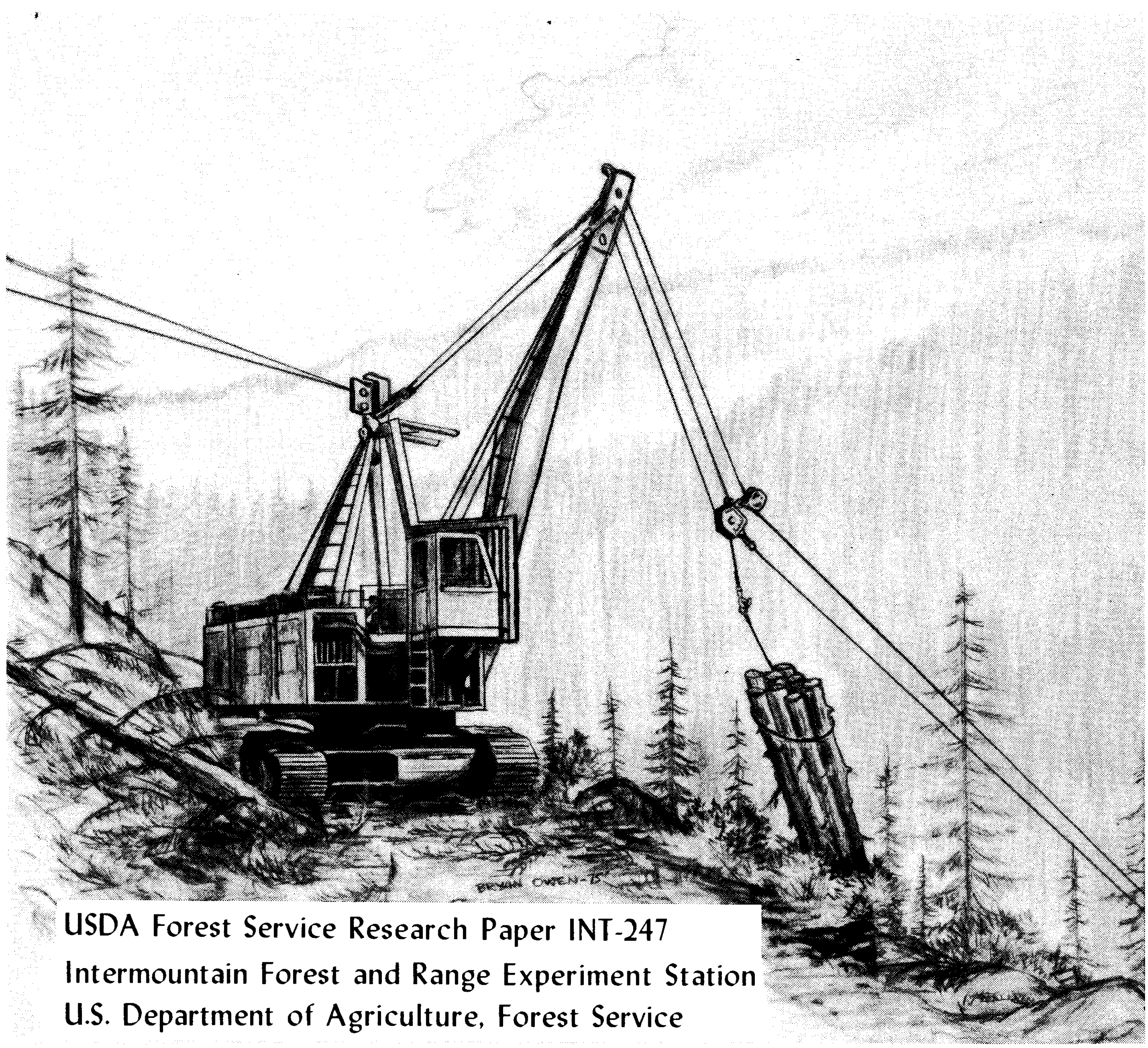
SKYLINE LOGGING PRODUCTIVITY UNDER ALTERNATIVE HARVESTING PRESCRIPTIONS AND LEVELS OF UTILIZATION IN LARCH-FIR STANDS

Rulon B. Gardner



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RESEARCH SUMMARY

Little information is available to assess the economic and environmental feasibility of harvesting timber at more intensive levels of utilization in steep terrain. In this study in a larch-fir stand, four levels of wood utilization, ranging from conventional saw log to almost total fiber recovery, were harvested using running skyline and live skyline yarding equipment. All four levels of utilization were applied under each of three silvicultural prescriptions--shelterwood, group selection, and clearcut harvesting.

The general objectives of the study were to determine the influence of intensive levels of wood utilization upon skyline system productivity under each silvicultural prescription, and to determine the important variables influencing rates of production.

The highest average production experienced, in total cubic feet of fiber removed, occurred in group selection cutting units for the running skyline yarding downhill in treatment 4--1,047 ft^3/h (29.3 m^3/h). The least productive logging occurred with the running skyline logging uphill in shelterwood cutting in treatment 3--353 ft^3/h (10.0 m^3/h.

The most important variables influencing rate of production were yarding distance, lateral yarding distance to the skyline, and number of pieces per turn, in that order.

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INTRODUCTION

The broad objective of the study on which this report is based was to evaluate skyline harvesting feasibility (economic and environmental) under the full array of silvicultural and utilization practices that could be used in managing a larch-fir timber stand.

Intensive wood utilization would reduce the waste of a valuable resource and extend an ever-shrinking wood fiber supply. Reductions in land available for growing timber because of urbanization and removal for other uses such as recreation, wildlife habitat, and wilderness, come at a time when demand for wood products continues to increase. Utilization of forest residues, estimated at 6 billion cubic feet (0.17 billion m^3) annually, could increase the total fiber yield by as much as 50 percent on a national basis.

Intensive wood utilization can have positive or negative environmental impacts, depending on the level of utilization, harvesting methods, and ecosystem response. Although some general information is available from past studies about responses--hydrology, flora, and fauna--the net results of applying increasing levels of timber utilization have not been adequately determined. Hence, a study was designed for the larch-fir type in Montana (fig. 1) to monitor biological-ecological responses to an array of alternative silvicultural and utilization timber harvesting prescriptions.

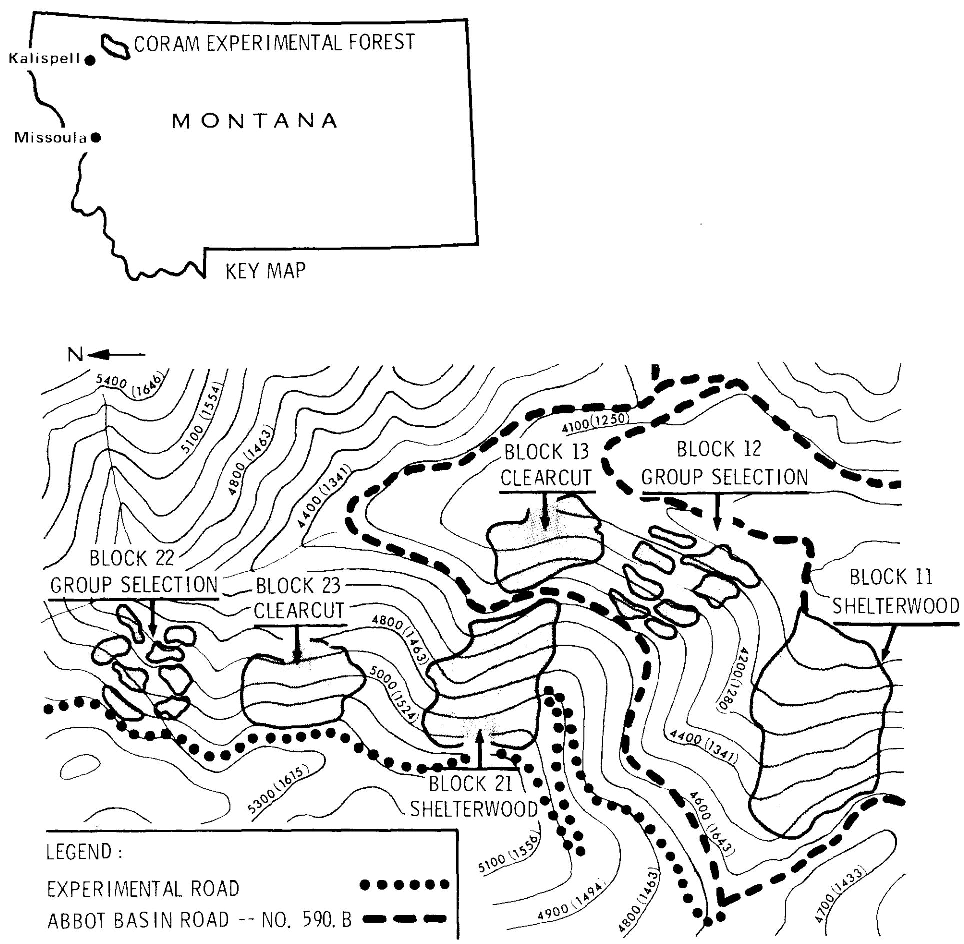

Figure 1.--Experimental road and logging location.

Because of the relatively steep slopes (45 to 60 percent) on the study area, cable yarding was appropriate. Past experience in the Rocky Mountain area has been largely with Idaho jammers or high-lead systems that require dense road networks because of limited skidding capabilities--300 to 500 ft (91 to 152 m) for jammer skidding and slightly more, 400 to 700 ft (122 to 213 m) for high-lead yarding.

For this experimental harvesting study, where one of the objectives was to reduce environmental impacts, it was decided to use a running skyline system to reduce road requirements. Road spacing was to be on the order of 1,500 to 2,000 ft (457 to 610 m); thus, the requirement for the basic system was a 1,000-foot (305 m) yarding capability uphill or downhill. Because of road width limitations and landing restrictions, the yarding equipment also had to be able to swing logs to the road. This report describes the logging methods, logging equipment, productivity, and factors affecting productivity.

OBJECTIVES

The specific objectives of the harvesting study were as follows:

1. Determine the influence of successively more intensive levels of wood utilization upon harvesting productivity for skyline systems operating under clearcut, shelterwood, and group selection silvicultural prescriptions.

2. Identify and quantify the stand and operation variables that significantly affect harvesting productivity.

3. Develop a statistical data base for estimating system yarding productivity, given some measure of the important variables describing the harvesting situation.

