A Comparison of Skyline Harvesting Costs for Alternative Commercial Thinning Prescriptions

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ABSTRACT

Harvesting production and costs were examined for three alternative silvicultural prescriptions at two sites in the Coast Range of Oregon. Thirty-three-year-old Douglas fir stands were commercially thinned to residual densities of 247, 148, and 74 trees per hectare (tph) [100, 60, and 30 trees per acre (tpa), respectively]. Detailed time studies were conducted on manual felling and uphill skyline yarding with small yarders. Separate regression equations were developed to predict delay-free felling cycle time and delay-free yarding cycle time. The 74 tph [30 tpa] treatment had the highest production rate and was the least costly to harvest. Total harvesting costs of the other two treatments averaged from 6.0% (148 tph [60 tpa]) to 12.3% (247 tph [100 tpa]) more than the 74 tph [30 tpa] treatment.

Keywords: *thinning costs, logging productivity, skyline yarding, young stands, commercial thinning.*

INTRODUCTION

The objective of commercial thinning in the past has been to capture mortality, gain an early return on investments, and maintain or accelerate tree growth. In the past few years, forest management objectives have been changing to include maintenance of ecosystem values in addition to wood production [4, 6, 15]. Public land agencies and some private forest landowners are developing and implementing ecosystem management concepts [8].

Silvicultural prescriptions are changing to address these new management objectives. One management objective is to accelerate the development of habitat characteristics for old-growth and late-successional wildlife species in young stands. Current research indicates that young stands can be manipulated to provide some of the old-growth habitat characteristics in a relatively short time frame—in a matter of decades instead of centuries [16, 17]. Commercial thinning is used to thin young stands to low residual densities and stimulate rapid growth of dominant trees. The understory is allowed to develop from natural regeneration, or seedlings are planted after thinning, to create a multistoried stand [19].

Thinning prescriptions with wider spacing between residual trees than for conventional commercial thinning are required to achieve these results [16, 17]. Information is needed on production rates and costs of appropriate logging systems for these alternative silvicultural prescriptions [11].

Previous research on harvesting costs shows that light thinnings cost more than heavier thinnings or clearcuts. In a Douglas fir *(Pseudotsuga menziesii)* thinning, skyline yarding costs per cunit were 20 to 22% more in a light thinning, which removed 198 trees per hectare (tph) [80 trees per acre (tpa)], than in a heavy thinning, which removed 309 tph [125 tpa], depending on yarder size [10]. In a western hemlock (*Tsuga heterophylla*)-Sitka spruce (*Picea sitchensis*) thinning with a mid-size yarder, skyline yarding costs per cunit were 14% higher in a light thinning that removed 269 tph [109 tpa] and left 205 tph [83 tpa] compared to a heavy thinning that removed 319 tph [129 tpa] and left 156 tph [63 tpa] [12]. Bennett [1] found that costs for falling and skidding a partial cut in second-growth Douglas fir were 20 to 30% higher than conventional clearcut harvesting.

To obtain current information on harvesting production and costs for alternative silvicultural prescriptions, harvest operations were studied as part of an integrated research project. The integrated project was designed to investigate the effect of different commercial thinning intensities and a control on accelerating the development of old-growth habitat characteristics in young stands. Ongoing aspects of the integrated project addressed by other researchers include wildlife habitat suitability, tree growth, and understory vegetation development after thinning [19]. This paper reports results of the harvesting study only.

The main objectives of the harvesting study were to determine felling and yarding production rates

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and costs for three commercial thinning treatments at two sites. The harvesting study was operational in nature, as opposed to a strictly controlled study. Logging procedures were left up to each contractor, with requirements to use small yarders and to obtain similar stand conditions after thinning. Therefore, the sites and thinning treatments were similar, but the logging layouts, logging equipment, and felling methods used at each site differed.

