

Tractor-Logging Costs and Production in Old-Growth Redwood

Kenneth N. Boe



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Acknowledgments

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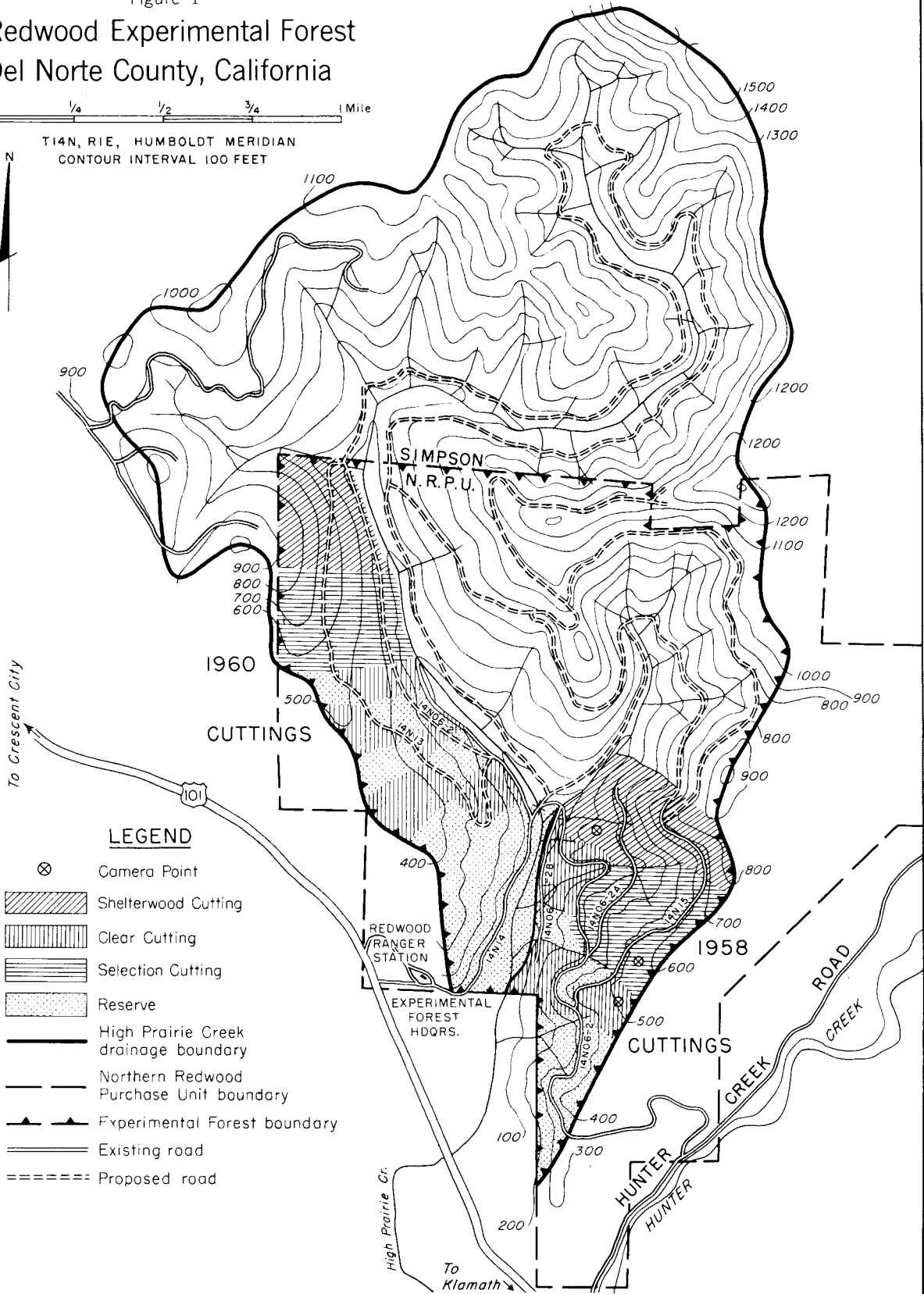
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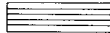
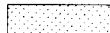


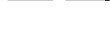
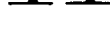
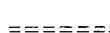
Figure 1
 Redwood Experimental Forest
 Del Norte County, California

0 1/4 1/2 3/4 1 Mile

T14N, R1E, HUMBOLDT MERIDIAN
 CONTOUR INTERVAL 100 FEET



LEGEND

- ⊗ Camera Point
-  Shelterwood Cutting
-  Clear Cutting
-  Selection Cutting
-  Reserve
-  High Prairie Creek drainage boundary
-  Northern Redwood Purchase Unit boundary
-  Experimental Forest boundary
-  Existing road
-  Proposed road

The cost of harvesting old-growth redwood (*Sequoia sempervirens* [D. Don] Endl.) is of concern to logging managers, timber appraisers, forest land managers, gyppos, and others. This paper reports on a study of full-scale logging operations in heavy stand volumes of old-growth redwood in the Redwood Experimental Forest in north coastal Del Norte County, California, carried out cooperatively by the Pacific Southwest Forest and Range Experiment Station and the Simpson Timber Company.

The cost figures in published studies of old-growth redwood are essentially out-dated because of today's changes in machines, methods, and rates. But where principles are involved, some of this information is still useful.

Skidding production is affected by load per turn, distance, and gradient. Stahelin and Hallin¹ have illustrated the importance of skidding capacity loads on each turn. They found that skidding time per thousand board feet in a load less than 3,000 board feet was double or more than in loads greater than 3,000 board feet.

Person² reported higher yarding costs for smaller logs as compared to larger logs. He also found that costs per thousand decreased much slower and at a nearly constant rate above 4,000

board feet per log than for smaller sizes.

For tractors of 75 to 95 horsepower, Hallin³ found that minimum slopes for efficient skidding of logs began at 5 percent for 2,000-board-foot loads, 7 percent for 5,000-board-foot loads, and 15 percent for 8,000-board-foot loads. For combined out and in times, the most efficient slope was probably 25 to 35 percent. Output was increased by one quarter if loads of 6,000 instead of 4,000 board feet were skidded.

In the work reported here, three experimental cutting methods were studied (fig. 1). One logging side worked for 2 years (1959 to 1960) to harvest 22.5 million board feet (net Scribner scale) of timber. The experimental cuttings are still in progress.