4. Develop, field test, and demonstrate harvesting practices and techniques that can improve the efficiency of running skyline systems, and thus enhance the opportunities for increased utilization.

In this report, the productivity experienced in each harvesting situation is presented and identified with the variables that influenced production.

The report further develops and illustrates procedures for estimating yarding turn time and associated productivity--a major cost determinant for the system.

EXPERIMENTAL HARVESTING UNITS

Logging Area and Blocks

Two blocks of each silvicultural prescription were laid out as shown in figure 1.

In each block, four levels of utilization were prescribed as shown in table 1. Treatment units run perpendicular to the slope.

The topography is generally steep (45 to 60 percent) and loggable only with cable equipment. To reduce hydrologic, esthetic, and biological impacts, logging equipment was needed that would reduce both the impacts from logging and attendant roads. The system also had to be portable and relatively easily rigged. The running skyline system was best for satisfying all of these requirements.

Table 1.--*Logging area treatments and utilization prescriptions*

Prescribed utilization	Material removed	Postharvest treatment	Treatment designation[1]
Conventional sawlog	Green and recent dead logs, to 5-1/2 inch (14 cm) top; 1/3 or more sound	Remaining understory slashed; broadcast burned	1
Close log utilization, trees 7 inches (17.8 cm) d.b.h.+ (sawtimber trees)	Green logs, to 3 inches x 8 ft (7.6 cm x 2.4 m); dead and down logs, to 3 inches x 8 ft (7.6 cm x 2.4 m), if sound enough to yard	Understory retained; left as is	2
Close log utilization, trees 5 inches (12.7 cm) d.b.h.+	Green logs, to 3 inches x 8 ft (7.6 cm x 2.4 m); dead and down logs to 3 inches x 8 ft (7.6 cm x 2.4 m), if sound enough to yard	Remaining understory slashed; broadcast burned	3
Close fiber utilization, all trees	Green 1-5 inches (2.5-12.7 cm) d.b.h. material tree length, in bundles;[2] green trees >5 inches (12.7 cm) d.b.h., tree length; dead and down, to 3 inches x 8 ft (7.6 cm x 2.4 m), sound enough to yard	Remaining understory slashed; left as is	4

[1]Treatment designation numbers used in this report are assigned in successive order of utilization intensity, 1 through 4. They do not correspond to the random treatment numbers assigned and used on the ground, which appear in various other reports based on this study site.

[2]Trees 1-5 inches (2.5-12.7 cm) d.b.h. cut and prebundled prior to logging activity on the site.

The upper part of blocks 11 and 12, all of 13, and the lower part of 21 were loggable from Abbott Basin Road 590-B, built in the 1950's (fig. 1). New access was needed for upper 21, 22, 23, and lower 11 and 12. Whenever it is desired to reduce road spacings in steep areas, it is usually efficient to gain elevation by switching back at favorable locations on the terrain and then log with a cable system with a fairly long reach. Figure 1 shows the new section of road that started from 590-B, near the upper part of block 11, and switched back on the gentle terrain of broad ridges to gain access above blocks 21, 22, and 23. A new short section of road was also built to access lower 11 and 12, as shown in figure 1. (A separate report by the author [Gardner 1978] describes the road portion of the study.)

PLANNING AND CONDUCTING HARVESTING

Equipment

YARDERS

The contractor selected a Skagit GT-3 (fig. 2) to meet the requirements for logging. Initial logging was done with the GT-3; later, two sides were logged simultaneously when a Link Belt 78 Log Mover (fig. 3) was put on the job. Both yarders had 1,000-foot (305 m) yarding capability. The Link Belt 78 was rigged as a live skyline using a gravity return carriage and, therefore, only able to log uphill. Figures 4 and 5 show how each system is rigged and operates (specifications for the yarder are in appendix A).

Figure 2.--Skagit GT-3 located at fan-shaped set below block 21.

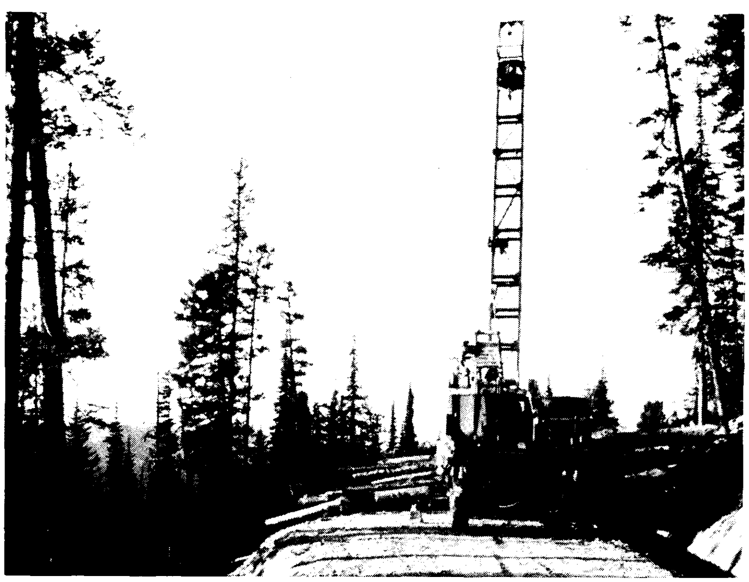

Figure 3.--Link Belt 78 Log Mover logging block 23.

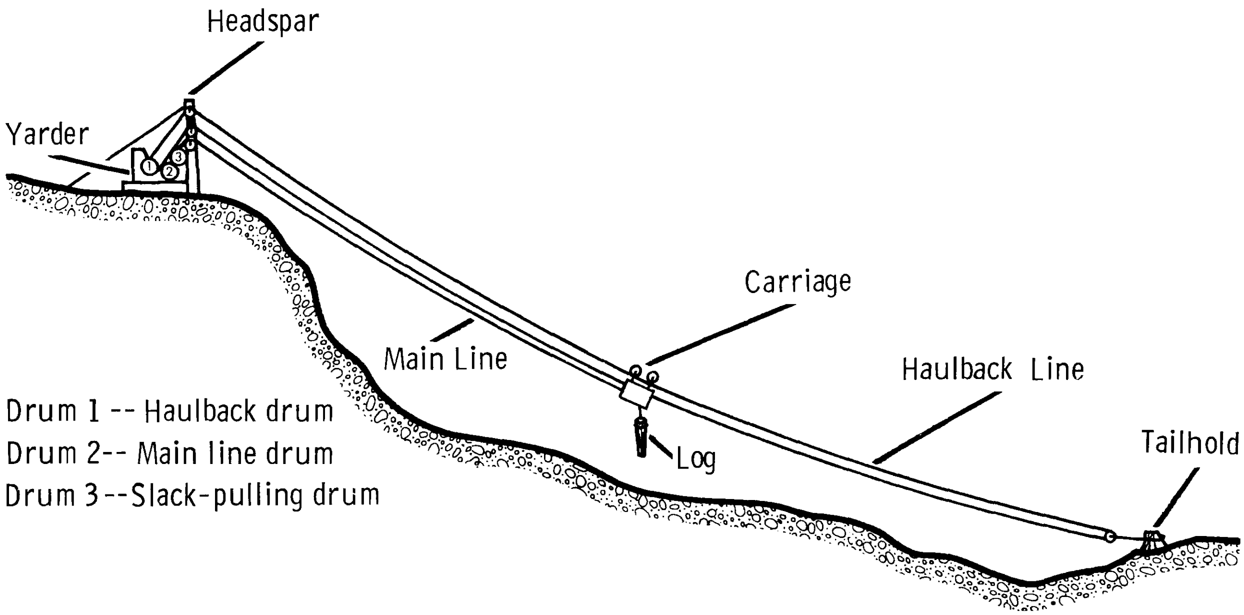

Figure 4.--Running skyline. Drums 1 and 2 on the yarder are interlocked for horsepower exchange during yarding operation, drum 3 operates the slack puller.

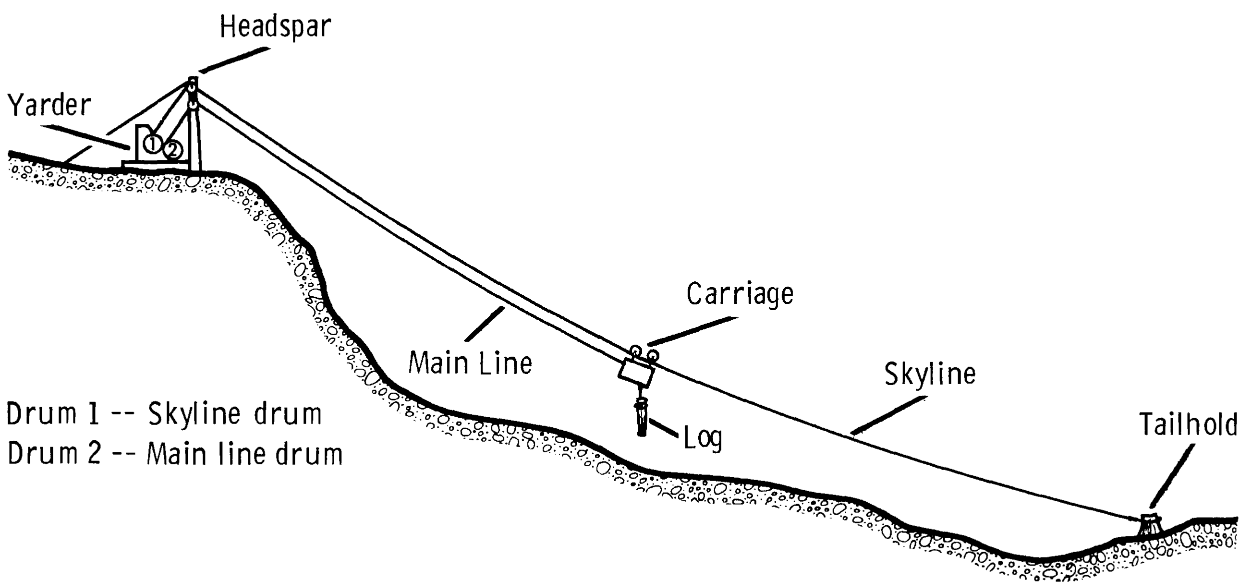

Figure 5.--Live skyline, gravity carriage. The skyline drum is powered so skyline tension can be varied during yarding operation.