METHODS

Study Sites and Treatments

Two sites were selected in the Coast Range of Oregon, near the towns of Hebo and Yachats on Siuslaw National Forest land. The sites are within the western hemlock vegetation series [7] and are planted second-growth stands of Douglas fir. Both sites have a McArdle site index of II for Douglas fir, which rates the sites as capable of producing trees 48.8 m [160 ft] tall in 100 years [14].

Three different commercial thinning treatments were tested at each site, each leaving a prescribed number of residual tph [tpa]: conventional (247 tph [100 tpa]), wide (148 tph [60 tpa]), and very wide (74 tph [30 tpa]). Site and stand characteristics before thinning are shown in Table 1.

Table 1. Study site and stand characteristics before thinning. Stand characteristics are all trees in stand, including merchantable and nonmerchantable trees.

Characteristic	Yachats	Hebo
Total size in ha [acres]	10.9 [26.9]	9.2 [22.6]
Treatment size in ha [acres]		
74 tph [30 tpa]	2.0 [4.9]	4.5 [11.1]
148 tph [60 tpa]	3.6 [9.0]	2.4 [5.9]
247 tph [100 tpa]	5.3 [13.0]	2.3 [5.6]
Latitude (North)	44°17'	45°19'
Elevation in m [ft]	244 [800]	305 [1000]
Aspect	Northwest, Northeast	Southwest
Percent slope	15-60	15-70
Species composition	99% Douglas fir	93% Douglas fir 6% Western hemlock
Stand age in years	33	33
Trees/ha [trees/acre	588 [238]	791 [320]
Average dbh in cm [in.]	29.5 [11.6]	26.9 [10.6]
Range of dbh in cm [in.]	3-53 [1-21]	5-56 [2-22]
Volume in m^3/ha [ft^3/acre]	506 [7226]	514 [7343]
Basal area in m^2/ha [ft^2/acre]	44.3 [193.1]	48.4 [210.6]
Trees ≥15 cm [6 in.] dbh	92%	97%

Selected commercial-value trees from the mid-size diameter classes (18 to 41 cm [7 to 16 in.]) were removed, leaving the larger trees on site. After thinning, the number of residual trees corresponded to the silvicultural prescription for each treatment: 74, 148, and 247 tph [30, 60, and 100 tpa, respectively]. Other stand characteristics after thinning are shown in Table 2.

Forest Operations

Each study site was thinned by a different logging contractor. The U.S. Forest Service planned the locations of landings and skyline corridors, and marked leave trees. The logging contractors flagged skyline corridor locations, making adjustments for actual harvesting with Forest Service review. Felling and yarding took place from December 1993 to February 1994.

Trees were manually felled and bucked into logs with chainsaws. A standing skyline with gravity carriage return was used to yard logs uphill to the landings. A six-person yarding crew consisting of a loader operator, yarder engineer, hooktender, rigging slinger, choker setter, and chaser was used at each site.

Yachats

Fallers left the top of the tree attached to the last log, and limbed only the top side of the trees. The logs were utilized down to a 13-cm [5-in.] top for plywood peelers, and down to a 5-cm [2-in.] top for chips. Preferred log lengths were 13.1, 10.4, 7.9, or 5.2 m [43, 34, 26, or 17 ft, respectively] with a 25 to 28 cm [10 to 11 in.] trim allowance.

The logging equipment used included

- Koller K501 yarder
  - 10-m [33-ft] tower
  - Skyline drum, 500 m [1640 ft] of 20-mm [0.75-in.] diameter wire rope
  - Mainline drum, 600 m [1965 ft] of 12-mm [0.50-in.] diameter wire rope
- Koller SKA 2.5 manual slackpulling carriage
- Prentice 600 B rubber-tired loader
- Landing bulldozer

The skyline corridors were arranged in a fan-shaped pattern from three landings (Figure 1A). Tailtrees were used on all 26 skyline corridors. Intermediate supports were used on 10 corridors. 820 ft]. The logging layout at Yachats resulted in logs being yarded under the tree canopy, mostly partially suspended above the ground.