Current costs have been tabulated for three different cutting methods and for all methods combined. Such information will be useful in appraising other timber tracts. Different dollar rates, depending on economic trends, may be applied now or in the future to the recorded work units for doing different jobs. Analysis in this report of some key-factor effects on felling-bucking, skidding, and loading production provides basic information for planning decisions by managers and appraisers.

Timber, Topography, and Climate

The old-growth redwood stand in this study is representative of the northern redwoods growing on low-elevation, medium to good sites (fig. 2). Gross volume per acre on cutting units of 13 acres and over ranged from 95,000 to 280,000 board feet (Scribner). Merchantable trees ranged in diameter from 14 to 198 inches d.b.h. The number of merchantable trees per acre ranged from 29 to 46. Snags and windfalls averaged one each per acre.

Smaller trees included all species, but the majority were the whitewoods: Douglas-fir (*Pseudo-*

tsuga menziesii [Mirb.] Franco), Sitka spruce (*Picea sitchensis* [Bong.] Carr.), Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.). The larger trees were principally redwood, although a few Douglas-fir and Sitka spruce reached 96 inches d.b.h. Above this size, all trees were redwood.

V-shaped water courses and narrowly rounded ridges dissect the Redwood Experimental Forest at many places. Slope gradients are moderate to very steep, although many small benches of gentle

¹Stahelin, R., and Hallin, W. Importance of large loads in redwood tractor logging. West Coast Lumberman 64(2) :22-23, illus. 1937.

²Person, Hubert L. Comparative costs for slackline, highlead and tractor yarding-redwood region. U.S. Forest

Serv. Calif. Forest & Range Expt. Sta. Res. Note 15, 5 pp., illus. 1937.

³Hallin, William. Redwood tractor yarding costs as affected by slope gradient and load volume. U.S. Forest Serv. Calif. Forest & Range Expt. Sta. Res. Note 16, 4 pp., illus. 1937.



Figure 2.—This old-growth redwood stand is representative of the redwoods in northern California.

slopes are present. On three-tenths of the cutover stand, slopes averaged 10 to 30 percent gradient, on another three-tenths, 30 to 50 percent, and on the remaining four-tenths, 50 percent or more. On a small portion of this steep ground, slopes are 70 to 95 percent.

Soil over much of the area is deep, well-drained, moderately fine textured clay loam. Near tops of main ridges, the soil becomes somewhat shallower, is medium textured, and has a stony profile. When soil moisture was below field capacity, only short

delays in logging were experienced after 1- to 2-inch rains. Winter rains that usually began in November stopped tractor logging for several months.

The climate is mild and humid. Rainfall has averaged 84 inches annually (19-year record). The 3-month average for July, August, and September—the summer fog months—is 2.7 inches. Average rainfall increases to 7 inches per month in October and 14 inches in January, then dips to about 1 inch in June. Snow occurs infrequently, and lasts only one or two days.

Methods⁵

The general method used in this study consisted in recording man- and machine-hours by days or

⁵See Appendix for detailed description of methods.

fractional days for doing specific portions of the logging job. The hourly or contract labor cost for each man and machine rental cost was compiled.

These cost and production data were collected by cutting method and by landing-stage combinations within each cutting method.

Stage logging was employed primarily to learn something about the effect of tree size on logging costs. Actually stage logging—the removal of trees in successive operations over the same area—is necessary in old-growth redwoods because not enough ground space exists for all felled trees at one time. We logged trees under 6 feet d.b.h. first and called this stage "A". Trees 6 feet d.b.h. and over were logged next for stage "B". Usually this stage required more than one operation.

The three reproduction cutting methods tested were selection, shelterwood, and clear cutting. On each of the 60-acre selection, 69-acre shelterwood, and 13-, 18-, and 20-acre clear cuttings, trees of all sizes were harvested. Data on volumes harvested by cutting appear elsewhere in this report.

We used cost accounting analysis as one of two main procedures. It included computing labor- and machine-hours and costs by the different logging activities required to load logs on trucks. Log volume totals were calculated from the scale tickets for each combination of cutting method and landing stage. From these basic data, we calculated labor-hours, machine-hours, and costs per thousand board feet (gross Scribner log scale) for logs hauled.

The analysis was based on gross log scale. This long-log basis was adopted (a) to eliminate differences between cutting methods that are associated with different amounts of defect in logs hauled; and (b) to relate production output more nearly to dimensions of logs to the extent that board foot volume is correlated with diameter.

Subsequently, gross log scale values may be readily converted to a net log scale basis by dividing each value by a factor. This factor is the quotient of net log volume divided by gross log volume. Similarly these costs can be easily converted to another log scale basis. For example, to convert to a Humboldt scale basis (70 percent of gross Spaulding and essentially the same percent of gross Scribner), divide costs and work units per thousand and board feet by 0.70.

The second main procedure consisted of statistical analyses of the three key activities—felling-bucking, skidding, and loading—all in relation to the different factors affecting production output.

Felling-bucking⁶ board-foot volume was evaluated for a 2-man crew on an 8-hour per day basis. We compiled average d.b.h. and gross Scribner volume of trees felled and bucked from random samples of daily output.

Each observation of skidding production included the volume of all logs skidded to a landing during one stage of logging. The dependent variable was expressed as average gross Scribner board-foot volume of logs skidded per tractor hour. The multiple regression and analysis included five independent variables and 30 sets of observations.

Loading production was analyzed by simple linear regression for each of two loaders and to determine significance between outputs. The independent variable was average gross Scribner volume per log, and the dependent variable was average gross Scribner volume loaded per hour. These averages were based on production for a day or fractional day for one stage-landing logging unit.

Results

Costs and Work Units to Log Redwood

The direct costs of logging old-growth redwood, excluding road construction and hauling, were less than \$15 per thousand board feet (gross Scribner scale). These figures are based on 1959-1960 rates. Costs on selection cuttings were slightly lower than those on the clear cuttings (table 1; also see table 7, Appendix, for detailed costs). Costs were highest for shelterwood cuttings. When expressed on a net log scale basis, costs were lowest on the clear cuttings.

The work units by cuttings ranked similarly to costs. They were lowest by a slight margin on the selection cutting, next on clear cutting, and highest on the shelterwood cutting (table 2). Others may wish to use their own average rates with these units, or with the itemized values in table 3 and in table 7 (Appendix) to arrive at their own costs. In this study; crew organization resulted in a ratio about 4 to 1 of labor-hours to machine-hours on each cutting.

⁶The colorful regional term "chopping" is used in the redwoods to mean the same as felling and bucking.

