heights needed to obtain partial log suspension and protect the soil during yarding.

SINGLE-GRIP HARVESTER

The single-grip harvester consisted of a Link Belt "C" Series II tracked carrier (LS 2800), a Pierce modified feller buncher boom, and a Waratah 20-inch single-grip hydraulic felling and processing head (**Fig. 2**). Its original purchase price in 1992 was $345,000; the hourly owning, operating, and labor cost, including support equipment in 1994 was calculated to be $89.41 per scheduled machine hour (SMH) (5). The harvester operator was responsible for felling and processing unmarked standing trees and processing merchantable dead and down stems. Processing involved delimbing, topping, measuring, and bucking both sawlogs and pulplogs into predominately 16- or 32-foot (4.9- or 9.8-m) lengths; some pulplogs were cut at random lengths. Sawlogs and pulplogs were sorted at the landing. There was no recutting of logs and, therefore, little woodwaste occurred at the deck area. The harvester processed strips approximately 50 feet (15.2 m) wide that were generally parallel to the marked skyline corridors. Operating parallel to the corridors whenever possible resulted in better log orientation for cable yarding. The harvester operator had operated similar machines for 4 years, but this operation was his first attempt at felling and processing timber for a cable yarding operation.

SKYLINE YARDING

The yarding system consisted of a 1994 Koller K501 yarder (trailer mounted) combined with a 1993 Eagle Eaglet radio-controlled slackpulling carriage (**Fig. 3**). The Koller yarder had a tower height of 33 feet (10 m) and three drums to hold the skyline (0.75 in., (19.1 mm)), mainline (0.5 in., (12.7 mm)), and haulback line (0.375 in., (9.5 mm)). The system's purchase price, including lines and rigging, was $166,500; its 1994 hourly owning, operating, and labor cost, including support equipment, was calculated to be $132.79/SMH (5). The yarding crew consisted of a hook tender (20 yr. of experience), a rigging slinger (10 yr. of experience), a choker setter (2 yr. of experience), and a yarding engineer (1 yr. of experience). The crew were skilled at climbing and rigging tailtrees, but new to logging on flat ground with intermediate supports.

The cable system was rigged as a standing skyline that utilized tailtrees

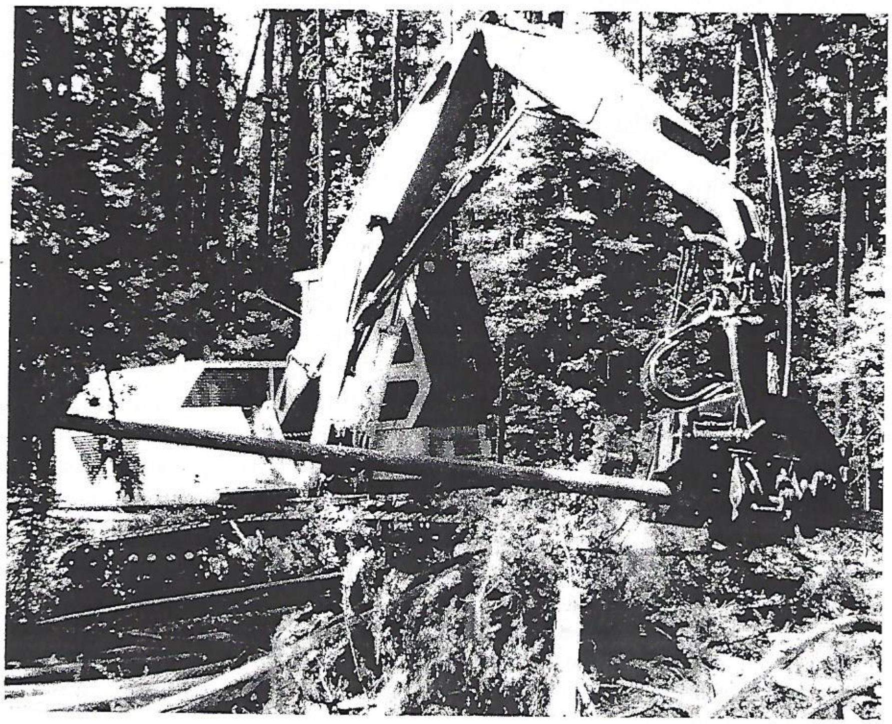

Figure 2. — Link belt tracked carrier fitted with a Waratah single-grip harvester head.