Hebo

Fallers bucked the top off the last log and limbed three sides of the trees. The logs were utilized down

Table 2. Stand characteristics after thinning.

Characteristic	Yachats	Hebo
Average dbh in cm [in.]	35.9 [14.1]	34.3 [13.5]
Range of dbh in cm [in.]	18-51 [7-20]	23-56 [9-22]
Volume in m^3/ha [ft^3/acre]		
74 tph [30 tpa]	98 [1405]	84 [1203]
148 tph [60 tpa]	179 [2557]	183 [2619]
247 tph [100 tpa]	297 [4245]	260 [3720]
Basal area in m^2/ha [ft^2/acre]		
74 tph [30 tpa]	8.0 [34.9]	7.1 [30.9]
148 tph [60 tpa]	15.0 [65.4]	15.3 [66.7]
247 tph [100 tpa]	24.6 [107.2]	22.4 [97.4]

to a 13-cm [5-in.] top for sawlogs. Preferred log lengths were multiples of 2.4 m [8 ft].

The logging equipment used included

- Thunderbird TMY 40 yarder
    - 12.2-m [40-ft] tower
    - Skyline drum, 610 m [2000 ft] of 20-mm [0.75-in.]diameter wire rope
    - Mainline drum, 610 m [2000 ft] of 12-mm [0.50-in.] diameter wire rope
- Maki Mini Mak II mechanical slackpulling carriage
- Thunderbird 838 hydraulic, heel-boom crawler-mount loader
- Tailhold bulldozer

The skyline corridors were arranged in a parallel pattern from 9 landings (Figure 1B). The 14 skyline corridors used 13 mobile tailholds and one tailtree. No intermediate supports were used. To obtain skyline deflection, the mobile tailholds were located on a road outside the study site and across a ravine, an average of 275 m [900 ft] from the study site boundary. Yarding distances ranged from 9 to 201 m [30 to 660 ft]. The logging layout at Hebo resulted in logs being yarded above or within the canopy, often fully suspended above the ground.

Felling Study

Felling production rates were measured by conducting a detailed time study on the felling foreman at each site. Between 150 to 200 felling cycles were timed in each treatment at each site.