Table 1. Cost per thousand board feet log scale to harvest old-growth redwood by three cutting methods

Basis: log rule	Direct costs loaded on trucks excluding road construction		
	Selection cutting	Shelterwood cutting	Clear cutting
	Dollars	Dollars	Dollars
Gross log scale of logs hauled: Scribner rule, all species	11.37	14.30	11.45
Net log scale of logs hauled: Humboldt rule, redwood; Scribner rule, other species	16.15	19.73	16.05
Scribner rule, all species ¹	13.13	17.02	12.92

¹Net log scale averaged 86.6 percent of gross on selection cutting, 88.6 percent on clear cutting, and 84.0 percent on the shelterwood cutting. By contract definition, merchantable logs scaled 50 percent or more of gross volume.

Differences Between Cuttings

Some logging cost differences between cuttings are attributed to ordinary variation associated with difficulties of preparing to log. For example, the skidroad and landing construction costs on clear cuttings (table 7, Appendix) were only one-fourth that on the other two cuttings. Favorable terrain for the fewer landings per area resulted in low landing-construction costs. And on two of the clear cuttings, skidroad construction was easy.

Post-logging slash disposal and erosion control costs were; almost twice as much on the selection as on the other two cuttings. The extra cost was caused principally by the need for more preparation before burning. On the selection area, the slash was cleared away from the reserve trees by bulldozer wherever possible and piled in openings.

Real differences appear when we consider the principal activities in logging—felling-bucking,

skidding, and loading. But such other cost variables as construction or slash disposal costs, plus Social Security-payrolling, supervision, transportation, felling and bucking unmerchantable trees, layout construction, and woods scaling tend to conceal the differences, if any, due to cutting methods.

Weighted Costs and Work Units

For appraisal and other purposes, the weighted costs and work units listed in table 3 may be particularly useful. The values are expressed on a gross Scribner scale basis. Conversion to a net log scale basis has been previously described.

Logging Roadways

The cost of logging the roadway timber was essentially the same as that for logging clear cuttings. For five identical cost items, roadways totaled \$10.46 and clear cuttings \$10.74 per thousand (tables 7 and 8, Appendix). Only selected cost items were compared because some items either did not apply to roadway logging or they appeared in other road construction costs. It is not surprising that the costs were similar because roadway logging is simply clear cutting a narrow strip. Apparently the narrowness of the strip did not increase these costs.

Tree Size , Methods, and Costs

Felling and bucking costs were particularly variable between broad tree sizes and methods (tables 4 and 9, Appendix), although within respective cuttings it cost more to log the smaller than the

Table 2. Work units to harvest each thousand board feet (gross Scribner scale) of logs in old-growth redwood by three cutting methods

Item	Work to get logs on trucks, excluding road construction		
	Selection cutting	Shelterwood cutting	Clear cutting
	Hours	Hours	Hours
Labor	1.36	1.78	1.39
Machines	.33	.40	.32

Table 3. Average weighted cost and hours per thousand board feet (gross Scribner log scale) to harvest old-growth redwood

Cost items ¹	Work units and direct costs for logs loaded on trucks ²		
	Labor	Machines	Cost
	Hours	Hours	Dollars
Felling-bucking	0.31	--	2.89
Scaling (woods)	.06	--	.15
Skidroad-landing construction	.02	0.01	.18
Layout construction (redwood)	.12	.07	1.39
Skidding (D-8 tractor)	.64	.16	3.88
Loading	.17	.07	1.44
Felling-bucking unmerchantable	.02	--	.15
Slash disposal-erosion control	.07	.03	.61
Supervision-transportation	.09	--	.42
Social Security-payrolling	--	--	1.13
Total	1.50	.34	12.24

¹ Cost of peeling redwood has been omitted because only part of the volume was peeled, and the trend is now to peel at the mill instead of in the woods.

² Excluding road construction.

larger trees. This work was all contract chopping, or payment on the basis of volume of trees cut. However, we also recorded man-hours for the work record listed in table 9, Appendix. Hence the cost difference when respective hours were

nearly the same is attributable to the fact that this was contract work. The higher costs for similar hours reflect a different combination of breakage, total cull portions of otherwise merchantable trees, and bucking of windfalls—each paid at a differ-

Table 4. Cost per thousand board feet (gross Scribner log scale) to harvest old-growth redwood, by cutting methods and tree-size classes

TREES UNDER 6 FEET D.B.H.			
Cost items	Selection cutting	Shelterwood cutting	Clear cutting
	Dollars	Dollars	Dollars
Felling-bucking	3.25	3.24	2.49
Skidding	4.31	6.61	4.10
Loading	1.37	1.85	1.56
Total	8.93	11.70	8.15
TREES 6 FEET D.B.H. AND OVER			
Felling-bucking	2.48	3.08	3.19
Skidding	3.18	3.96	2.78
Loading	1.23	1.70	1.25
Total	6.89	8.74	7.22

ent rate. The variation between the woods-scale volume and gross volume of logs actually hauled also contributed to these erratic differences.

The most significant comparisons between methods and broad tree sizes are shown by the skidding and loading costs (table 4). Costs were higher for the smaller trees within respective cuttings. And in relation to methods, the shelterwood ranked highest and the selection and clear cuttings were essentially the same.

That cost differences between shelterwood and the other cuttings may be partly attributable to average volume of logs is indicated as follows:

Cutting method:	Less than 6 ft. d.b.h.	6 ft. or more d.b.h.
	—(bd. ft. gross Scribner)—	
Selection	1,700	2,631
Shelterwood	980	2,248
Clear cutting	1,290	2,917

The higher costs in each tree category for shelterwood logging are associated with average smaller logs. Although the relationships between the other two methods and log sizes were not as closely correlated, they were judged to be within the variation range.

Two other direct costs (table 9, Appendix) contribute to differences between methods and tree sizes, but their effects are variable. The cost of woods scaling is a minor item and variable. Cost comparisons that include constructing layouts are unproportional. Layouts are constructed for most of the better quality redwoods between 4 and 6 feet d.b.h. and almost all redwoods over 6 feet

d.b.h. Hence this work is related to only a small fraction of the smaller trees. Therefore, cost differences between the two size-groups do not measure difficulty but rather lack of work.

Costs and Work Units to Build Roads

The main road cost almost \$54,000 per mile and the secondary road more than \$25,000 per mile (table 5 and table 10, Appendix). Most operators would rate these costs rather high. But when evaluated in relation to the road specifications, topography, and size of cull material removed in clearing, the cost items will be more meaningful and useful to compare to other jobs.