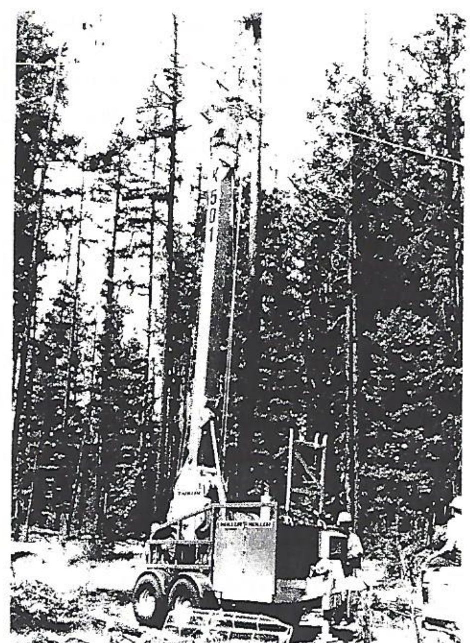

Figure 3. — Koller K501 yarder.

Table 1. — Gross volumes removed from the 40-acre (16.2-ha) study unit.

Measure	Sawlogs	Pulplogs	Total
Logs	6,461	14,460	20,921
Cunits	226	587	813
MBF	115	288	403
Tons	635	1,222	1,857
m^3	639	1,662	2,301

Table 2. — Average log descriptions.

Measure	Sawlogs	Pulplogs	All logs
Small-end diameter (in.)	6.91	4.37	4.77
	(17.6 cm)	(11.1 cm)	(12.1 cm)
Length (ft.)	19.30	18.32	18.47
	(5.88 m)	(5.58 m)	(5.63 m)
$Ft.^3$/log	7.00	3.41	3.89
BF/log	35.73	16.73	19.26
Ton/log	0.194	0.069	0.089
m^3/log	0.198	0.097	0.110

and, occasionally, double-tree intermediate supports to create multiple spans. A haulback line was necessary to pull the carriage out into the setting because of the flat terrain. The yarding engineer controlled the movement of the carriage along the skyline, but all other carriage functions were controlled by radio signals from the rigging slinger. All chokers were preset with four chokers typically used per turn. The yarding engineer was responsible for unhooking the turn at the landing.

In the yarding/loading phase, the processed logs were moved to the landing and then loaded onto trucks. The loader worked with the yarder to clear the landing chute and to deck logs into two sorts (pulp or sawlogs) or load waiting log trucks. The loader was a 1994 John Deere 690 ELC grapple loader; its hourly owning, operating, and labor cost in 1994 was calculated to be $67.64/SMH (5).

Data collection

Logging production and cost information was obtained on the harvester, yarding, and loading operations through several types of studies. Shift-level studies summarized production, scheduled hours worked, and delay-free hours each day. Shift-level information was collected on forms filled out by the timber layout consultant, the harvester operator, the yarding engineer, and the loader operator (5). Intensive, short-term sampling studies provided details that could not be captured in the shift-level approach. Every truckload was weight-scaled, and data on volumes and log grades were obtained by roll-out scaling every sawlog load and every third pulpwood load.

Intensive sampling took place at random times throughout the operation. An activity sampling study that collected 50 samples of 20 trees being felled and processed was performed on the harvester. In each of the 50 harvester activity samples, operations were recorded in 1 of 8 categories every 12 seconds until 20 stems had been processed. A typical sample lasted approximately 15 minutes. These samples defined the proportion of time spent on specific activities and provided detailed information on harvester production and log types produced. A detailed time study of the yarding cycle that included approximately 500 samples (yarding cycles) quantified the time spent on each segment of the cycle and provided detailed information on the yarding operation. In addition, data were collected on 7 skyline road/landing changes and 22 truck-loading times.