LOADERS

Three different types of loaders were used in situations that were normally hot logging operations (hot logging means skidding, loading, and hauling are going on simultaneously). For the first setting (block 21), which was downhill logging in a shelterwood cut, a jammer or heel boom loader was used (fig. 6). For all other loading, either a long boom (fig. 7) or a rubber-tired, front-end (fig. 8) loader was used. All loaders loaded both logs and currently unmerchantable material designated for removal under the more intensive utilization standards.

Figure 6.--Heel boom loading dump truck with residue from block 21.

Figure 7.--Long boom loader.

Figure 8.--Front-end loader working with Link Belt yarder keeping loading area clear on 14-foot (4.2 m) road without landings.

TRUCKS

Because of the large amount of currently nonmerchantable material that had to be removed to meet the previously discussed utilization standards, dump trucks were used for hauling this material. Conventional tractor-trailer units were used for the merchantable material.

Layout and Operation

The layout of blocks is shown in figure 1. Treatment units are numbered (1-4) and run perpendicular to the slope for clearcut and shelterwood blocks.

Planning logging sets and skyline roads is the key to successful operation of any cable logging system, particularly live or running skyline systems, which require deflection for suspension of the haulback line. In the generally uniform terrain (as seen by the contours in figure 1) of this logging chance, it was usually necessary to rig tail spar trees for deflection. The number and location of rigged tail spar trees are shown in table 2. Figure 9 shows a typical rigging, with nylon strap, block, and guylines. Only 14 of the 69 skyline sets did not require rigging to provide deflection.

Table 2.--*Number of trees rigged when additional deflection was needed*

Block	Direction yarded	No. of sets	No. of roads	No. of trees rigged	No. of roads without rigged trees
11	up	7	10	9	1
(Selection cut)	down	1	12	5	7
12	up	6	6	6	0
(Group selection cut)	down	4	5	1	4
13	up	5	6	6	0
(Clearcut)	--	--	--	--	--
21	up	5	10	9	1
(Selection cut)	down	1	6	6	0
22	up	4	6	5	1
(Group selection cut)	--	--	--	--	--
23	up	7	8	8	0
(Clearcut)	--	--	--	--	--
Total	--	40	69	55	14

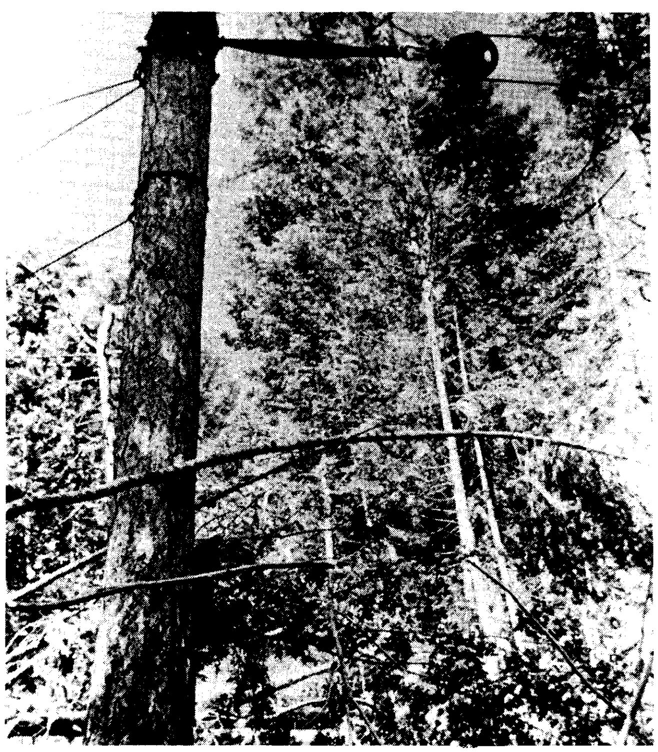

Figure 9.--Typical tail spar rigging with nylon strap, block, and guylines.

For this study, the position of each skyline set was located cooperatively by the logger and research personnel. Potential sets were located on the topographic map and then investigated in the field. A field crew of two was trained to run levels from the set (road) to a suitable spar tree. A profile was then plotted to show the deflection needed to operate the set. A tree was rigged at the height necessary to provide the deflection. This step was done well ahead of the logging crew.

Topping of spar trees was deemed essential primarily for safety because of the risk of branches and dead tops shaking loose and dropping to the ground. Also, in the event of tail spar failure, the "radius of danger" would be less. Initially, topping was performed using about 60 sticks of dynamite with a Primacord belt wrapped around an 18- to 24-inch (45.7 to 56.9 cm) diameter tree. An improved technique was developed that utilized six or seven pouches of a liquid/powder mixture with holes through each pouch using Primacord like a string of beads. The belt of explosives was installed at the point of topping by a rigger who would climb the tree with conventional pole climbing apparatus and lower a rope to raise the belt of explosives. Then a length of Primacord sufficient to reach the ground was tied to the belt. Finally a detonating cap and a length of fuse were attached to the end of the Primacord that reached the ground. The fuse was of sufficient length to allow all personnel to walk several hundred feet from the impending blast. Before igniting the fuse, the yarder operator was contacted by radio, and he activated his whistle-signaling device to warn everyone in the area of the blast.

The explosion caused a relatively clean, horizontal severance, with a zone of crushing and ring separation extending no greater than about 12 inches (30.5 cm) from the cut.

All skyline roads were held to a maximum width of 10 ft (3.05 m) in the shelterwood blocks, and in leave strips between group selection blocks, to reduce visual impacts.

Logging for the most part was conducted as a hot logging operation. Landings were usually not available, with the exception of the downhill yarding in blocks 11, 12, and 21. Downhill yarding from blocks 11 and 12 was to open, near-level areas seen from the contours in figure 1. A stretch of wide road between the yarder and block 21 was used as a landing (fig. 3) for downhill yarding in that block. A typical set yarding to the road is seen in figure 4. This photograph illustrates why the yarders were required to have swing capability so they could land the logs on the road.

The yarding crews consisted of the operator, two choker setters, a knot bumper-chaser, and a side foreman, who supervised both yarding crews. The loading and hauling operations were required to keep logs clear of the yarder. Merchantable material and unmerchantable were separated at the landing by the loaders or loaded directly to the truck, depending on the situation at the yarder and availability of the trucks. The usual situation was trucks waiting for loads.

Logging by Utilization Prescription

Recall that the primary purpose of the study was to determine the economic and environmental impacts of different levels of utilization under alternative silvicultural practices. Previous studies had indicated that it may be possible to utilize sawtimber trees down to 3-inch (7.6 cm) diameters in lengths of at least 8 feet (2.4 m); i.e., treatment 3. Treatments 4 and 2 are respectively more and less intensive than 3 to adequately identify feasibility limits.

Conventional sawlog (1).--In this treatment, the logs were yarded in a conventional manner with the limbs and top removed. The slash was disposed of by broadcast burning.

Close log utilization (2, 3).--All of the material was yarded to meet the utilization prescriptions as defined in table 1.

Close fiber utilization (4).--In treatment 4, trees were yarded as whole trees (or as nearly so as possible) and the merchantable logs removed in the conventional manner. Limbing and topping was accomplished on the landing.

One operation in treatment 4 was unique to this study. The understory trees designated for removal (1 to 5 inches [2.54 to 12.7 cm]), were cut and bundled by research crews prior to any logging activity, and subsequently yarded by the contractor. Rope was used to make a bundle the size a choker could handle--about 3 ft (0.9 m) in diameter and tree length long. A choker was put around the bundle for yarding. Handling the understory material in this manner was the only practical way to achieve intensive fiber recovery because it is not economically feasible to yard very small pieces individually.

In systems other than clearcutting, it can be difficult to yard material laterally. Before logging began, it was thought that yarding downhill in selectively cut blocks could cause serious problems because the load would have to be turned downhill in a fairly narrow corridor when it reached the skyline road. However, this did not prove to be as difficult as anticipated.

TIMBER VOLUMES LOGGED

Preharvest inventory of all material was at a more intensive level than for ordinary sales because a good estimate of the total biomass was desired for estimating potential removals. All harvested and removed material was also measured at the landing except solid volumes for bundled material from treatment 4 that were estimated. Table 3 shows inventoried and removed volumes by block and treatment. Removals in treatment 4 for blocks 21 and 22 exceed inventoried estimates. Since removal measurements represent a 100 percent sample, it is believed they are more accurate. Inventoried merchantable volumes per acre in treatments varied from approximately 2,050 ft^3/acre (140 m^3/ha) (8,660 bd.ft./acre) to over 6,000 ft^3/acre (420 m^3/ha) (25,980 bd.ft./acre). From a total volume of fiber removed of 405,879 ft^3 (11 494 m^3), 298,455 ft^3 (8 452 m^3) (1,292,310 bd.ft.) was merchantable or 74 percent.

HARVESTING PRODUCTIVITY

The differences in timber composition, size, and density among blocks allows for productivity comparisons only between treatments within blocks. Therefore, conclusions about productivity differences between silvicultural prescriptions should not be attempted. Also, the differences in landing conditions along with the above tend to confound differences between uphill and downhill yarding production.

Table 3.--*Preharvest and removed volumes* (ft^3)

Block/treatment	Acres	Volumes: Preharvest	Volumes: Removed	Percent removal
11-1	14.9	98,027	21,495	21.9
-2	6.2	37,324	17,368	47.3
-3	6.7	47,603	17,545	36.9
-4	7.3	48,854	48,354	99.0
Subtotal	35.1	231,808	104,762	45.2
12-1	2.3	14,823	6,537	44.1
-2	1.7	16,232	8,668	53.4
-3	1.7	14,341	10,407	72.6
-4	1.9	18,344	16,244	88.5
Subtotal	7.6	63,740	41,856	65.7
13-1	3.8	26,325	14,668	55.7
-2	3.2	24,333	18,481	76.0
-3	2.9	26,248	9,676	36.9
-4	3.7	26,366	14,975	56.1
Subtotal	13.6	103,272	57,800	56.0
21-1	4.8	31,834	12,539	39.4
-2	4.6	25,056	19,554	78.0
-3	6.7	42,572	30,946	72.7
-4	5.4	26,881	29,572	110.0
Subtotal	21.5	126,343	92,611	73.3
22-1	1.3	14,404	7,710	53.5
-2	1.5	14,493	8,231	56.8
-3	1.6	17,029	12,564	73.8
-4	1.6	11,562	11,818	102.2
Subtotal	6.0	57,488	40,323	70.1
23-1	3.4	34,476	11,343	32.9
-2	3.4	25,711	8,721	33.9
-3	5.1	39,414	26,738	54.1
-4	4.7	32,002	21,740	67.9
Subtotal	16.6	131,603	68,542	52.1
Total	100.4	714,254	405,879	56.8

Tables 4, 5, and 6 summarize data related to each silvicultural system, including acreage, volumes, layout and equipment, and average yarding production by equipment type, treatment, and direction of yarding. The mean, standard deviation, and standard error by block and direction of yarding for pieces per turn, turns per hour, and pieces per hour are summarized in appendix B (table 9).