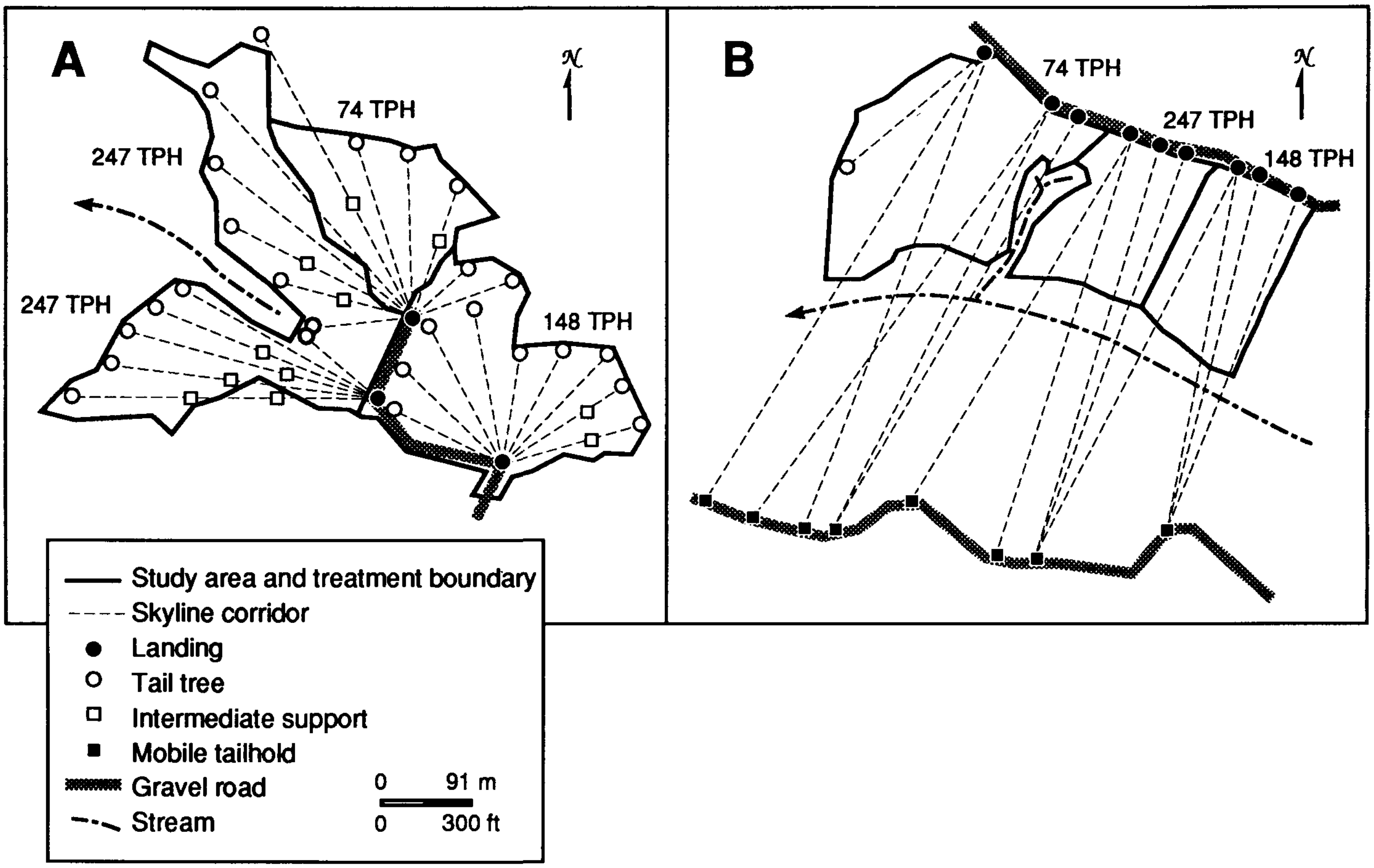

Figure 1. Layout of landings and skyline corridors at the A) Yachats and B) Hebo study sites.

Elements of the cycle included travel, fell, limb and buck, and delays. Other data collected for each tree included butt diameter, number of logs, number of bucking cuts, whether or not it required wedging, and ground slope where it was felled. When delays occurred, the type of delay was recorded. Elements of the cycle were timed in centiminutes and data were collected with a Husky Hunter II hand-held computer and SIWORK3 software [3].

Data collected with the hand-held computer were downloaded to a desktop personal computer for analysis. Forward stepwise multiple regression in Statgraphics 7.0 [13] was used to develop an equation for predicting felling cycle time without delays (delay-free) based on significant ($P \leq 0.05$) independent variables.

In addition to the detailed time study we performed, the felling foreman recorded felling production on daily shift-level forms. Data recorded for each feller included the thinning treatment, hours worked, number of trees cut, and delays greater than 10 minutes. Total percent delay time was calculated by adding the percent delay time less than 10 minutes from the detailed time study to the percent delay time greater than 10 minutes from the shift-level study.

Using truckload scale information from the mill, we calculated the average board-foot volume per log and the percent net-to-gross volume for each site. This information was used with the average delay-free cycle time from the regression equation and percent delay time to calculate the volume produced per hour for each treatment.

The owning, operating, and labour cost per hour for felling (in 1993 US dollars) was computed with the PACE program [18]. The resulting cost was divided by the production rate to determine the cost per thousand board feet (MBF) for each treatment at each site. Conversion factors were used to convert the production and cost values to approximate metric equivalents [9].