Logging costs per scheduled hour were calculated from the owning, operating, and labor costs associated with the equipment and personnel used in this study; they do not include an allowance for profit or risk. Calculated cost rates were similar to the contract rates used in this logging operation. The scheduled hours for each component of the logging operation were obtained from the shift-level studies. The contractor did not own his own log trucks; therefore, log hauling was contracted on a ton basis. Because data on the trucking component of the operation were insufficient to allow cost calculation based on owning, operating, and labor costs, the trucking contract rates applied by Louisiana-Pacific were used for this cost component.

Results and discussion

Fiber recovery and utilization

Wood fiber recovered was broken into two product types: sawlogs and pulpwood. **Table 1** provides a breakdown of the total gross volumes removed. Cubic feet ($ft.^3$), board feet (BF), and tons were not interconverted because the weight scales and roll-out scales provided all three volume measures. There was less than 1 percent deduction between gross volume (BF) and net volume for sawlogs. Approximately 11 percent of the gross pulpwood volume was considered to be culls and deductions.

Approximately 5.7 cunits/acre (39.4 m^3/ha) of sawlogs and 14.7 cunits/acre (102.6 m^3/ha) of pulpwood were obtained from the study site. Seventy-two percent of the volume removed was pulpwood because the dead material salvaged from the stand was only suitable for chips and the live stems were generally small. Because the pulpwood contained a large amount of completely dry dead material, it weighed approximately 2.1 tons per cunit, whereas the same volume of sawlogs weighed approximately 2.8 tons per cunit (**Table 1**). Sawlogs made up 28 percent of the total cubic volume and 34 percent of the total weight removed from the site.

The average pulplog and sawlog removed from the unit are described in **Table 2**. Because of the small log sizes, it was important that the logging system was efficient at handling multiple logs simultaneously to achieve productivity.

The proportion of dead to live material harvested on the site (BF volume) was estimated in the harvester activity sampling study to be 42 percent live, 14 percent dead and standing, and 44 percent dead and down. This estimate is based on the material that the harvester processed; the actual ratio of dead to live material removed from the site depends on the proportion of processed material removed by yarding.

The gross volume (BF) removed, by species, was 23 percent Douglas-fir, 31 percent white fir (grand fir), 33 percent lodgepole pine, 1 percent ponderosa pine, and 12 percent western larch.

Felling and processing

The harvester operated in conditions typical of the region, and the operator encountered no significant problems. The only difference from its usual mode of operation was that the operator needed to be conscious of where logs were placed with respect to skyline corridors in order to facilitate productive yarding.

The utilization rate for the harvester was 80 percent. The harvester's activities as a proportion of total productive time (no delays) were:

Positioning/clearing (32%). — Time spent positioning the harvesting head for felling or processing and clearing brush or nonmerchantable trees.

Felling (12%). — Time spent felling trees, defined as the time from when the harvester head first grabs the tree until the tree hits the ground.

Processing dead (23%). — Time spent on delimbing and/or bucking dead trees (dead = no green needles).

Processing live (19%). — Time spent on delimbing and/or bucking live trees (live = any green needles).

Swinging to bunch (3%). — Time spent positioning logs for yarding beyond what occurred during the felling and processing activities.

Traveling (11%). — Time spent moving, defined as any time that the harvester's tracks were rotating.

Most of the synchronization between the harvester and the yarder resulted from using the marked skyline corridors as guides for the felling and processing pattern of the stand. This technique resulted in the majority of logs being reasonably well oriented for yarding. Occasionally, the harvester did not travel parallel to a skyline corridor because it converged with another skyline corridor or the operator did not consider it productive to follow the standard travel pattern. This sometimes resulted in poorly oriented logs for yarding, but was not a significant problem.

Yarding and Loading

The operation was most efficient when the loader worked beside the yarder and cleared the landing chute after each turn arrived at the landing. A total of 19 skyline roads were used during logging. Corridor width was approximately 10 feet (3.0 m) to 15 feet (4.5 m). Partial log suspension occurred predominately on all skyline roads. The logger utilized double-tree intermediate supports to gain lift on only 3 of the 19 skyline roads; tailtrees were utilized on all skyline roads. The typical rigging height for tailtrees was 45 feet (13.7 m), with some rigged as high as 65 feet (19.8 m). Three tailtrees broke during yarding because the yarding crew often chose to push the limits of a tailtree instead of rigging an intermediate support.