Productivity data were derived from time and motion studies. These studies extended over the entire duration of the logging, covering over 7,200 turns made by the running and live skyline systems.

Table 4.--*Skyline yarding summary--shelterwood units*

LOGGING UNITS

Block number	Block size		Total volume		Number pieces	Average piece size	
	Acres	*ha*	*Ft³*	*m³*		*Ft³*	*m³*
11	35.1	14.2	104,762	2 967	7,471	14.02	0.397
21	21.5	8.74	92,611	2 623	6,338	14.61	.414

YARDING LAYOUT

Block number	Number skyline roads		Yarding distance			
	Uphill	Downhill	Average		Range	
			Ft	*m*	*Ft*	*m*
11	10	12	508	155	0-1,050	0-320
21	10	6	557	170	25-1,150	8-350

EQUIPMENT

21 Yarding - Skagit GT-3 rigged as running skyline, yarding uphill and downhill
Loading - Both long boom and front end loader used at times
Hauling - 6.0 M bd.ft. truck and trailers for logs, and 10-yard dumps for residues

11 Yarding - Skagit GT-3 rigged as running skyline, yarding uphill and downhill
Link Belt 78 Log Mover rigged as a live skyline, yarding uphill
Loading - Same as Block 21
Hauling - Same as Block 21

AVERAGE PRODUCTION PER HOUR[1]

Treatment	System	Total volume	
		Ft³	*m³*
Conventional saw log (1)	Running skyline, uphill yarding	497	13.6
Close log, trees 7"+ (2)		358	10.1
Close log, trees 5"+ (3)		353	10.1
Close fiber (4)		568	16.1
Conventional saw log (1)	Running skyline, downhill yarding	644	18.2
Close log, trees 7"+ (2)		561	15.9
Close log, trees 5"+ (3)		615	17.4
Close fiber (4)		813	23.0
Close log, trees 7"+ (2)	Live skyline, uphill yarding	321	9.1
Close fiber (4)		747	21.2

[1]Production per hour includes foreign element delay time occurring within a turn cycle, but not nonproductive hours for rest breaks, repairs, rerigging, etc. Foreign element delays are those caused by machines, manpower, materials, or environmental factors.

Table 5.--*Skyline yarding summary--group selection units*

LOGGING UNITS

Block number	Block size		Total volume		Number pieces	Average piece size	
	Acres	*ha*	*Ft*^{3}	*m*^{3}		*Ft*^{3}	*m*^{3}
12	7.60	3.04	41,856	1 185	2,670	15.63	0.443
22	6.0	2.40	40,323	1 142	2,585	15.60	.442

YARDING LAYOUT

Block number	Number skyline roads		Yarding distance			
	Uphill	Downhill	Average		Range	
			Ft	*m*	*Ft*	*m*
12	6	5	322	98	50-760	15-232
22	6	0	524	160	0-1,250	0-381

EQUIPMENT

12 Yarding - Skagit GT-3 rigged as running skyline and yarding downhill only
Link Belt 78 Log Mover rigged as a live skyline and yarding uphill
Loading - Both long boom and front end loader used at times
Hauling - 6.0 M bd.ft. truck and trailers for logs, and 10 yard dumps for residues

22 Yarding - Skagit GT-3 rigged as running skyline and yarding uphill only
Link Belt 78 Log Mover rigged as a live skyline and yarding uphill
Loading - Same as Block 12
Hauling - Same as Block 12

AVERAGE PRODUCTION PER HOUR[1]

Treatment	System	Total volume	
		Ft^3	*m*^{3}
Conventional saw log (1)	Running skyline, uphill yarding	500	14.2
Close log, trees 7"+ (2)		590	16.7
Close log, trees 5"+ (3)		590	16.7
Close fiber (4)		490	13.9
Conventional saw log (1)	Running skyline, downhill yarding	826	23.4
Close log, trees 7"+ (2)		815	23.1
Close log, trees 5"+ (3)		815	23.1
Close fiber (4)		1,047	29.7
Conventional saw log (1)	Live skyline, uphill yarding	511	14.5
Close log, trees 7"+ (2)		469	13.3
Close log, trees 5"+ (3)		605	17.1
Close fiber (4)		816	23.1

[1]See table 4 footnote.

Table 6.--*Skyline yarding summary--clearcut units*

LOGGING UNITS

Block number	Block size		Total volume		Number pieces	Average piece size	
	Acres	*ha*	*Ft*^{3}	*m*^{3}		*Ft*^{3}	*m*^{3}
13	13.60	5.44	57,800	1 637	3,906	14.80	0.419
23	16.6	6.64	68,542	1 941	5,201	13.18	.373

YARDING LAYOUT

Block number	Number skyline roads		Yarding distance			
	Uphill	Downhill	Average		Range	
			Ft	*m*	*Ft*	*m*
13	6	0	478	146	50-900	15-274
23	8	0	488	149	0-950	0-290

EQUIPMENT

13
Yarding - Skagit GT-3 rigged as a running skyline and yarding uphill only
Loading - Both long boom and front end loader used at times
Hauling - 6.0 M bd.ft. truck and trailers for logs and 10 yard dumps for residues

23
Yarding - Link Belt 78 Log Mover rigged as a live skyline and yarding uphill
Loading - Same as Block 13
Hauling - Same as Block 13

AVERAGE PRODUCTION PER HOUR[1]

Treatment	System	Total volume	
		Ft^3	*m*^{3}
Conventional saw log (1)	Running skyline, uphill yarding	989	28.0
Close log, trees 7"+ (2)		622	17.6
Close log, trees 5"+ (3)		850	24.1
Close fiber (4)		583	16.5
Conventional saw log (1)	Live skyline, uphill yarding	930	26.4
Close log, trees 7"+ (2)		503	14.2
Close log, trees 5"+ (3)		632	17.9
Close fiber (4)		595	16.8

[1]See table 4 footnote.

Felling and Bucking

Time and motion studies did not include felling and bucking. Production and cost were estimated for the sale, using Northern Region timber sale appraisal guides. The base cost adjusted for average d.b.h., trees/acre, slope, and tree defect was $11.86/M bd.ft. ($2.62/m^3$) (1974). This cost was assumed to be applicable to clearcut units under conventional saw log specification, or treatment 1. It was adjusted for the requirements of the other treatments as follows:

+32.5 percent for cutting 5- to 7-inch (12.7 to 17.8 cm) d.b.h. in treatment 3.
+50.0 percent to avoid damaging residual in shelterwood units.
+50.0 percent to avoid damage to adjoining stands near group selection units.
+10.0 percent for limbing to 3-inch (7.6 cm) top in treatments 2 and 3.

It was assumed that production, and therefore cost, would be equal to Regional averages, with the above added for special treatment requirements.

Comparing observed sawyer production with estimated production shows a slight overestimation in some treatments and underestimation in others, with similar averages: 0.79 M bd.ft./h (3.58 m^3/h) observed production rate vs. 0.87 M bd.ft./h (3.94 m^3/h) estimated production rate (table 10 in appendix B).

Yarding

The greatest productivity for total solid volumes was from group selection units using a running skyline logging downhill--1,047 ft^3 (29.6 m^3) per hour in treatment 4. The least productive logging was in running skyline units logging uphill in shelterwood blocks--productivity was 353 ft^3 (10.0 m^3) in treatment 3. Factors affecting productivity are discussed in detail in the next section.

Nonproductive time--yarding.--The percentage of total yarding time actually spent yarding was estimated for each block from data recorded by research personnel (table 11, appendix B). These times could be expected to vary between organizations.

Loading

Time and motion studies were not made for the loading operation. However, a record was kept of the number and type of trucks loaded each day. In table 12 (appendix B) the mean, standard deviation, and standard error for trucks loaded per day are shown for each operation.

Waiting and loading times for log and dump trucks were recorded for a sample of logging sets as shown in table 7.

Hauling

Hauling distance for the dump trucks was approximately 7.5 miles (12.1 km) to the disposal area--an average of 1 mile (1.6 km) on the new road and 6.5 miles (10.4 km) of single-lane, unsurfaced road with turnouts (No. 590). Hauling distance for the logs to the Columbia Falls, Mont., mill consisted of approximately 1 mile (1.6 km) on the new road, 5.8 miles (9.3 km) of single-lane, unsurfaced road with turnouts, 1.5 miles (2.4 km) of lane and one-half [20 ft (6.1 m)] gravel surfaced, and 10 miles (16.1 km) of paved, double-lane (U.S. No. 2) for a total of 17.3 miles (27.8 km). A tabulation of transport mileages for logs and residue and estimated average speed and hours of travel one way is shown in table 8.

Table 7.--*Waiting and loading times for log and dump trucks (in hours)*

Statistic	Log trucks Waiting	Log trucks Loading	Unmerchantable trucks Waiting	Unmerchantable trucks Loading
n	32	32	32	32
$\bar{x}$	2.43	1.89	1.05	0.86
Sx	1.56	1.18	1.31	1.24

n = number of observations.

$\bar{x}$ = mean waiting or loading time.

Sx = standard error of the mean.

Table 8.--*Transport distances and times for merchantable and residue material*

Road section	Distance *Miles*	Distance *km*	Average speed *Mi/h*	Average speed *km/h*	Hours
			Residue		
New section 590B	1.0	1.6	15	24.1	0.067
Old section 590B	6.5	10.4	17	27.4	.382
				Total	0.449
			Logs		
New section 590B	1.0	1.6	15	24.1	.067
Old section 590B	5.8	9.3	17	27.4	.341
Country road	1.5	2.4	24	38.6	.341
U.S. No. 2	10.0	6.1	50	80.4	.200
				Total	0.670

Nonproductive time is not included.