Road Specifications and Quantities

The main road is single lane, 18 feet wide including ditch, with intervisible turnouts averaging 10 per mile. Alignment specified minimum curve radius of 100 feet. Cut slopes were mostly three-quarters to one in earth with very little one-half to one in loose rock. Fill slopes were one and one-half to one. Rock and gravel surfacing combined was at least 12 inches deep, and 14 feet or more wide. The amount of corrugated metal pipe used per mile was approximately: (a) 18 inch diameter-180 feet, (b) 24 inch--350 feet, (c) 36 inch—370 feet, and (d) 48 inch-75 feet. Excavation of about 60,000 cubic yards of earth was required per mile.

Secondary roads are single lane, 16 feet wide if ditch was needed, otherwise 14 feet wide. Align-

Table 5. Cost per mile to construct main and secondary roads in old-growth redwood

Cost items	Main road		Secondary roads	
	Dollars	Percent	Dollars	Percent
Clearing, stumping, slash disposal	18,012	34	4,212	16
Excavation, grading, drainage	20,556	38	10,189	40
Surfacing, grading	10,322	19	8,876	35
Supervision, transportation	2,235	4	1,136	4
Social Security, payrolling	2,833	5	1,170	5
Total	53,958	100	25,583	100

ment, turnouts, and cut and fill slopes are the same as for the main road. However, the secondary roads tended to follow topography somewhat more than on the main roads, with more grade changes and less excavation. For an average mile of secondary road, about 11,000 cubic yards of excavation were required. Rock and gravel surfacing was at least 12 inches deep, and about 12 feet wide. Length of corrugated metal pipe per mile by diameter classes was: (a) 18-inch diameter—350 feet, (b) 24-inch—135 feet, (c) 30-inch—100 feet, (d) 36-inch—20 feet, (e) 48-inch—20 feet.

Topography and Soil

Both topography and soil affected road construction costs. The sandstone bedrock usually could be ripped by a bulldozer. Infrequent blue-clay intrusions caused only minor construction difficulties, but later becomes expensive maintenance problems. The main road crossed two particularly steep side slopes of 80 to 90 percent, each about two-tenths mile long. These sections contributed materially to expensive excavation. They are also evidence of the necessity for thorough reconnaissance before beginning a road survey. If such steep areas can be avoided, a substantial saving in construction and maintenance can be achieved.

We encountered short sections of expensive excavation and fill on two of the secondary roads. But these high costs were somewhat counterbalanced by other inexpensive sections. Therefore, average secondary road costs may be considered representative for the class of road, soil, and topography encountered on the Redwood Experimental Forest.

Clearing and Slash Disposal

In old-growth redwood, the broken, rotten chunks and tops, many of which are 4 to 8 feet in diameter, are difficult to move, pile, and destroy by burning. Stumps vary in diameter, ranging up to 18 feet. An average of about 32 stumps per acre in the sizes 2 feet and over were removed in road clearing.

Table 5 shows a clearing-cost difference of \$13,800 per mile between the main and secondary roads. Some of this difference is attributable to wider clearing on main roads. However, the principal reason is that about one-third of the mileage of main road traversed reserved stands with relatively few places available to pile the debris. The

waste material had to be moved considerable distances at extra cost. In contrast, all of the secondary roads were within cutting units. Hence, after clearing, the roadway slash burning job and costs were included with the cutting-units slash disposal.

Development Costs per Timber Volume

The road development costs for 1.5 miles of main road and 2.1 miles of secondary roads were \$5.19 per M board feet (gross Scribner log scale) for all timber hauled. The road system made accessible the entire block comprised of the three cutting methods. Therefore, the average development charge is made to all cuttings alike.

Factors Affecting Key Logging Activities

Felling-Bucking

The over-all cost per thousand board feet of logs hauled for felling and bucking varied between cutting methods and for different size-groups of trees. Among the factors affecting these differences were (a) difficulty of terrain and brush affecting movement of men, (b) differences between woods scale and truck scale because of breakage, defect, and incomplete utilization, (c) amount of bucking in defective logs and breaks that result in no merchantable volume, and (d) size of trees and logs. We studied the latter factor only in this project.

These results are for contract (gyppo) felling and bucking by 2-man crews. The independent variable is average tree d.b.h., computed for a day or sometimes fractional part of a day. The dependent variable is average gross Scribner board foot volume per tree including the break and defect bucking cuts as part of the volume. Days on which more than two windfalls were bucked were not included in this analysis because the stump cutting time would be disproportionately small compared to the felling time of a standing tree.

Average volume that could be felled and bucked per day depends partly on the size or d.b.h. of the trees. The relationship, although not strongly correlated ($r = 0.360$), is significant at the 5 percent level. The equation for the linear regression is:

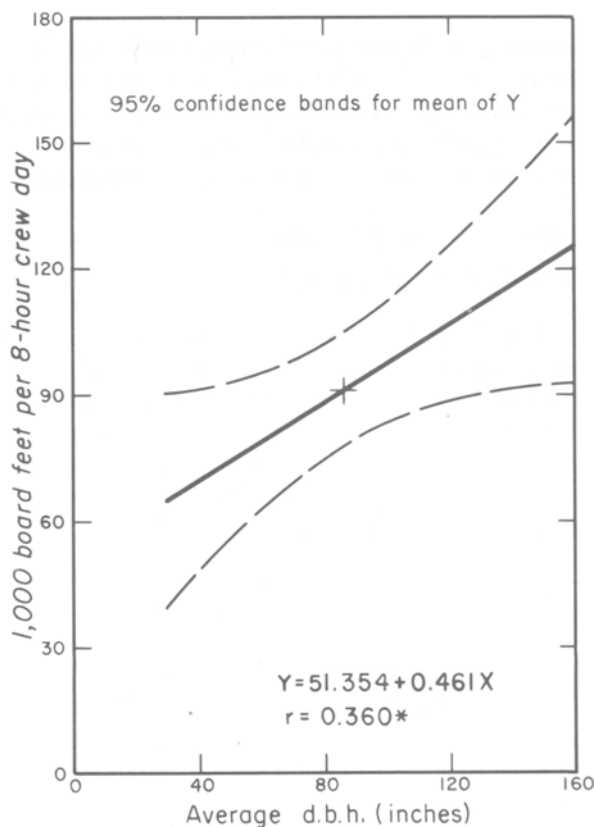


Figure 3.—Volume of logs in thousand board feet gross Scribner volume felled and bucked by 2-man gyppo crews during 8-hour days as related to average d.b.h. of trees.

$$Y = 51.354 + 0.461 X$$

in which Y = M bd. ft. (gross Scribner log scale) felled and bucked per 8-hour day by a 2-man crew
and X = average d.b.h. of trees felled and bucked

The 95 percent confidence belt plotted in figure 3 shows the range in values for predicting felling-bucking mean volumes for trees of a given average diameter. For example, if trees average 40 inches d.b.h., output will average between 48,000 and 91,000 bd. ft. Nearer the mean of sample tree d.b.h., predictions will have less variation. If trees should average 90 inches, the expected output 95 times in 100 chances would fall between 79,000 and 106,000 bd. ft. In the upper range of tree sizes as in the lower, expected output will vary widely (fig. 4.)