The utilization rate of the yarder was 57 percent, compared to typical utilization rates for this type of yarder of approximately 70 percent. For example, a commercial thinning study on steep terrain with a Koller K501 yarder, tailtrees, and intermediate supports had an average utilization rate of 74 percent (18). Thus, activities such as skyline road changes and rigging delays required a large portion (43%) of the yarder's time. The crew was relatively inexperienced at moving the yarder, and road changes regularly took longer than 2 hours. Flat terrain and the lack of a strawline drum on the yarder also lengthened road change times.

Yarding statistics are summarized in **Table 3**. On average, approximately 10 logs were yarded per cycle, and 3 logs hooked per choker (**Fig. 4**). The average yarding cycle, based on 518 samples (turns), took 3.79 minutes when delays were excluded and was broken down into seven components:

Outhaul (12%). — Carriage pulled by haulback from landing to drop location.

Drop (6%). — Load hook and chokers lowered from the carriage.

Lateral outhaul (7%). — Load hook carried laterally to the preset chokers.

Hook (17%). — Load hook passed through all preset choker rings.

Lateral inhaul (18%). — Logs pulled laterally to the skyline corridor.

Inhaul (16%). — Logs pulled along the skyline corridor to the landing.

Unhook (24%). — Logs lowered from the carriage and chokers released.

Unhooking consumed an unusually high proportion of time. The large number of logs arriving in each turn made it difficult for the yarder operator to unhook all of the chokers at once. He often had to go back to the yarder and raise and lower the load to expose the chokers that were still hooked.

Loading a stinger-type log truck took approximately 30 minutes for sawlogs or 60 minutes for pulpwood. These trucks carried an average of 95 sawlogs (range: 67 to 194 pieces) or 188 pieces of pulpwood (range: 160 to 213 pieces) per load. Mule-train log trucks were loaded with an average of 297 pieces, with sawlogs (range: 94 to 238 pieces) on the truck and

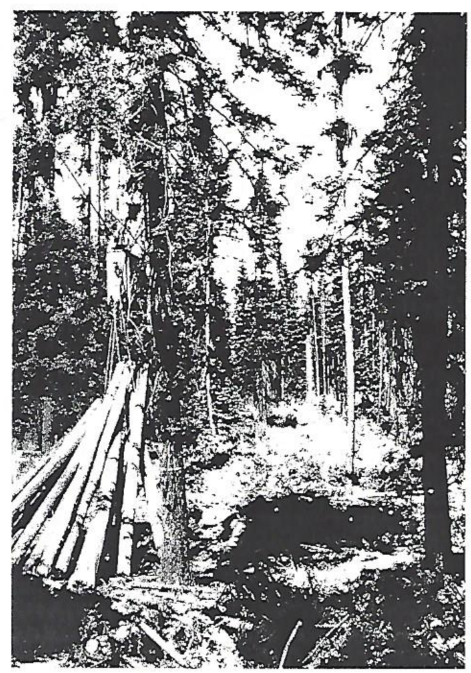

Figure 4. — Yarding bunched logs on flat terrain with a smallwood yarder and slackpulling carriage.

Table 3. — Descriptive yarding statistics.

Variable[a]	Mean (SD)[b]	Range
Turn time (min.)	3.81 (1.23)	1.84 to 11.29
Logs/turn	10.3 (4.34)	1.0 to 30.0
Chokers/turn	3.8 (0.52)	1.0 to 6.0
Logs/choker	2.7 (1.10)	1.0 to 9.33
Yarding distance (ft.)	329 (n/a) (100 m)	10 to 800 (3 to 244 m)
Lateral distance (ft.)	39 (n/a) (12 m)	0 to 165 (50 m)
Skyline road length (ft.)[c]	658 (158.5) (79 m) (48.3 m)	380 to 912 (116 to 278 m)
Road change times (hr.)[c]	2.1 (0.62)	1.22 to 3.2

[a] The variables "turn time" through "lateral distance" are based on 518 samples obtained during detailed time studies on 7 skyline roads.
[b] SD = standard deviation.
[c] Based on all 19 skyline roads in the 40-acre (16.2-ha) study unit.

pulpwood (range: 288 to 668 pieces) on the trailer. This configuration required approximately 75 minutes to load.