Yarding Study

Yarding production rates were also measured with a detailed time study. Timed elements of the yarding cycle included outhaul, drop chokers from carriage to ground, lateral out, hook, lateral in, inhaul, unhook, and delays. Other data collected for each cycle included number of logs, number of chokers used, yarding distance, lateral distance, height of skyline above the ground, slope steepness where logs were hooked, single span or multispan, hotset (chokers placed on logs while carriage waits) or preset (chokers placed on logs before carriage returns), whether stand damage occurred (bark of one or more live trees removed to the cambium, scarring an area larger than 20 cm^2 [3 $in.^2$]), and type of delay whenever a delay occurred. Yarding data were collected and analyzed through the same procedure used in the felling study.

Delays greater than 10 minutes, and road and/or landing changes to the nearest 10 minutes, were recorded on daily shift-level forms by a member of the yarding crew. Daily load information was also recorded, including number of loads and trip ticket numbers.

Move-in and Move-out Costs

Additional fixed yarding costs were figured to determine total harvesting costs. We calculated the costs to move the logging equipment to the site, set it up, tear it down, and move it out, following the methods in Edwards [5]. Move-in and move-out costs included moving the yarder, loader, a landing bulldozer for Yachats, and a tailhold bulldozer for Hebo. Associated costs included flag and pilot vehicles, highway permits, and lowboy transport as needed. It was assumed that the equipment was transported 80 km [50 miles] one way. To calculate set-up and tear-down costs, the set-up time was assumed to be equivalent to the average road change time at each site, and the tear-down time was assumed to be equivalent to half of the average road-change time. These fixed costs were divided by the total net volume harvested to determine the cost per m^3 [cunit] at each site.

Our method for calculating costs reflected average industry costs for the equipment and logging systems studied, using standard cost appraisal procedures [2]. They are not necessarily the actual owning and operating costs of the logging contractors. Profit and risk allowances were not included in the costs.

RESULTS

Felling

The amount of time consumed by individual elements in an average felling cycle at each site is shown in Table 3. "Limb and buck" was the longest element in the felling cycle (including delays), averaging a third of the cycle time at Yachats, and over half of the cycle time at Hebo.

Felling delays averaged over both sites accounted for 21.7% of the total felling cycle time. Of this time, mechanical delays consumed the most (35.3%) and included fueling the saw, repairing the saw, and moving the fuel or saw. Other delays included personal (20.9%), operational (19.1%), planning (12.5%), and miscellaneous (12.2%). One operational delay, tree hung-up, was found to be significantly different ($P \leq 0.05$) between the 74 tph [30 tpa] and 247 tph [100 tpa] treatments at Yachats, but showed no significant difference among treatments at Hebo.

The regression equation developed from the detailed time study observations to predict delay-free felling cycle time is

$$\begin{aligned} \text{FELL (min)} = & -1.492 \\ & + 0.088\ \text{DIAM (cm)} \\ & + 0.728\ \text{LOGS (\#)} \\ & + 0.853\ \text{WEDGE (0-1)} \\ & + 1.054\ \text{SITE (0-1)} \\ & + 0.292\ \text{TRT148 (0-1)} \\ & + 0.523\ \text{TRT247 (0-1)} \end{aligned}$$

(Adjusted $R^2 = 0.61$; MSE = 0.773; sample size = 1124 trees.)

The regression equation in English units is the same, except the coefficient for DIAM (in.) is 0.224. Definitions and values of variables in the regression equation are listed in Table 4. All independent variables were significant ($P \leq 0.01$) in determining delay-free felling time, including type of treatment. Slope was not a significant variable.

Felling production rates and costs are shown in Table 5. Both sites showed about a 9% increase in cost for the 148 tph [60 tpa] treatment over the 74 tph [30 tpa] treatment, and a 16 to 17% cost increase in the 247 tph [100 tpa] treatment compared to the 74 tph [30 tpa] treatment.

Table 3. Average felling cycle from detailed time study observations.

	Yachats		Hebo	
Element	Average time (min)	Percent of cycle	Average time (min)	Percent of cycle
Travel	0.87	19.9	0.61	13.7
Fell	1.03	23.5	0.55	12.4
Limb and buck	1.47	33.6	2.38	53.6
Delay-free cycle	3.37	77.0	3.54	79.7
Delays	1.01	23.0	0.90	20.3
Total felling cycle	4.38	100.0	4.44	100.0

Table 4. Variables in the felling regression equations.