Skidding

Skidding production, expressed in average volume gross Scribner log scale skidded per tractor hour, varied significantly only by average volume per log. The other factors, such as gradient of skid roads, skidding distance, and volume skidded per acre, did not materially affect production within the range and the combination of variables measured in this study.

As described elsewhere, the 30 sets of observations were made on a landing-stage basis. The variables had the following values:

Figure 4.—Daily production may be low and at other times very high when felling huge redwoods.



Variable:	Range	Average
Log volume in bd. ft. (gross Scribner scale)	884-3,402	2,043
Main skid road gradient in percent	12-36	22
Skidding distance in feet	291-1,024	515
Volume skidded per acre in bd. ft. (gross Scribner scale)	15,457-229,896	74,492
Volume skidded per D-8 tractor hour in bd. ft. (gross Scribner scale)	2,410-11,911	6,708

The interpretation of the stepwise regression analysis is summarized below. All simple correlation coefficients are recorded in table 6.

The volume skidded per acre had no particular effect on skidding output in conjunction with the other variables. This result seemed anomalous because the simple correlation coefficient between the volume per acre and volume skidded was highly significant (table 6). However, the positive correlation of average volume per log and average volume per acre skidded was highly significant. Therefore, the real meaningful factor, as will be shown, is volume per log.

Skidding distance was not a meaningful factor in its effect on skidding production for the distances studied. This result is contrary to our prac-

tical knowledge about effects of distance. Common sense tells us that for longer average skidding distances—other factors being equal—production will diminish. Simple correlations showed significant negative relationship between distance and production; that is, for the longer distance, lower production. However, a similar negative correlation existed between average log volume and distance, indicating that smaller logs were logged on landings with greatest skidding distances. If there had been no correlation between log volume and distance, then the distance variable could have contributed useful information in the production equation. But since they were correlated, we cannot use the skidding-distance regression coefficient in estimating production.

The average gradients of main skid roads had no particular effect on skidding production for the gradients considered. Skidding distance and gradient of main skid roads were highly, significantly, and positively correlated: the longer skidding distances were associated with the steeper gradients. However, since smaller average logs were associated with the longer distance-steeper gradient variables, the stronger effect was log size. Average volume per log is the single most important variable affecting skidding production within the value range of the variables studied in these cuttings. The regression is highly significant. About 66 percent of predicted output in skidding

Figure 5.—Skidding production may be estimated rather accurately by the average volume per log.



Table 6. Simple correlation coefficients between variables analyzed in skidding production

Variables	X ₁	X ₂	X ₃	X ₄
Y - Average volume gross Scribner per tractor hour	0.813**	0.053	-0.396*	0.601**
X ₁ - Average volume gross Scribner per log	--	- .026	- .366*	.657**
X ₂ - Average skidroad gradient	--	--	.510**	-.118
X ₃ - Average skidding distance	--	--	--	-.351
X ₄ - Average volume gross Scribner cut per acre	--	--	--	--

* Significant at 5 percent level; significant at 1 percent level.

production can be accounted for by average volume of logs if trees are stratified into at least broad size groups (fig. 5) and skidding distances and main skid road gradients do not exceed those encountered in these cuttings. Furthermore, the Y and X relationship is a conditional estimate applying only for data having similar correlations among variables. The equation for this regression is plotted in figure 6 and is:

$$Y = 1.394 + 2.601 X$$

in which Y = production in M bd. ft. (gross Scribner scale) per D-8 tractor hour

and X = average log volume in M bd. ft. (gross Scribner scale) of broadly stratified size groups of trees

Average skidding output for stand conditions similar to these based on average log volume of a stratified size group can be estimated reliably from figure 6. If logs average 1,000 bd. ft., skidding production will be between 3,100 and 4,900 for probabilities of 95 percent. Nearer the midpoint, the range is narrower for estimated values. For logs averaging 2,000 bd. ft., output will average 5,900 to 7,200. The range widens for the larger logs as for the smaller. If the average is 3,000 bd. ft., estimated production is 8,300 to 10,100.

Loading

The gross board-foot volume of logs loaded per hour varied significantly with average volume per log when based on a day or fractional day's production. The relationship is expressed as a simple

linear regression in the following equation:

$$Y = 6.437 + 3.506 X$$

in which Y = production in M bd. ft. (gross Scribner volume) per loader hour and X = average log volume in M bd. ft. (gross Scribner volume)

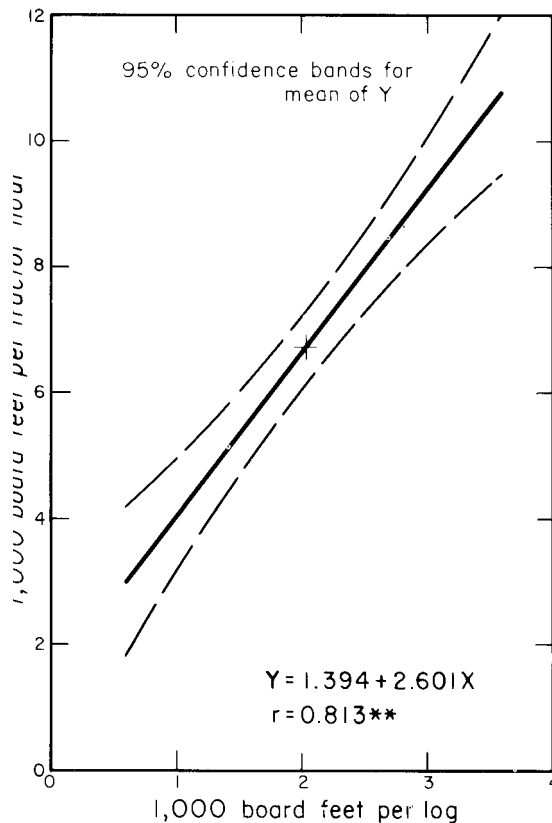


Figure 6.—Gross Scribner volume skidded per tractor hour as related to average volume per log.