FACTORS AFFECTING PRODUCTIVITY

In this study, the principal variables influencing yarding were distance, lateral distance, slope, volume, number of logs, and weight in various combinations, depending on the equipment and silvicultural prescription.

The principal variables influencing the production of logging systems and equipment are fairly well known from studies conducted over the years. However, the relative influence of some variables is still being debated by researchers. Therefore, all of the variables thought to be potentially significant for influencing production were recorded using a standardized methodology developed over the past several years by Intermountain Station's Engineering Research Work Unit at Bozeman, Mont.

The final equations for logging production were selected on the basis of the simultaneous consideration of the following criteria discussed in more detail by Gibson (1975).

1. R^2 or percent of variation explained by the equation.
2. F-ratio for significance of the regression.
3. Standard error of the independent variable (expressed as a percentage of the mean).
4. Analysis of residual plots.
5. Subjective consideration of information available to those who may use the equations for predicting production.

The principal variables retained for each equation as a result of the above criteria are shown in table 13 (appendix B). Also table 14 (appendix B) shows the significance of the variables. Distance was the major variable influencing production in every case. Lateral distance appears in every equation except for the live skyline in shelterwood units. All equations are for the conventional logging utilization treatments (1).

ESTIMATING TURN TIME AND PRODUCTIVITY

Harvesting productivity in general, and for the Coram sale in particular, was discussed under harvesting productivity (tables 4, 5, and 6). These statistics are useful for comparing production for different utilization standards, and equipment types used on the sale. They show what could be expected at other locations with conditions similar to those at Coram, but what about other areas and situations?

Regression equations (appendix B, table 13) can be used to estimate production when information is available about the independent variables. Most of this information is available whenever a sale is prepared or can be derived from timber surveys and topographic maps.

To facilitate the use of the regression equations and foreign element delay times derived from the study, tables 15 through 23 in appendix B were prepared. They can be used to estimate turn time computed from each equation in table 13, appendix B.

To illustrate how productivity can be estimated, the following examples are presented.

Computation of Turn Time and Productivity for Assumed Yarding Conditions (all tables used are in appendix B)

Case 1: Running skyline, shelterwood cut, uphill yarding
--Average yarding distance--500 feet (152 m)
--Average lateral yarding distance--60 feet (18.3 m)
--Average number of logs--4.0
--Average weight of load--2,800 lb (1,270 kg)
--Average piece size--14 ft^3 (0.33 m^3)

Estimating Turn Time (T.T.)

from table 15:

Matrix A, factor = 5.87 (extrapolated)
Matrix B, factor = 1.027
T.T. = 5.87 x 1.027 = 6.03 min

from table 22: Percent foreign element = 14.4

T.T. = 6.03 x 1.144 = 6.72

Estimating Productivity

Turn time = 6.72

from table 23:

4.0 logs, 14 ft^3 (0.33 m^3) piece size
V = 501 ft^3/h (14.2 m^3/h) (extrapolated)

(These are productive hours for all estimates.)

Case 2: Live skyline, clearcut, uphill yarding
--Average yarding distance--400 feet (122 m)
--Average lateral yarding distance--90 feet (27.4 m)
--Average number of logs--5.0
--Average slope--60 percent
--Average piece size--12 ft^3 (0.29 m^3)

Estimating Turn Time (T.T.)

from table 21:

Matrix A, factor = 10.16 (extrapolated)
Matrix B, factor = 0.612
T.T. = 10.16 x 0.612 = 6.22

from table 22: Percent foreign element = 10.8

T.T. = 6.22 x 1.108 = 6.89

Estimating Productivity

Turn Time = 6.89

from table 23:

5.0 logs, 12 ft^3 (0.29 m^3) piece size
V = 512 ft^3/hr (14.5 m^3/hr) (extrapolated)

(These are productive hours for all estimates.)

SUMMARY AND CONCLUSIONS

For shelterwood and group selection units, the cubic foot volume of material removed per hour was greatest in treatment 4, as would probably have been expected. However, cubic foot volume removed per hour in clearcut units was greatest in treatment 1 (conventional logging). Production per hour was generally greater for all treatments in clearcut units. This may have been due to greater ease of lateral skidding.

The important measured variables influencing turn cycles, and therefore production, were (1) distance, (2) lateral distance, (3) slope, (4) number of logs, (5) volume, and (6) weight. In table 14 (appendix B), the relative importance of these variables for each harvesting situation is shown by their contribution to the correlation coefficient (R^2). *Distance* was the most important variable in every case, and *lateral distance* appears in every equation. *Number of logs* appears in every equation except the running skyline yarding uphill in a shelterwood cut. If information is available for these three variables, a reasonably good estimate of production is possible.

The room to maneuver yarders, trucks, and loaders on this sale was rather restricted because of the 14-foot (4.3 m), single-lane road, few turnouts, and no planned landings. In fact, landing construction was prohibited. However, turnouts could be used effectively as could the relatively flat areas below blocks 11 and 12. These landing areas in blocks 11 and 12 were undoubtedly partly responsible for the greater production experienced from downhill yarding in these blocks.

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APPENDIX A--YARDER SPECIFICATIONS

GENERAL YARDER SPECIFICATIONS

Skagit GT-3

Dimensions: Boom Height - 38' 6" (11.7 m)
Working Height - 44' (13.4 m)
Overall Width - 12' 6" (3.8 m)
Ground Clearance - 1' 4" (0.4 m)

Drum Capacity:

Mains - 1,700' (518 m) - 5/8" (1.6 cm) dia. cable
1,100' (335 m) - 3/4" (1.9 cm) dia. cable

Haulback - 2,400' (732 m) - 3/4" (1.9 cm) dia. cable
2,600' (792 m) - 3/8" (1.0 cm) dia. cable

Guyline - 109' (33.2 m) - 1" (2.54 cm) dia. cable

Power Unit - Cummings NH 220 with Allison Torque Converter

Shipping Weight - 95,040 lb (43,110 kg)

Link Belt HC-78B

Dimensions: Boom Height - 35' 0" (10.7 m)
Working Height - 41' 5" (12.6 m)
Overall Width - 9' 0" (2.7 m)
Minimum Ground Clearance - 0' 10" (2.1 cm)

Drum Capacity:

Skyline - 1,100' (335 m) - 5/8" (1.6 cm) dia. cable

Mainline - 1,300' (396 m) - 1/2" (1.3 cm) dia. cable

Power Unit - General Motors 6V-53

Shipping Weight - 68,775 lb (29,958 kg)

APPENDIX B--PRODUCTIVITY AND STATISTICAL ANALYSIS

Table 9.--*Mean, standard deviation, and standard error for pieces per turn, turns per hour, and pieces per hour*

Block[1/]	Pieces/turn			Turns/hour			Pieces/hour		
	$\bar{x}$[2/]	Sx	$S\bar{x}$	$\bar{x}$	Sx	$S\bar{x}$	$\bar{x}$	Sx	$S\bar{x}$
				SKAGIT					
21D(S)	2.39	0.63	0.18	10.64	2.96	0.86	25.58	10.30	2.97
11D(S)	4.37	.59	.13	10.89	2.90	.63	47.09	11.17	2.44
21U(S)	3.63	.56	.16	8.82	3.25	.60	35.42	13.15	2.44
11U(S)	3.89	.55	.16	9.13	2.40	.62	34.37	11.67	3.01
22U(GS)	4.74	.74	.21	6.72	2.63	.73	31.79	13.22	3.67
12D(GS)	5.16	.84	.25	11.23	2.17	.65	57.98	14.63	4.41
13U(C)	4.47	.61	.14	9.73	1.65	.39	42.40	7.49	1.77
ALL	4.14	1.02	--	10.12	6.84	--	39.14	14.48	--
				LINK BELT					
22(GS)	4.60	1.52	.76	7.82	2.27	1.36	38.40	22.35	11.17
12(GS)	4.60	.44	.17	9.39	1.24	.44	43.46	6.61	2.70
11(S)	4.96	.65	.19	7.74	1.97	.57	36.60	10.65	3.08
23(C)	4.89	.96	.19	8.43	2.13	.43	45.71	19.44	5.39
ALL	4.84	.87	--	8.19	2.04	--	38.54	13.96	--

1/ D = downhill yarding, U = uphill yarding, S = shelterwood, GS = group selection, C = clearcut.

2/ $\bar{x}$ = mean, Sx = standard deviation, $S\bar{x}$ = standard error of the mean.

Table 10.--*Falling statistics*

Treatment and silvicultural cut	Observed production rate		Estimated production rate based on cost	
	h/M bd.ft.	*(h/m^3)*	*h/M bd.ft.*	*(h/m^3)*
1/ 1 - CC	0.58	(0.13)	0.58	(0.13)
1 - GS	.69	(0.15)	.87	(0.19)
1 - SW	.93	(0.21)	.87	(0.19)
4 - CC	.59	(0.13)	.77	(0.17)
4 - GS	.60	(0.13)	1.06	(0.23)
4 - SW	1.01	(0.22)	1.06	(0.23)
3 - CC	.68	(0.15)	.82	(0.18)
3 - GS	.74	(0.16)	1.11	(0.24)
3 - SW	1.15	(0.25)	1.11	(0.24)
2 - CC	.72	(0.16)	.64	(0.14)
2 - GS	.81	(0.18)	.93	(0.21)
2 - SW	1.21	(0.27)	.93	(0.21)
Average	.79	(0.17)	.87	(0.19)

1/ Basis for estimates.