Variable	Definition	Yachats		Hebo	
		Average	Range	Average	Range
FELL	Delay-free felling cycle time in minutes	3.37	0.33-7.69	3.54	0.40-7.97
DIAM	Inside bark butt diameter in cm [in.]	33.4 [13.1]	13-58 [5-23]	28.8 [11.3]	15-53 [6-21]
LOGS	Number of logs per tree	1.84	1-4	1.46	1-3
WEDGE	1 = wedged tree 0 = otherwise	0.36	0-1	0.11	0-1
SITE	1 = Hebo, 0 = Yachats	0	0	1	1
TRT148	1 = 148 tph [60 tpa] treatment 0 = otherwise	0.35	0-1	0.31	0-1
TRT247	1 = 247 tph [100 tpa] treatment 0 = otherwise	0.33	0-1	0.38	0-1

Table 5. Felling production and cost.

Site and treatment	Delay-free cycle time[a] (min)	Production rate[b] in m^3/hr [cunits/hr]	Cost/net volume in $/$m^3$ [$/cunits]	Cost > 74 tph [30 tpa] (%)
Yachats				
74 tph [30 tpa]	3.09	11.313 [3.995]	3.26 [9.23]	0.0
148 tph [60 tpa]	3.38	10.342 [3.652]	3.56 [10.09]	9.2
247 tph [100 tpa]	3.62	9.657 [3.410]	3.82 [10.81]	17.2
Hebo				
74 tph [30 tpa]	3.25	7.000 [2.472]	5.64 [15.97]	0.0
148 tph [60 tpa]	3.54	6.427 [2.270]	6.14 [17.39]	8.9
247 tph [100 tpa]	3.77	6.035 [2.131]	6.54 [18.52]	16.0

[a]From regression.
[b]Gross scale volume; includes all delay time.

Notes:
1. Owning, operating, and labour cost per hour was US $34.77.
2. Number of logs per tree was 1.84 at Yachats and 1.46 at Hebo.
3. Gross volume per log was 0.411 m^3 [14.5 ft^3] at Yachats and 0.326 m^3 [11.5 ft^3] at Hebo.
4. Net-to-gross timber scale was 0.94 at Yachats and 0.88 at Hebo.
5. Delays averaged 23.0% of total felling time at Yachats and 20.3% at Hebo.
6. A conversion factor of 274 ft^3/MBF was used to convert original board foot volume data to cubic feet [9].

Yarding

The amount of time taken by individual elements in an average yarding cycle is shown in Table 6. Excluding delays, "hook" took the longest and "inhaul" the second longest time at both sites. Averaged over both sites, yarding delays (19.8%) and road/landing changes (14.5%) together made up 34.3% of the average yarding cycle time.

Yarding delays averaged over both sites included carriage repair (28.4% of all delays), operational delays such as reposition carriage or reset chokers (23.5%), rigging delays (19.6%), landing delays (11.4%), yarder delays (9.0%), and other (8.1%).

Table 7 shows the amount of time used for road and landing changes, the external yarding distance, and the required rigging length at each site.

A regression equation to predict delay-free yarding cycle time was developed for each site from the detailed time study observations.

Yachats

$$
\begin{aligned}
\text{YARD (min)} = {} & 2.3409 \\
& + 0.0056\ \text{YDIST (m)} \\
& + 0.0387\ \text{LDIST (m)} \\
& - 0.7222\ \text{PRESET (0-1)} \\
& + 0.1906\ \text{LOGS (\#)} \\
& + 0.3341\ \text{SPAN (0-1)} \\
& + 0.1697\ \text{DAMAGE (0-1)}
\end{aligned}
$$

(Adjusted $R^2 = 0.38$; MSE = 0.315; sample size = 536 yarding cycles.)