Two loaders, a Lima⁷ of 35- to 40-ton log capacity (g5-ton truck crane) and an Ateco of 25-ton log capacity, were used for two seasons' logging upon which these figures are based.

Before concluding that simple linear regression was an acceptable expression of loader production, we analyzed the outputs of the two loaders separately and for several variables by multiple regression. The four independent variables were: (a) average number of logs per load, (b) average gross volume per load, (c) average log length, and (d) average gross volume per log. The dependent variable was gross board foot volume of logs loaded per hour. These variables in combination did not increase the reliability of the estimate much above that obtained by using average volume per log. Furthermore, a linear regression best expressed the relationships. Because average volume per log correlated significantly with loader output, besides being a familiar measure, it was selected for simple linear regression analysis.

The outputs of the two loaders were analyzed separately. The equations were:

$$\text{Lima Loader — } Y = 6.477 - 1.3347 X \\ r = .715^{**}$$

$$\text{Ateco Loader — } Y = 6.534 + 3.511 X \\ r = .824^{**}$$

(Y and X have the same equivalents as before)

Covariance analysis revealed that the slope and intercept of these two regressions were not significantly different. Therefore, the single equation— $Y = 6.437 + 3.506 X$ —was calculated as the most useful expression (fig. 7).

Loading production for similar capacity loaders may be estimated from figure 7 if a reasonably accurate estimate of log volume is known. Each set of data entering the analysis had been computed for a day or fractional day's output. Log volume daily averages had a relatively low coefficient of variation because of the stratifying process of stage logging by cutting method and landing. The confidence belt demarcates the range of estimates for other averages of hourly loading production for probabilities of 95 percent. For example, if logs average, 1,200 bd. ft., then hourly production will be between 10,200 and 11,200 bd. ft. Similarly, for logs averaging 3,000 bd. ft., the hourly production is 16,400 to 17,600 bd. ft.

Discussion and Conclusions

Timber appraisers, logging managers, and others will find the weighted cost and production information contained in table 3 particularly useful. These figures are based on logging covering a wide variety of terrain and timber during variable weather. They include normal nonproductive time,

⁷Mention of commercial products does not constitute an endorsement by the U.S. Forest Service.

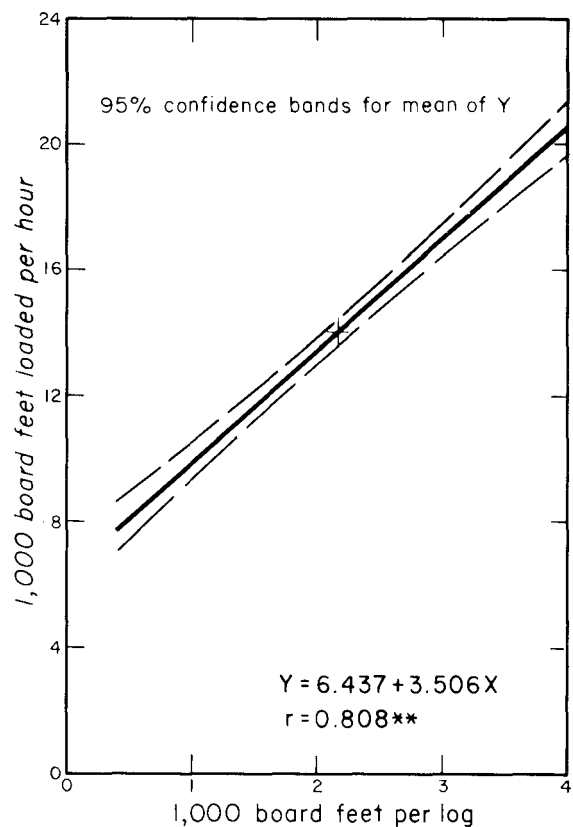


Figure 7.—Gross Scribner volume loaded per hour as related to average volume per log.

cient of variation because of the stratifying process of stage logging by cutting method and landing. The confidence belt demarcates the range of estimates for other averages of hourly loading production for probabilities of 95 percent. For example, if logs average, 1,200 bd. ft., then hourly production will be between 10,200 and 11,200 bd. ft. Similarly, for logs averaging 3,000 bd. ft., the hourly production is 16,400 to 17,600 bd. ft.

such as waiting for trucks and changing winch lines. Therefore, they are representative average costs. However, some may wish to adjust a specific item, or all items, by a given percentage because of different experience or anticipated different output of the key logging activities in other timber stands. To convert the costs to a net log scale basis, divide by the ratio of net log volume to gross volume of logs hauled.

One example will illustrate a method for adjusting the weighted costs for felling-bucking, skidding, and loading:

An appraiser estimates that in a given tract, 75 percent of the volume is contained in trees averaging 48 inches d.b.h. with logs averaging 500 bd. ft., and 25 percent in trees 84 inches d.b.h. and logs 2,160 bd. ft. His calculations would be:

1. Felling-bucking
 - a. Average production (fig. 3) ---- 91,000 bd. ft.
 - b. Estimated average production for given tract (fig. 3);
 $(.75 \times 60,000 = 45,000) +$
 $(.25 \times 81,000 = 20,250)$ ----- 65.250 bd. ft.
 - c. Weighted cost for felling-bucking (table 3) ----- \$2.89 per M bd. ft.
 - d. Adjusted weighted cost;
 $91,000/65,250 \times \$2.89$ ---- \$4.03 per M bd. ft.
2. Skidding
 - a. Average production (fig. 6) ----- 6,700 bd. ft.
 - b. Estimated average production for given tract (fig. 6);
 $(.75 \times 2,700 = 2,025) +$
 $(.25 \times 7,000 = 1,750)$ ----- 3 775 bd. ft.
 - c. Weighted cost for skidding (table 3) ----- \$3.88 per M bd. ft.
 - d. Adjusted weighted cost;
 $6,700/3,775 \times 3.88$ ----- \$6.89 per M bd. ft.
3. Loading
 - a. Average production (fig. 7) --- 13,900 bd. ft.
 - b. Estimated average production for other tract (fig. 7);
 $(.75 \times 8,200 = 6,150)$
 $(.25 \times 14,000 = 3,500)$ ----- 9,650 bd. ft.
 - c. Weighted cost for loading (table 3) ...\$1.44 per NI bd. ft.
 - d. Adjusted weighted cost;
 $13,900/9,650 \times \$1.44$ ----- \$2.07 per M

Costs can be kept reasonably current by using the recorded work units with the present price paid per work unit. Furthermore, if different machinery rental rates are thought to be more applicable than those used in this study, then machinery costs can be adjusted accordingly. Already much of the felling and bucking is on an hourly basis so that it will be necessary to substitute current costs in this activity. These adjusted costs can be expressed on a net log scale basis as described above.