Table 11.--*Estimates of productive hours*

Block	Percentage of total yarding time actually spent yarding
11	0.66
12	.70
13	.79
21	.67
22	.59
23	.65
Average	0.67

Table 12.--*Loading statistics for each operation*

SKAGIT

Trucks loaded per day

Loader	$\bar{x}$	Sx	$S\bar{x}$
Long boom	5.00	2.85	0.49
Front end	3.20	1.57	.40

Trucks loaded per day by class

Truck	$\bar{x}$	Sx	$S\bar{x}$
Logs-trailer	2.35	1.56	0.18
Residue-dump	3.19	2.29	.31

LINK BELT

Trucks loaded per day

Loader	$\bar{x}$	Sx	$S\bar{x}$
Long boom	3.79	1.44	0.33
Front end	4.44	2.50	.59

Trucks loaded per day by class

Truck	$\bar{x}$	Sx	$S\bar{x}$
Logs-trailer	2.21	1.10	0.21
Residue-dump	3.23	1.78	.33

Table 13.--*Regression equations*[1] *(equations apply to utilization level 1)*

Running, Shelterwood, Uphill

LN(TT) = 1.458050
+ (.001)(0.486540) Distance
+ .001145 Lateral Distance
+ (.001)(0.00896) Weight

Running, Shelterwood, Downhill

LN(TT) = 0.676830
+ .000240 (No. Logs)(Lateral Distance)
+ .132343 LN (Distance) - 0.000032 (Slope)(Volume)

Running, Group Selection, Uphill

LN(TT) = 0.580136
- .003076 (Slope)
+ .001928 (Lateral Distance) + 0,191832 LN (Distance)
+ (.00001)(0.400174)(No. Logs)(Weight)

Running, Group Selection, Downhill

LN(TT) = 0.689134
+ .002647 (Lateral Distance)
+ .337807 LN (Distance)
+ (.353655)(0.00001)(No. Logs)(Weight)

Running, Clearcut, Uphill

LN(TT) = 1.089454
+ .019567 (No. Logs) + 0.001065 (Distance)
+ .000617 (Volume) - (0.001)(0.000545)(Distance)
+ .000043 (Lateral Distance)(Slope)

Live, Group Selection, Uphill

LN(TT) = 1.812551
+ .000940 Distance
- .00950 Slope + 0.001721 Lateral Distance
+ (.00001)(0.277323)(No. Logs)(Weight)

Live, Clearcut, Uphill

LN(TT) = 1.910023
+ .000545 Distance
- .006795 Slope + 0.002118 Lateral Distance
- .4162 $(\text{No. Logs})^{-1}$

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[1] LN = natural log. TT = Turn time.

Table 14.--*Independent variables and their contributions to R^2 for each regression equation (equations apply to utilization level 1)*

Harvesting situation, regression equation	Dependent variable	Independent variable and contribution to R^2		R^2 for equation
		Variable	Contribution to R^2	
Running Skyline, Shelterwood, Uphill	[1] LN(TT)	Distance	0.2957	0.34
		Lateral Distance	.0135	
		Weight	.0047	
Running Skyline, Shelterwood, Downhill	LN(TT)	LN (Distance)	.2134	.44
		(Slope) (Volume) (-)	.0353	
		(No. Logs) (Lateral Distance)	.0257	
Running Skyline, Group Selection, Uphill	LN(TT)	LN (Distance)	.3787	.68
		Lateral Distance	.0375	
		(No. Logs) (Weight)	.0348	
		Slope	.0121	
Running Skyline, Group Selection, Downhill	LN(TT)	LN (Distance)	.1039	.32
		Lateral Distance	.0715	
		(No. Logs) (Weight)	.0261	
Running Skyline, Clearcut, Uphill	LN(TT)	Distance	.2176	.48
		(Lateral Distance) (Slope)	.0478	
		Volume	.0252	
		$(\text{Distance})^2$ (-)	.0222	
		No. Logs	.0160	
Live Skyline, Group Selection, Uphill	LN(TT)	Distance	.2578	.42
		Lateral Distance	.0276	
		Slope (-)	.0270	
		(No. Logs) (Weight)	.0112	
	LN(TT)	Distance	.2660	.41
		$(\text{No. Logs})^{-1}$ (-)	.0476	
		Lateral Distance	.0294	
		Slope (-)	.0208	

[1] LN = natural log. TT = turn time.

Table 15.--*Turn time prediction factors, running, shelterwood, uphill*

Matrix A

Lateral distance ft (m)

Skyline distance ft (m)	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
25 (7.6)	4.350	4.400	4.451	4.502	4.554	4.606	4.660	4.713	4.767	4.822	4.878
125 (38.1)	4.567	4.620	4.673	4.727	4.781	4.836	4.892	4.948	5.005	5.063	5.121
225 (68.6)	4.795	4.850	4.906	4.962	5.019	5.077	5.136	5.195	5.255	5.315	5.376
325 (99.1)	5.034	5.092	5.150	5.210	5.270	5.330	5.392	5.454	5.517	5.580	5.644
425 (130.0)	5.285	5.346	5.407	5.469	5.532	5.596	5.661	5.726	5.792	5.858	5.926
525 (160.0)	5.548	5.612	5.677	5.742	5.808	5.875	5.943	6.011	6.080	6.150	6.221
625 (190.0)	5.825	5.892	5.960	6.028	6.098	6.168	6.239	6.311	6.384	6.457	6.531
725 (221.0)	6.115	6.186	6.257	6.329	6.402	6.476	6.550	6.626	6.702	6.779	6.857
825 (252.0)	6.420	6.494	6.569	6.645	6.721	6.798	6.877	6.956	7.036	7.117	7.199
925 (282.0)	6.740	6.818	6.896	6.976	7.056	7.137	7.220	7.303	7.387	7.472	7.558
1025 (312.0)	7.076	7.158	7.240	7.324	7.408	7.493	7.580	7.667	7.755	7.844	7.935
1125 (343.0)	7.429	7.515	7.601	7.689	7.777	7.867	7.957	8.049	8.142	8.236	8.330

Matrix B

Weight lb (kg)

30 (13.6)	1510 (685)	2990 (1356)	4470 (2028)	5950 (2699)	7430 (3370)	8910 (4042)	10390 (4713)	11870 (5384)	13350 (6056)	14830 (6729)
1.000	1.014	1.027	1.041	1.055	1.069	1.083	1.098	1.112	1.127	1.142

Table 16.--*Turn time prediction factors, running, shelterwood, downhill*

Matrix A

Lateral distance ft (m)

Number of logs	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
1	1.968	1.972	1.977	1.982	1.987	1.991	1.996	2.001	2.006	2.011	2.015
2	1.968	1.977	1.987	1.996	2.006	2.015	2.025	2.035	2.045	2.054	2.064
3	1.968	1.982	1.996	2.011	2.025	2.040	2.054	2.069	2.084	2.099	2.115
4	1.968	1.987	2.006	2.025	2.045	2.064	2.084	2.104	2.125	2.145	2.166
5	1.968	1.991	2.015	2.040	2.064	2.089	2.115	2.140	2.166	2.192	2.218
6	1.968	1.996	2.025	2.054	2.084	2.115	2.145	2.176	2.208	2.240	2.272
7	1.968	2.001	2.035	2.069	2.104	2.140	2.176	2.213	2.251	2.289	2.328
8	1.968	2.006	2.045	2.084	2.125	2.166	2.208	2.251	2.294	2.339	2.384
9	1.968	2.011	2.054	2.099	2.145	2.192	2.240	2.289	2.339	2.390	2.442
10	1.968	2.015	2.064	2.115	2.166	2.218	2.272	2.328	2.384	2.442	2.501

Matrix B

Volume bd.ft. (m^3)

Slope (percent)	5 (0.02)	30 (0.14)	55 (0.25)	80 (0.36)	105 (0.48)	130 (0.59)	155 (0.70)	180 (0.82)	205 (0.93)	230 (1.04)	255 (1.16)
-30	1.005	1.029	1.054	1.080	1.106	1.133	1.160	1.189	1.218	1.247	1.277
-25	1.004	1.024	1.045	1.066	1.088	1.110	1.132	1.155	1.178	1.202	1.226
-20	1.003	1.019	1.036	1.053	1.070	1.087	1.104	1.122	1.140	1.159	1.177
-15	1.002	1.015	1.027	1.039	1.052	1.064	1.077	1.090	1.103	1.117	1.130
-10	1.002	1.010	1.018	1.026	1.034	1.042	1.051	1.059	1.068	1.076	1.085
- 5	1.001	1.005	1.009	1.013	1.017	1.021	1.025	1.029	1.033	1.037	1.042
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	.999	.995	.991	.987	.983	.979	.976	.972	.968	.964	.960
10	.998	.990	.983	.975	.967	.959	.952	.944	.937	.929	.922
15	.998	.986	.974	.962	.951	.940	.928	.917	.906	.895	.885
20	.997	.981	.965	.950	.935	.920	.906	.891	.877	.863	.849

Matrix C

Distance ft (m)

25 (7.6)	105 (32.0)	185 (56.4)	265 (80.8)	345 (105)	425 (130)	505 (154)	585 (178)	665 (204)	745 (227)	825 (251)
1.531	1.851	1.995	2.093	2.167	2.228	2.279	2.324	2.364	2.399	2.432

Table 17.--*Turn time prediction factors, running, group selection, uphill*

Matrix A

Weight lb (kg)

		200 (90.7)	1200 (544)	2200 (998)	3200 (1452)	4200 (1905)	5200 (2359)	6200 (2823)	7200 (3266)	8200 (3720)	9200 (4173)	10200 (4627)
	1	1.788	1.795	1.802	1.809	1.817	1.824	1.831	1.838	1.846	1.853	1.861
	2	1.789	1.804	1.818	1.833	1.847	1.862	1.877	1.892	1.907	1.923	1.938
	3	1.791	1.812	1.834	1.856	1.879	1.901	1.924	1.948	1.971	1.995	2.019
Number	4	1.792	1.821	1.850	1.880	1.910	1.941	1.973	2.004	2.037	2.070	2.103
of	5	1.793	1.830	1.867	1.904	1.943	1.982	2.022	2.063	2.105	2.147	2.191
logs	6	1.795	1.838	1.883	1.928	1.976	2.024	2.073	2.123	2.175	2.228	2.282
	7	1.796	1.847	1.900	1.954	2.009	2.066	2.125	2.185	2.248	2.311	2.377
	8	1.798	1.856	1.917	1.979	2.043	2.110	2.178	2.249	2.323	2.398	2.476
	9	1.799	1.865	1.934	2.004	2.078	2.154	2.233	2.315	2.400	2.488	2.579
	10	1.801	1.874	1.951	2.030	2.113	2.199	2.289	2.383	2.480	2.581	2.687

Matrix B

Lateral Distance ft (m)