Logging production

The production of the entire system is best expressed as the number of truckloads removed per day. Typically, three to four truckloads were hauled off the site per day, with a range of two to six loads. Truckloads averaged 5,000 BF (MBF) (24 tons, 1,000 $ft.^3$, or 28.3 m^3).

The yarding operation limited the production of the entire system, as its production rate was the lowest of all segments in the logging sequence (**Table 4**). The harvester spent only 3 percent of its time bunching and presenting wood for yarding beyond what occurred in the normal felling and processing activities. Improving the bunching and presentation of wood for yarding could improve yarding production and lower cable logging costs, but increase the harvester logging cost (5).

Cost breakdown

Total revenue generated by logging ($103,258) (**Fig. 5**) was determined from the market prices for sawlogs ($515/MBF, $93/$m^3$) and pulpwood ($36/ton, $26/$m^3$) at the time of the study. Total owning, operating, and labor cost of logging was $78,808 (no profit or risk allowance) (**Table 5**). Stump-to-mill logging costs ($42/ton) were higher than revenues generated from pulpwood. Thus, pulpwood was logged at a loss. Sawlogs were profitable to log and compensated for pulpwood losses, allowing a net profit of $24,450.

This result was obtained with sawlogs generating 57 percent of the revenue from 34 percent of the weight removed and 28 percent of the volume removed. In order to just cover logging costs at the market prices just mentioned, sawlogs must represent 11 percent of the total weight removed or 9 percent of the total volume removed and contribute 25 percent of the total revenue.

The small investment in layout (1.5% of the total logging cost) was instrumental in achieving the logging production and harvesting economics produced in this case study: layout gave the loggers a clear idea of how the entire stand was to be logged, allowed coordination between the contractors, and allowed the harvester operator to position logs better for yarding because the locations of the extraction corridors were known. Trees that were needed for intermediate supports or tailtrees during yarding were also marked for retention, a major benefit because there was a shortage of trees appropriate in size and location to provide adequate support. Productivity of the entire system could potentially be improved and total cost reduced by considering the relative costs of each component of the system (**Table 5**) and the importance of well-bunched wood for yarding efficiency and minimal stand damage.

Comparisons with other studies

Because of the many differences among logging study sites, comparing studies precisely is difficult. However, general indications of logging cost and productivity differences are useful in evaluating the potential economic feasibility of alternative harvesting methods.

Production was lower and costs were higher in this case study than in other studies of single-grip harvesters (2,16,17). This is likely due to the small piece size on the Deerhorn site. For example, in a thinning study in a second-growth Douglas-fir stand (average DBH = 13.5 in.) on the west side of the Oregon Cascades (16), the single-grip harvester cost was $11.81/cunit, 73.8 percent of that on the Deerhorn site (average DBH = 8 in.), while production in the Douglas-fir stand (1,087 $ft.^3$/productive machine hour (PMH), 750 $ft.^3$/SMH)) was nearly 50 percent higher on the basis of PMH and 27 percent higher on the basis of SMH. In addition to the difference in material size, the Douglas-fir thinning involved felling and processing only standing live trees, with a minimal amount of stems on the ground.

Yarding and loading costs were slightly lower in the Deerhorn study than in other studies using similar yarders in thinning operations. Several studies of small cable yarders incurred yarding and loading costs of $60 to $75/cunit for thinning second-growth stands on moderate to steep slopes in western Oregon (13-15), compared with $59/cunit in our study. Production was higher in the Deerhorn project than the best Koller K300

Table 4. — Logging production rates per scheduled machine hour (SMH) and productive machine hour (PMH).