The use of road construction costs and work units for planning or appraisal would require similar procedures to those described for logging. Any adjustments would usually be based on differences such as in quantities of excavation, culverts, clearing, and applied to itemized units for the different activities recorded in table 10, Appendix.

Logging managers and foremen can use the

production regressions for reaching decisions about scheduling men and equipment for a particular logging side. If contract felling and bucking are used, production estimates, although variable, are obtainable in figure 3. For similar terrain and stand conditions to those encountered in this study, skidding estimates can be reasonably accurate. If log volume for a given stage-landing is estimated to average 1,000 bd. ft., skidding production per tractor hour will be between 3,100 and 4,900 bd. ft. (fig. 6). The loader is estimated to load 9,400 to 10,600 bd. ft. per hour (fig. 7). Therefore three tractors will be needed to keep the landing supplied with logs.

Managers also can use knowledge of output related to log size to reduce costs. For example, smaller skidding tractors could be assigned to a logging side to skid all small logs, or to bunch small logs for the large tractor. Thus a different scheduling of machines offers the possibility of increasing output and lowering costs.

This study also suggests that:

- The results are most valuable as working tools. Tables and equations cannot replace the judgment and experience of the logging manager, appraiser, or foreman, but with these working tools for reference, they should do a much more efficient job.

- The two principal study procedures—cost accounting and statistical analysis of group data—provided much useful information with only minimum professional man-days required for collection of data. Now that cost relationships have been determined, future studies can concentrate on additional group data analysis of key logging activities; or on time and production studies with different machines and crews for specific jobs.

- Average gross log, volume is a particularly useful variable for analyzing logging production and costs. This variable relates work to dimensions of logs. Adjustment for defect for a given stand or between stands logically are made as a last calculation.

- An unqualified conclusion that shelterwood cuttings will cost more to log than selection or clear cuttings cannot be made from this study. Costs are inversely related to log volume. The average volume of logs was lowest on the shelter-wood and costs were highest. But until we complete other replications of these cuttings to determine if average log size will be consistently lower on shelterwood, we must relate costs to average log volume and not to cutting method.

Summary

The cost to tractor-log old-growth redwood averaged \$12.24 per M bd. ft. (gross Scribner log scale) loaded on trucks. Road development averaged an additional \$5.19 per M bd. ft. These costs are based on 2 years of logging in a wide variety of terrain and timber during variable weather. They may be easily converted to a net log scale basis by dividing by the ratio of net log volume to gross volume of logs hauled.

The comparison between costs of logging on the three experimental cuttings showed that: (a) costs were highest on the shelterwood, and (b) costs were lowest and about equal on the selection and clear cuttings. On all cuttings the higher costs were associated with the smaller trees and logs. Since log volumes averaged the lowest on the shelterwood, costs were highest, but additional replications of the cuttings are needed to determine if log volume will continually average lowest on shelterwood.

Felling-bucking production as related to tree diameter was expressed as a linear regression whose equation was calculated as:

$$Y = 51.354 + 0.461 X$$

with correlation coefficient of 0.360—significant at the 5 percent level.

In this equation, Y = M bd. ft. (gross Scribner log scale) felled and bucked per 8-hour day by a 2-man crew;

and X = average d.b.h. of trees felled and bucked. Confidence belts that are plotted in figure 3 for predicting other average production show a rather wide dispersion because of low correlation.

Although skidding production is known to be affected by a number of variables, only the average volume per log proved to be significant in this study. The relationship was determined to be linear and its equation is:

$$Y = 1.394 + 2.601 X$$

with correlation coefficient 0.813—highly significant at the 1 percent level. The equivalents are

Y = production in M bd. ft. (gross Scribner log scale) per D-8 tractor hour, and

X = average log volume in M bd. ft. (gross Scribner log scale) of broadly-stratified size-groups of trees.

The confidence belts that are plotted in figure 6 show a reasonably narrow dispersion for predicting average production based on mean log volume. Loader output of heavy capacity loaders varies directly with average volume of logs. The relationship is linear as expressed in the following equation:

$$Y = 6.437 + 3.506 X$$

and the correlation coefficient of 0.808 is highly significant at the 1 percent level. The equivalents for the variables are

Y = production in M bd. ft. (gross Scribner log scale) per loader hour, and

X = average log volume in M bd. ft. (gross Scribner log scale) of a stratified size-group of logs.

From the confidence belts plotted in figure 7, the output of similar loaders based on average log volumes can be predicted rather accurately.

Appendix

Data Collection

Logging costs and work units were collected by cutting method, stage, and landing. However, logging of the main road right-of-way was kept separate from all other logging because the road was constructed before logging of each unit began. Trees on the secondary roadways were logged with respective units through which the roads passed. Logs were branded with the cutting method, stage, and landing code before they were hauled from the woods. The scaler recorded this brand when the logs were scaled. The classification of activities was:

- I. Cutting method and landing area.
 - A. Stage A (trees under 6 feet d.b.h.)
 1. Log making.
 - a. Felling and bucking merchantable trees and windfalls.
 - b. Layout construction: This job consisted of smoothing uneven ground with a bulldozer a blade-width, then constructing loose-soil ridges crosswise in order to cushion the fall of large, quality redwoods. On some leaning trees we had to use a high climber to attach wire rope high enough on the tree so that a bulldozer could pull the tree into its layout. Tree pulling was recorded with layout construction.
 - c. Felling and bucking of total cull snags and trees.
 2. Stump to truck.
 - a. Landing and skid road construction.
 - b. Skidding.
 - c. Loading (includes rigging time).
 - B. Stage B (trees 6 feet d.b.h. and over)
Costs were collected by the same categories as above.
- II. Road Construction.
 - A. Logging the main road right-of-way.