		0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
	22	.935	.953	.971	.990	1.009	1.029	1.049	1.070	1.090	1.112	1.133
	27	.920	.938	.956	.975	.994	1.013	1.033	1.053	1.074	1.095	1.116
	32	.906	.924	.942	.960	.979	.998	1.017	1.037	1.057	1.078	1.099
	37	.892	.910	.928	.946	.964	.983	1.002	1.021	1.041	1.062	1.082
Slope	42	.879	.896	.913	.931	.949	.968	.987	1.006	1.025	1.045	1.066
(per-	47	.865	.882	.899	.917	.935	.953	.972	.990	1.010	1.029	1.049
cent)	52	.852	.869	.886	.903	.921	.938	.957	.975	.994	1.014	1.033
	57	.839	.856	.872	.889	.906	.924	.942	.960	.979	.998	1.018
	62	.826	.842	.859	.876	.893	.910	.928	.946	.964	.983	1.002
	67	.814	.830	.846	.862	.879	.896	.914	.931	.949	.968	.987
	72	.801	.817	.833	.849	.866	.882	.900	.917	.935	.953	.972

Matrix C

Distance ft (m)

50 (15.2)	170 (51.8)	290 (88.4)	410 (125)	530 (162)	650 (198)	770 (235)	890 (271)	1010 (308)	1130 (344)	1250 (381)
2.118	2.678	2.967	3.171	3.331	3.464	3.579	3.679	3.770	3.852	3.927

Table 18.--*Turn time prediction factors, running, group selection, downhill*

Matrix A

Weight lb (kg)

Number of logs	250 (113)	1150 (526)	2050 (930)	2950 (1338)	3850 (1746)	4750 (2155)	5650 (2563)	6550 (2971)	7450 (3379)	8350 (3788)	9250 (4196)
2	0.503	0.506	0.509	0.513	0.516	0.519	0.522	0.526	0.529	0.533	0.536
3	.503	.508	.513	.518	.523	.528	.533	.538	.543	.549	.554
4	.504	.510	.517	.523	.530	.537	.544	.551	.558	.565	.572
5	.504	.512	.521	.529	.537	.546	.555	.564	.573	.582	.591
6	.505	.514	.524	.534	.545	.555	.566	.577	.588	.599	.611
7	.505	.517	.528	.540	.552	.565	.577	.590	.604	.617	.631
8	.506	.519	.532	.546	.560	.574	.589	.604	.620	.636	.652
9	.506	.521	.536	.551	.567	.584	.601	.618	.636	.655	.674
10	.506	.523	.540	.557	.575	.594	.613	.633	.653	.674	.696
11	.507	.525	.544	.563	.583	.604	.625	.648	.671	.695	.719

Matrix B

Distance ft (m)

Lateral distance ft (m)	180 (54.9)	240 (73.2)	300 (91.4)	360 (110)	420 (128)	480 (146)	540 (165)	600 (183)	660 (201)	720 (219)	780 (238)
10 (3.0)	5.934	6.540	7.052	7.499	7.900	8.265	8.600	8.912	9.204	9.478	9.738
20 (6.1)	6.093	6.715	7.241	7.701	8.112	8.487	8.831	9.151	9.450	9.732	9.999
30 (9.1)	6.257	6.895	7.435	7.907	8.330	8.714	9.068	9.396	9.704	9.993	10.267
40 (12.2)	6.424	7.080	7.634	8.119	8.553	8.948	9.311	9.649	9.964	10.261	10.543
50 (15.2)	6.597	7.270	7.839	8.337	8.783	9.188	9.561	9.907	10.232	10.537	10.826
60 (18.3)	6.774	7.465	8.049	8.561	9.018	9.434	9.817	10.173	10.506	10.819	11.116
70 (21.3)	6.955	7.665	8.265	8.790	9.260	9.688	10.081	10.446	10.788	11.110	11.414
80 (24.4)	7.142	7.871	8.487	9.026	9.509	9.947	10.351	10.726	11.077	11.408	11.720
90 (27.4)	7.333	8.082	8.715	9.268	9.764	10.214	10.629	11.014	11.374	11.714	12.035
100 (30.5)	7.530	8.299	8.948	9.517	10.026	10.488	10.914	11.309	11.679	12.028	12.357

Table 19.--*Turn time prediction factors, running, clearcut, uphill*

Matrix A

Volume bd.ft. (m^3)

Distance ft (m)	5 (0.02)	25 (0.11)	45 (0.20)	65 (0.29)	85 (0.38)	105 (0.48)	125 (0.57)	145 (0.66)	165 (0.75)	185 (0.84)	205 (0.93)
60 (18.3)	3.172	3.212	3.252	3.293	3.334	3.375	3.417	3.460	3.503	3.579	3.591
145 (44.2)	3.440	3.483	3.527	3.571	3.615	3.660	3.706	3.752	3.799	3.846	3.894
230 (70.1)	3.701	3.747	3.794	3.842	3.889	3.938	3.987	4.037	4.087	4.138	4.190
315 (96.0)	3.951	4.000	4.050	4.101	4.152	4.204	4.256	4.309	4.363	4.417	4.473
400 (122)	4.184	4.237	4.289	4.343	4.397	4.452	4.508	4.564	4.621	4.678	4.737
485 (148)	4.397	4.452	4.507	4.563	4.620	4.678	4.736	4.796	4.855	4.916	4.977
570 (174)	4.584	4.641	4.699	4.758	4.817	4.877	4.938	4.999	5.062	5.125	5.189
655 (200)	4.741	4.800	4.860	4.921	4.982	5.045	5.108	5.171	5.236	5.301	5.367
740 (226)	4.866	4.926	4.988	5.050	5.113	5.177	5.242	5.307	5.373	5.440	5.508
825 (251)	4.954	5.016	5.079	5.142	5.206	5.271	5.337	5.403	5.471	5.539	5.608
910 (277)	5.005	5.067	5.130	5.194	5.259	5.325	5.391	5.459	5.527	5.596	5.665

Matrix B

Lateral distance ft (m)

Slope (percent)	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
20	1.000	1.009	1.017	1.026	1.035	1.044	1.053	1.062	1.071	1.080	1.090
25	1.000	1.011	1.022	1.033	1.044	1.055	1.067	1.078	1.090	1.102	1.113
30	1.000	1.013	1.026	1.039	1.053	1.067	1.080	1.095	1.109	1.123	1.138
35	1.000	1.015	1.031	1.046	1.062	1.078	1.095	1.111	1.128	1.145	1.162
40	1.000	1.017	1.035	1.053	1.071	1.090	1.109	1.128	1.148	1.167	1.188
45	1.000	1.020	1.039	1.060	1.080	1.102	1.123	1.145	1.167	1.190	1.213
50	1.000	1.022	1.044	1.067	1.090	1.113	1.138	1.162	1.188	1.213	1.240
55	1.000	1.024	1.048	1.074	1.099	1.126	1.152	1.180	1.208	1.237	1.267
60	1.000	1.026	1.053	1.080	1.109	1.138	1.167	1.198	1.229	1.261	1.294

Matrix C

Number of logs

1	2	3	4	5	6	7	8	9	10
1.020	1.040	1.060	1.081	1.103	1.125	1.147	1.169	1.193	1.261

Table 20.--*Turn time prediction factors, live, group selection, uphill*

Matrix A

Lateral distance ft (m)

Slope (percent)	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
40	4.189	4.262	4.336	4.411	4.488	4.566	4.645	4.726	4.808	4.891	4.976
45	3.995	4.064	4.135	4.207	4.280	4.354	4.430	4.506	4.585	4.664	4.745
50	3.810	3.876	3.943	4.012	4.081	4.152	4.224	4.297	4.372	4.448	4.525
55	3.633	3.696	3.760	3.825	3.892	3.959	4.028	4.098	4.169	4.242	4.315
60	3.464	3.525	3.586	3.648	3.711	3.776	3.841	3.908	3.976	4.045	4.115
65	3.304	3.361	3.419	3.479	3.539	3.601	3.663	3.727	3.791	3.857	3.924
70	3.150	3.205	3.261	3.317	3.375	3.434	3.493	3.554	3.615	3.678	3.742

Matrix B

Weight lb (kg)

Number of logs	75 (34.0)	875 (397)	1675 (760)	2475 (1123)	3275 (1486)	4075 (1848)	4875 (2211)	5675 (2574)	6475 (2937)	7275 (3300)	8075 (3663)
1	1.000	1.002	1.005	1.007	1.009	1.011	1.014	1.016	1.018	1.020	1.023
2	1.000	1.005	1.009	1.014	1.018	1.023	1.027	1.032	1.037	1.041	1.046
3	1.001	1.007	1.014	1.021	1.028	1.034	1.041	1.048	1.055	1.062	1.069
4	1.001	1.010	1.019	1.028	1.037	1.046	1.056	1.065	1.074	1.084	1.094
5	1.001	1.012	1.023	1.035	1.046	1.058	1.070	1.082	1.094	1.106	1.118
6	1.001	1.015	1.028	1.042	1.056	1.070	1.084	1.099	1.114	1.129	1.144
7	1.001	1.017	1.033	1.049	1.066	1.082	1.099	1.116	1.134	1.152	1.170
8	1.002	1.020	1.038	1.056	1.075	1.095	1.114	1.134	1.154	1.175	1.196
9	1.002	1.022	1.043	1.064	1.085	1.107	1.129	1.152	1.175	1.199	1.223
10	1.002	1.025	1.048	1.071	1.095	1.120	1.145	1.170	1.197	1.224	1.251
11	1.002	1.027	1.052	1.078	1.105	1.132	1.160	1.189	1.218	1.248	1.279
12	1.002	1.030	1.057	1.086	1.115	1.145	1.176	1.208	1.240	1.274	1.308

Matrix C

Distance ft (m)

50 (15.2)	125 (38.1)	200 (61.0)	275 (83.8)	350 (107)	425 (130)	500 (152)	575 (175)	650 (198)	725 (221)	800 (244)
1.048	1.125	1.207	1.295	1.390	1.491	1.600	1.717	1.842	1.977	2.121