	Single-grip harvester		Koller K501 yarder	
Measure	(SMH)	(PMH)	(SMH)	(PMH)
Logs	151.5	188.5	78.5	139.0
$Ft.^3$	589.4	733.3	305.4	540.7
BF	2,918	3,631	1,512	2,677
Tons	13.5	16.8	7.0	12.4
m^3	16.7	20.8	8.7	15.3

Table 5. — Logging costs in the Deerhorn project.

Operation	SMH[a]	Cost/ hr.	Total cost	Cost/ cunit	MBF	ton	m^3	acre[b]	ha[b]
		($)							
Layout[c]	21.27	55.5	1,180	1.45	2.93	0.64	0.51	30	73
Harvester	89.41	144.7	12,937	15.92	32.11	6.97	5.62	323	799
Yarder	132.79	248.1	32,944	40.53	81.78	17.74	14.31	824	2,035
Loader	67.64	218.1	14,750	18.15	36.61	7.94	6.41	369	911
Trucking[d]			16,997	20.91	42.19	9.15	7.39	425	1,050
Totals			78,810	96.97	195.63	42.44	32.24	1,970	4,869

[a] Scheduled machine hour.
[b] Based on a total of 40 acres (16.2 ha).
[c] Layout hourly rate includes a pickup and 40 percent for wage fringe benefits.
[d] Trucking rates are based on Louisiana-Pacific's contract rates.

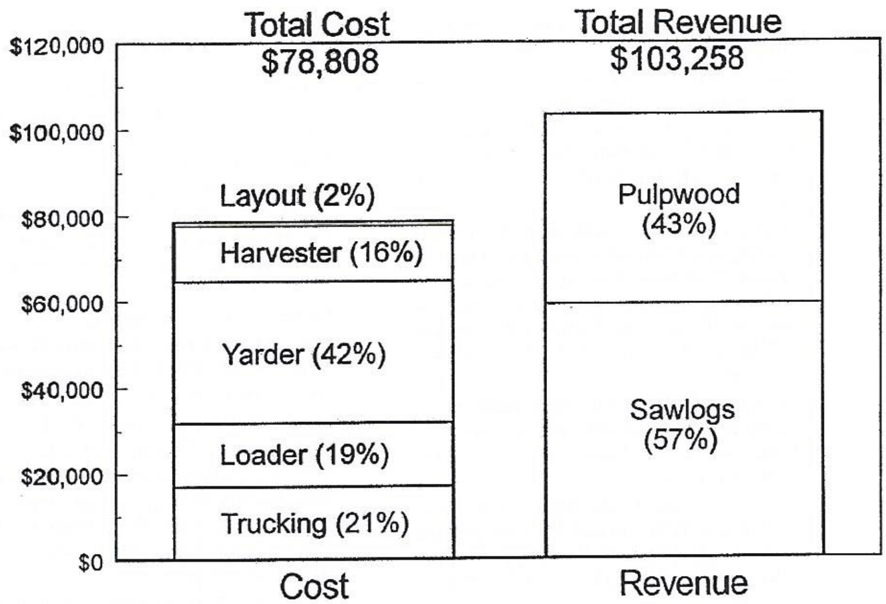

Figure 5. — Total logging costs and revenues.

thinning results (3.57 cunits/PMH) but lower than the best Madill 071 thinning results (7.15 cunits/PMH). Thus, in this case study, an unconventional use of a small cable yarder cost slightly less than did typical skyline thinning with larger timber. The added expense of obtaining lift on flat terrain by using tailtrees and, occasionally, intermediate supports likely was offset by the improved yarding production that resulted from bunching logs with the harvester. Bunching logs produced larger, more consistent payloads with less effort than the scattered pattern of logs generally produced by manual felling and no bunching.

The cost and production of the yarding equipment used in the Deerhorn study can also be compared with that of forwarders or grapple skidders, primary log transport equipment traditionally used in areas similar to the Deerhorn site. Forwarding costs ($19.26/cunit) with a FMG 910 forwarder hauling mixed sawlog and pulplog loads in the coast range of Oregon (16) were less than half the cost of yarding in the Deerhorn study. If only pulpwood production rates are considered from the same study, the cost difference is less pronounced. Yarding production in the Deerhorn study was 305 ft.^{3}/SMH (540 ft.^{3}/PMH), whereas the forwarder study (pulpwood only) had a production rate of 275 ft.^{3}/SMH or 359 ft.^{3}/PMH. At the hourly owning and operating costs of $70.41/SMH presented in (16), forwarding cost for pulpwood would be $25.60/cunit. Thus, production of the Deerhorn yarding operation was higher than that of the forwarder, but its hourly rate was almost double that of the forwarder's, resulting in considerably higher cable yarding costs per cunit.