Activities were the same as listed under logging of units except stage logging was omitted.

- B. Construction activities on main and secondary roads.
 1. Stump shooting, clearing, slash disposal.
 2. Excavation, grading, drainage.
 3. Surfacing and grading.

Machines were assigned hourly rental rates that covered operation, maintenance, repair, and depreciation, but not operators' wages. The hourly rates used throughout this job were:

	<u>Hourly rate</u>
D-8 bulldozer (old model)	\$12
D-8 bulldozer (new model)	15
D-9 bulldozer	18
Lima Loader	18
Ateco	12
Scoopmobile	10
DW-20 Scraper	15
Road grader	17
Link belt shovel	12

Cutting Methods and Marking Guides

On the 60-acre selection cutting, about half the stand volume was cut, including both large and small trees. Seventy-nine percent of the merchantable volume logged was from the larger or "B" trees. All windfalls and most of the snags and cull trees were cut.

About three-fourths of the stand volume was harvested on the 69-acre shelterwood cutting. Usually well-spaced codominant trees were reserved for seed production and growth. All windfalls, snags, and cull trees were cut. Fifty-three percent of the merchantable volume logged was from "B" trees.

All merchantable trees, snags, cull trees, and windfalls were cut on the 13-, 18-, and 20-acre clear cuttings. Of this volume 64 percent was contained in trees over 6 feet d.b.h.

Table 7. Cost and hours per thousand board feet (gross Scribner log scale) to harvest old-growth redwood by three cutting methods

Cost items	Selection			Shelterwood			Clear cutting		
	Labor	Machines	Cost	Labor	Machine	Cost	Labor	Machines	Cost
	<i>Hours</i>	<i>Hours</i>		<i>Hours</i>	<i>Hours</i>		<i>Hours</i>	<i>Hours</i>	
Felling-bucking -----	0.28	--	\$2.65	0.36	--	\$3.16	0.30	--	\$2.94
Scaling (woods) -----	.04		.12	.07	--	.18	.06	--	.15
Skidroad-landing ----- construction -----	.02	0.01	.23	.03	0.01	.27	.01	0.01	.06
Layout construction (redwood only) -----	.09	.07	1.31	.12	.07	1.37	.14	.08	1.48
Skidding (D-8 tractor) -----	.60	.14	3.42	.83	.22	5.20	.54	.14	3.26
Loading (Lima & Ateco)	.14	.07	1.26	.21	.08	1.77	.16	.07	1.36
Felling-bucking unmerchantable -----	.01	--	.11	.02	--	.19	.02	--	.17
Slash disposal- erosion control -----	.10	.04	.84	.05	.02	.47	.06	.02	.48
Supervision- transportation -----	.08	--	.37	.09	--	.44	.10	--	.45
Social Security- payrolling -----	--	--	1.06	--	--	1.25	--	--	1.10
Total loaded on trucks exclusive of road construc- tion-----	1.36	.33	11.37	1.78	.40	14.30	1.39	.32	11.45

Table 8. Cost and hours per thousand board feet (gross Scribner log scale) to harvest all timber on the main roadway

Cost items ¹	Labor	Machines	Cost
	<i>Hours</i>	<i>Hours</i>	<i>Dollars</i>
Felling-bucking--	0.25	--	2.36
Scaling (woods)--	.05	--	.14
Layout construc- tion (redwood only) -----	.06	0.04	.69
Skidding -----	.71	.17	4.27
Loading -----	.17	.08	1.42
Supervision- transportation --	.13	--	.60
Social Security- payrolling -----	--	--	.98
Total loaded on trucks -----	1.37	.29	10.46

¹ Fewer items are listed here than in table 7 because some work was not needed or was included in the road construction activity.

Table 9. Cost and hours per thousand board feet (gross Scribner log scale) to harvest old-growth redwood, by cutting methods and tree-size classes

TREES UNDER 6 FEET D.B.H.									
Cost items	Selection cutting			Shelterwood cutting			Clear cutting		
	Labor	Machines	Cost	Labor	Machines	Cost	Labor	Machines	Cost
	Hours	Hours		Hours	Hours		Hours	Hours	
Felling-bucking ----	0.38	--	\$3.25	0.40	--	\$3.24	0.28	--	\$2.49
Scaling (woods) ----	.05	--	.13	.08	--	.21	.08	--	.21
Layouts -----	.07	0.05	.93	.03	0.02	.42	.09	0.04	.86
Skidding ----	.75	.17	4.31	.99	.28	6.61	.68	.17	4.10
Loading -----	.17	.08	1.37	.24	.10	1.85	.19	.08	1.56
Total loaded on trucks--	1.42	.30	9.99	1.74	.40	12.33	1.32	.29	9.22

TREES 6 FEET D.B.H. AND OVER									
Cost items	Selection cutting			Shelterwood cutting			Clear cutting		
	Labor	Machines	Cost	Labor	Machines	Cost	Labor	Machines	Cost
	Hours	Hours		Hours	Hours		Hours	Hours	
Felling-bucking ----	.25	--	2.48	.33	--	3.08	.30	--	3.19
Scaling (woods) ----	.04	--	.11	.06	--	.16	.04	--	.12
Layouts -----	.10	.07	1.38	.14	.08	1.60	.15	.09	1.71
Skidding ----	.55	.13	3.18	.68	.16	3.96	.47	.12	2.78
Loading -----	.14	.06	1.23	.18	.08	1.70	.15	.06	1.25
Total loaded on trucks--	1.08	.26	8.38	1.39	.32	10.50	1.11	.27	9.05

Table 10. Cost and hours per mile to construct main and secondary roads in old-growth redwood stands

Cost items	Main road				Secondary roads			
	Labor	Machines	Materials	Cost	Labor	Machines	Materials	Cost
	Hours	Hours			Hours	Hours		
Clearing, stumping slash disposal---	3,014	551	\$1,904	\$18,014	703	110	\$900	\$4,212
Excavation, grading; drainage---	1,532	688	6,640	20,556	809	312	3,555	10,189
Surfacing, grading-----	790	759	1133	10,322	651	607	10	8,876
Supervision-transportation---	460	--	--	2,235	238	--	--	1,136
Social Security-payrolling-----	--	--	--	2,833	--	--	--	1,170
Total-----	5,796	1,998	8,677	53,958	2,401	1,029	4,455	25,583

¹ Rock and gravel were obtained without charge. Loading and hauling costs for delivering the surfacing appear under machines and labor.