Table 21.--*Turn time prediction factors, live, clearcut, uphill*

Matrix A

Distance ft (m)	Lateral distance ft (m): 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
10 (3.0)	6.790	6.935	7.084	7.236	7.390	7.549	7.710	7.875	8.044	8.216	8.392
90 (27.4)	7.093	7.245	7.400	7.558	7.720	7.885	8.054	8.226	8.402	8.582	8.766
170 (51.8)	7.409	7.567	7.729	7.895	8.064	8.236	8.413	8.593	8.777	8.965	9.157
250 (76.2)	7.739	7.905	8.074	8.247	8.423	8.604	8.788	8.976	9.168	9.364	9.565
330 (101)	8.084	8.257	8.434	8.614	8.799	8.987	9.179	9.376	9.577	9.781	9.991
410 (125)	8.444	8.625	8.810	8.998	9.191	9.387	9.588	9.794	10.003	10.217	10.436
490 (149)	8.820	9.009	9.202	9.399	9.600	9.806	10.016	10.230	10.449	10.637	10.901
570 (174)	9.214	9.411	9.612	9.818	10.028	10.243	10.462	10.686	10.915	11.148	11.387
650 (198)	9.624	9.830	10.041	10.255	10.475	10.699	10.928	11.162	11.401	11.645	11.894
730 (223)	10.053	10.268	10.488	10.713	10.942	11.176	11.415	11.660	11.908	12.164	12.425
810 (247)	10.501	10.726	10.955	11.190	11.429	11.674	11.924	12.179	12.440	12.706	12.978
890 (271)	10.969	11.204	11.444	11.689	11.939	12.194	12.455	12.722	12.994	13.272	13.557
970 (296)	11.458	11.703	11.954	12.209	12.471	12.738	13.010	13.289	13.573	13.864	14.161

Matrix B

Slope (percent)	Number of logs: 1	2	3	4	5	6	7	8	9	10
45	0.486	0.598	0.641	0.664	0.678	0.687	0.694	0.699	0.703	0.707
50	.470	.578	.620	.642	.655	.664	.671	.676	.680	.683
55	.454	.559	.599	.620	.633	.642	.648	.653	.657	.660
60	.439	.540	.579	.599	.612	.621	.627	.631	.635	.638
65	.424	.522	.560	.579	.592	.600	.606	.610	.614	.617
70	.410	.505	.541	.560	.572	.580	.586	.590	.593	.596

Table 22.--*Total foreign element statistics. (Foreign elements are delays attributed to machines, manpower, material, and environmental factors)*

System	Turns with foreign elements	Av. total foreign element time in turns with foreign elements	Av. foreign element time for all turns
	Percent	*Minutes*	*Percent*
Running Skyline Shelterwood Uphill	30.6	28.0	14.4
Running Skyline Shelterwood Downhill	27.7	3.8	23.7
Running Skyline Group Selection Uphill	40.7	2.5	26.3
Running Skyline Group Selection Downhill	14.7	2.2	6.4
Running Skyline Clearcut Uphill	15.7	3.0	8.2
Live Skyline Group Selection Uphill	20.0	11.0	27.8
Live Skyline Clearcut Uphill	19.6	3.2	10.8

Table 23.--*Cubic foot (m^3) volume per hour for turn times given piece size and number of logs*

Turn time (min)	Piece size in ft^3 (m^3)											
	4.0 Log/Load						5.0 Log/Load					
	10 (0.24)	12 (0.29)	14 (0.33)	16 (0.38)	18 (0.43)	20 (0.48)	10 (0.24)	12 (0.29)	14 (0.33)	16 (0.38)	18 (0.43)	20 (0.48)
3.0	800 (22.6)	960 (27.2)	1120 (31.7)	1280 (36.2)	1440 (40.8)	1600 (45.3)	1000 (28.3)	1200 (34.0)	1400 (39.7)	1600 (45.3)	1800 (51.0)	2000 (56.6)
.2	750 (21.2)	900 (25.5)	1050 (29.7)	1200 (34.0)	1350 (38.2)	1500 (42.5)	938 (26.6)	1125 (31.9)	1312 (37.2)	1500 (42.5)	1688 (47.8)	1875 (53.1)
.4	706 (20.0)	847 (24.0)	988 (27.9)	1129 (32.0)	1271 (36.0)	1412 (40.0)	882 (25.0)	1059 (30.0)	1235 (35.0)	1412 (40.0)	1588 (45.0)	1765 (50.0)
.6	667 (18.9)	800 (22.6)	933 (26.4)	1067 (30.2)	1200 (34.0)	1333 (37.8)	833 (23.6)	1000 (28.3)	1167 (33.1)	1333 (27.8)	1500 (42.5)	1667 (47.2)
.8	637 (18.0)	756 (21.4)	884 (25.0)	1010 (28.6)	1137 (32.2)	1263 (35.8)	789 (22.3)	947 (26.8)	1105 (31.3)	1263 (35.8)	1421 (40.2)	1579 (44.7)
4.0	600 (17.0)	720 (20.4)	840 (23.8)	960 (27.2)	1080 (30.6)	1200 (34.0)	750 (21.2)	900 (25.5)	1050 (29.7)	1200 (34.0)	1350 (38.2)	1500 (42.5)
.2	571 (16.2)	686 (19.4)	800 (22.6)	914 (25.9)	1029 (29.1)	1143 (32.4)	714 (20.2)	857 (24.3)	1000 (28.3)	1143 (32.4)	1286 (36.4)	1429 (40.5)
.4	546 (15.5)	655 (18.5)	764 (21.6)	873 (24.7)	982 (27.8)	1091 (30.9)	682 (19.3)	818 (23.2)	955 (27.0)	1091 (30.9)	1228 (34.9)	1364 (38.6)
.6	522 (14.8)	626 (17.7)	730 (20.7)	835 (23.6)	939 (26.6)	1043 (29.5)	652 (18.5)	782 (22.1)	913 (25.9)	1043 (29.5)	1174 (33.2)	1304 (36.9)
.8	500 (14.2)	600 (17.0)	700 (19.8)	800 (22.6)	900 (25.5)	1000 (28.3)	625 (17.7)	750 (21.2)	875 (24.9)	1000 (28.3)	1125 (31.9)	1250 (35.4)
5.0	480 (13.6)	576 (16.3)	672 (19.0)	768 (21.7)	864 (24.5)	960 (27.2)	600 (17.0)	720 (20.4)	840 (23.8)	960 (27.2)	1080 (30.6)	1200 (34.0)
.2	462 (13.1)	554 (15.7)	646 (18.3)	738 (20.9)	831 (23.5)	923 (26.1)	577 (16.3)	692 (19.6)	808 (22.9)	923 (26.1)	1038 (29.4)	1154 (32.7)
.4	444 (12.6)	533 (15.1)	622 (17.6)	711 (20.1)	800 (22.6)	889 (25.2)	556 (15.7)	667 (18.8)	778 (22.0)	889 (25.2)	1000 (28.3)	1111 (31.5)
.6	429 (12.1)	514 (14.6)	600 (17.0)	686 (19.4)	771 (21.8)	857 (24.3)	536 (15.2)	643 (18.2)	750 (21.2)	857 (24.3)	964 (27.3)	1071 (30.3)
.8	414 (11.7)	497 (14.1)	579 (16.4)	662 (18.7)	745 (21.1)	828 (23.4)	517 (14.6)	621 (17.6)	724 (20.5)	828 (23.4)	931 (26.4)	1034 (29.3)
6.0	400 (11.3)	480 (13.6)	560 (15.9)	640 (18.1)	720 (20.4)	800 (22.6)	500 (14.2)	600 (17.0)	700 (19.8)	800 (22.6)	900 (25.5)	1000 (28.3)
.2	387 (11.0)	464 (13.1)	542 (15.3)	619 (17.5)	697 (19.7)	774 (21.9)	484 (13.7)	581 (16.5)	677 (19.2)	774 (21.9)	871 (24.7)	968 (27.4)
.4	375 (10.6)	450 (12.7)	525 (14.9)	600 (17.0)	675 (19.1)	750 (21.2)	469 (13.3)	562 (15.9)	656 (18.6)	750 (21.2)	844 (23.9)	938 (26.6)
.6	364 (10.3)	436 (12.3)	509 (14.4)	582 (16.5)	655 (18.5)	727 (20.6)	455 (12.9)	545 (15.4)	636 (18.0)	728 (20.6)	819 (23.2)	909 (25.7)
.8	353 (10.0)	423 (12.0)	494 (14.0)	565 (16.0)	635 (18.0)	706 (20.0)	441 (12.5)	529 (15.0)	618 (17.5)	706 (20.0)	794 (22.5)	882 (25.0)
7.0	343 (9.7)	411 (11.6)	480 (13.6)	549 (15.5)	617 (17.5)	686 (19.4)	429 (12.1)	514 (14.6)	600 (17.0)	686 (19.4)	771 (21.8)	857 (25.3)
.2	333 (9.4)	400 (11.3)	467 (13.2)	533 (15.1)	600 (17.0)	667 (18.9)	417 (11.8)	500 (14.2)	583 (16.5)	667 (18.9)	750 (22.1)	833 (23.6)
.4	324 (9.2)	389 (11.0)	454 (12.9)	519 (14.7)	584 (16.5)	649 (18.4)	405 (11.5)	486 (13.8)	568 (16.1)	649 (18.4)	730 (20.7)	811 (23.0)
.6	316 (8.9)	379 (10.7)	442 (12.5)	505 (14.3)	568 (16.1)	632 (17.9)	395 (11.2)	474 (13.4)	553 (15.7)	632 (17.9)	711 (20.1)	790 (22.4)
.8	308 (8.7)	369 (10.5)	431 (12.2)	492 (13.9)	554 (15.7)	615 (17.4)	385 (10.9)	461 (13.1)	538 (15.2)	616 (17.4)	692 (19.6)	769 (21.8)
8.0	300 (8.5)	360 (10.2)	420 (11.9)	480 (13.6)	540 (15.3)	600 (17.0)	375 (10.6)	450 (12.7)	525 (14.9)	600 (17.0)	675 (19.1)	750 (21.2)

Gardner, Rulon B.
1980. Skyline logging productivity under alternative harvesting prescriptions and levels of utilization in larch-fir stands. USDA For. Serv. Res. Pap. INT-247, 35 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Larch-fir stands in northwest Montana were experimentally logged to determine the influence of increasingly intensive levels of utilization upon rates of yarding production, under three different silvicultural prescriptions. Variables influencing rate of production were also identified.

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Larch-fir stands in northwest Montana were experimentally logged to determine the influence of increasingly intensive levels of utilization upon rates of yarding production, under three different silvicultural prescriptions. Variables influencing rate of production were also identified.

KEYWORDS: Skyline yarding, productivity, utilization.

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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)