Grapple skidding has also proven to be cost effective for primary log transport on flat terrain. We calculated the owning, operating, and labor cost for a John Deere 648E grapple skidder to be $52.64/SMH, which is less than that of a forwarder. Grapple skidder production can be similar to or higher than that of a forwarder when the logs are bunched properly. On a flat site in South Carolina (21), where the stand was thinned with a feller buncher and the logs were skidded with a Franklin 105 grapple skidder, average skidder production was 28.3 tons/PMH, more than twice the Deerhorn cable yarding production. It is important to note that the large component of dead and dry wood yarded in the Deerhorn project weighed less than the live, whole trees skidded in the South Carolina study.

Other Resource Issues

As part of the larger Deerhorn project, several management issues other than cost were studied. Impacts on fuel loading, soils, and animal habitat were assessed and the available results have been published in detail by McIver (19).

To summarize McIver, total fuel loading was reduced by 20 percent and the fuel's structure was shifted toward much finer fuels. These changes result in a stand that is less susceptible to high-intensity fire. This susceptibility will likely continue to decrease over time as the small fuel loses needles, compresses, and decays. Soil disturbance and compaction were minimal, with significant soil disturbance occurring only in locations where intermediate supports should have been used to improve log clearance. The ant populations that depend on down logs for habitat and serve as a major food source for the pileated woodpecker are being assessed post treatment. Residual stand damage from logging was not measured, but appeared to be minimal.

Conclusions

This study demonstrates the influence of different wood products and their values on overall harvesting economics in fuels reduction. Combining a single-grip harvester and small cable yarder in a fuels reduction project on flat terrain was economically feasible with the removal of sawlogs and pulpwood. Harvesting only pulpwood would have been uneconomical under the conditions of this study. Fuel loading was altered to make the stand less susceptible to high-intensity fire, and soil impacts were minimal (19). In some watershed areas where soil impacts are of critical importance, this harvesting system may provide a viable method of carrying out stand management treatments where they would otherwise not be allowed. Further replications of this study are needed in order to increase confidence in the generality of its conclusions for other situations. A follow-up fuel reduction study is being developed to compare the harvester/skyline system to more traditional rubber-tired skidding and forwarding systems.

Literature Cited

1. Agee, J.K. 1990. The historical role of fire in Pacific Northwest forests. *In*: Natural and Prescribed Fire in Pacific Northwest Forests. J.D. Walstad, S.R. Radosevich, R. Steven, D.V. Sandberg, eds. Oregon State Univ. Press, Corvallis, Oreg. pp. 25-39.
2. Andersson, B. 1991. Evaluation of a Rottne cut-to-length harvesting system. Proc. Forestry Operations in the 1990's; Challenges and Solutions. Council on Forest Engineering Annual Meeting, Nanaimo, B.C., Canada. pp. 61-67.
3. Andrus, C.W. and H.A Froehlich. 1983. An evaluation of four implements used to till compacted forest soils in the Pacific Northwest. Res. Bull. 45. Forest Res. Lab., Oregon State Univ., Corvallis, Oreg. 12 pp.
4. Bradshaw, G.R. 1979. Preplanned skid trails and winching versus conventional harvesting on a partial cut. Res. Note 62. Forest Res. Lab.,

Oregon State Univ., Corvallis, Oreg. 4 pp.

5. Brown, C.G. 1995. The deerhorn case study: a production and cost analysis of a single-grip harvester and small cable yarder performing a thinning/salvage operation in eastern Oregon. M.F. pap., Oregon State Univ., Corvallis, Oreg. 119 pp.
6. Evans, J.W. 1990. Powerful Rockey: The Blue Mountains and the Oregon Trail, 1811-1883. Pika Press, Eastern Oregon State College, Enterprise, Oreg. 374 pp.
7. Froehlich, H.A., D.E. Aulerich, and R. Curtis. 1981. Designing skid trail systems to reduce soil impacts from tractive logging machines. Res. Pap. 44. Forest Res. Lab., Oregon State Univ., Corvallis, Oreg. 15 pp.
8. __________ and D.H. McNabb. 1984. Minimizing soil compaction in Pacific Northwest forests. *In*: Forest Soils and Treatment Impacts, E.L. Stone, ed. Proc. 6th N. Am. Forest Soils Conf., Univ. of Tennessee, Knoxville, Tenn. pp. 159-162.
9. __________ and D.W.R. Miles. 1984. Winged subsoiler tills compacted forest soil. Forest Industries 111:42-43.
10. Hall, F.C. 1976. Fire and vegetation in the Blue Mountains: implications for land managers. In: Proc. Tall Timbers Fire Ecology Conf. 15. Tall Timbers Res. Sta., Tallahassee, Fla. pp. 155-170.
11. Hochrein, P.H. and L.D. Kellogg. 1988. Production and cost comparison for three skyline thinning systems. Western J. of Applied Forestry 3:120-123.
12. Hogervorst, J.B. and P.W. Adams. 1994. Soil compaction from ground based thinning and effects of subsequent skid trail tillage in a Douglas-fir stand. Dept. of Forest Eng., Oregon State Univ., Corvallis, Oreg. 27 pp.
13. Howe, D.L. 1994. Application of a skyline yarding technique in harvesting ecologically sensitive flat sites. Proc. Applied Forestry in Action: Advanced Technology in Forest Operations, Council on Forest Industries and IUFRO Conf., Portland/Corvallis, Oreg. pp. 125-134.
14. Kellogg, L.D. 1980. Thinning young timber stands in mountainous terrain. Res. Bull. 34. Forest Res. Lab., Oregon State Univ., Corvallis, Oreg. 19 pp.
15. __________ and P. Bettinger. 1994. Thinning productivity and cost for a mechanized cut-to-length system in the northwest Pacific Coast region of the USA. J. of Forest Eng. 5:43-54.
16. __________, __________, S. Robe, and A. Steffert. 1992. Mechanized harvesting: a compendium of research. Forest Res. Lab., Oregon State Univ., Corvallis, Oreg. 401 pp.
17. __________, E. Olsen, and M.A. Hargrave. 1986. Skyline thinning a western hemlock-Sitka spruce stand: harvesting costs and stand damage. Res. Bull. 53. Forest Res. Lab., Oregon State Univ., Corvallis, Oreg. 21 pp.
18. King, G. 1995. Commercial thinning and underplanting to enhance structural diversity of young Douglas-fir stands in the Oregon Coast Range. Skyline thinning study, shift level production rept. for Yachats, Keller Creek unit 3. Preliminary rept. prepared for Future Logging Co., Inc., Springfield, Oreg. Dept. of Forest Eng., Oregon State Univ., Corvallis, Oreg.
19. McIver, J. 1995. Deerhorn fuels reduction: economics and environmental effects. Tech. Note BMNRI-TN-6. Blue Mountains Natural Resources Inst., La Grande, Oreg.
20. Mutch, R.W., S.F. Arno, J.K. Brown, C.E. Carlson, R.D. Ottmar, and J.L. Peterson. 1993. Forest health in the Blue Mountains: a management strategy for fire adapted ecosystems. Gen. Tech. Rept. PNW-GTR-310. USDA Forest Serv., PNW Res. Sta., Portland, Oreg. 14 pp.
21. Robe, S.C., R.M. Shaffer, and W.B. Stuart. 1989. Comparison of large and small grapple skidders for corridor thinning of pine plantations. Forest Prod. J. 39(2):66-68.
22. Wickman, B.E. 1992. Forest health in the Blue Mountains: the influence of insects and disease. Gen. Tech. Rept. PNW-GTR-295. USDA Forest Serv., PNW Res. Sta., Portland, Oreg. 9 pp.