The regression equation in English units is the same, except the coefficient for YDIST (ft) is 0.0017 and for LDIST (ft) is 0.0118.

Table 6. Average yarding cycle from detailed time study observations.

	Yachats		Hebo	
Element	Average time (min)	Percent of cycle	Average time (min)	Percent of cycle
Outhaul	0.51	9.0	0.46	7.6
Drop	0.11	2.0	0.33	5.5
Lateral out	0.47	8.3	0.42	7.0
Hook	0.91	16.1	0.81	13.4
Lateral in	0.42	7.5	0.64	10.6
Inhaul	0.77	13.6	0.73	12.1
Unhook	0.45	8.0	0.65	10.8
Delay-free cycle	3.64	64.5	4.04	67.0
Yarding delays	1.15	20.3	1.16	19.2
Road/landing changes	0.86	15.2	0.83	13.8
Total yarding cycle	5.65	100.0	6.03	100.0

Table 7. Road and landing changes.

Study site	Type of change[a]	Number of changes	Change time in hours		External yarding distance in m [ft]		Required rigging length[b] in m [ft]	
			Average	Range	Average	Range	Average	Range
Yachats	Road	23	1.4	0.3-2.8	177 [580]	94-317 [310-1040]	183 [600]	94-335 [310-1100]
	Landing	2	2.5	1.0-4.0	210 [690]	107-317 [350-1040]	210 [690]	107-317 [350-1040]
Hebo	Road	5	2.1	1.3-4.0	210 [690]	183-299 [600-980]	451 [1480]	192-585 [630-1920]
	Landing	8	2.3	1.3-4.0	195 [640]	174-232 [570-760]	485 [1590]	393-567 [1290-1860]

[a]A landing change includes both a landing and a road change.
[b]Required rigging length is the slope distance between yarder and tailhold.

Hebo

YARD (min) = 1.8053
+ 0.0135 YDIST (m)
+ 0.0226 LDIST (m)
-0.4292 PRESET (0-1)
+ 0.1273 LOGS (#)
+ 0.0118 SLOPE (%)
+ 0.1894 DAMAGE (0-1)
(Adjusted R^2 = 0.68; MSE = 0.270; sample size = 515 yarding cycles.)

The regression equation in English units is the same, except the coefficient for YDIST (ft) is 0.0041 and for LDIST (ft) is 0.0069.

The definitions and values of variables in the regression equations are listed in Table 8. A different equation was developed for each site because a slightly different set of independent variables was significant at each site. At Yachats, all independent variables were significant at the $P \leq 0.01$ level, except stand damage, which was significant at the $P \leq 0.05$ level. At Hebo, all independent variables were significant at the $P \leq 0.01$ level. Type of treatment was not significant in predicting yarding cycle time at either site. A *t*-test showed yarding cycle time was significantly different ($P \leq 0.01$) at the two sites.

Yarding production rates and costs are shown in Table 9. If costs are averaged over both sites, there was a 5.7% increase in the cost of yarding the 148 tph [60 tpa] treatment over the 74 tph [30 tpa] treatment, and an 11.9% increase in the 247 tph [100 tpa] treatment over the 74 tph [30 tpa] treatment.

Move-in and Move-out Costs

The cost of moving logging equipment to and from the site was US \$0.70/net m³ [US \$1.99/net cunit] at Yachats and US \$1.29/net m³ [US \$3.65/net cunit] at Hebo. The cost to set up and tear down the logging equipment was US \$0.15/net m³ [US \$0.42/net cunit] at Yachats and US \$0.36/net m³ [US \$1.02/net cunit] at Hebo. These fixed yarding costs were added to the previously calculated felling and yarding costs to determine total harvesting costs at each site.

The total harvesting costs for each treatment at each site are illustrated in Figure 2. If total harvesting costs are averaged over both sites, the 148 tph [60 tpa] treatment cost 6% more and the 247 tph [100 tpa] treatment cost 12.3% more to harvest than the 74 tph [30 tpa] treatment.

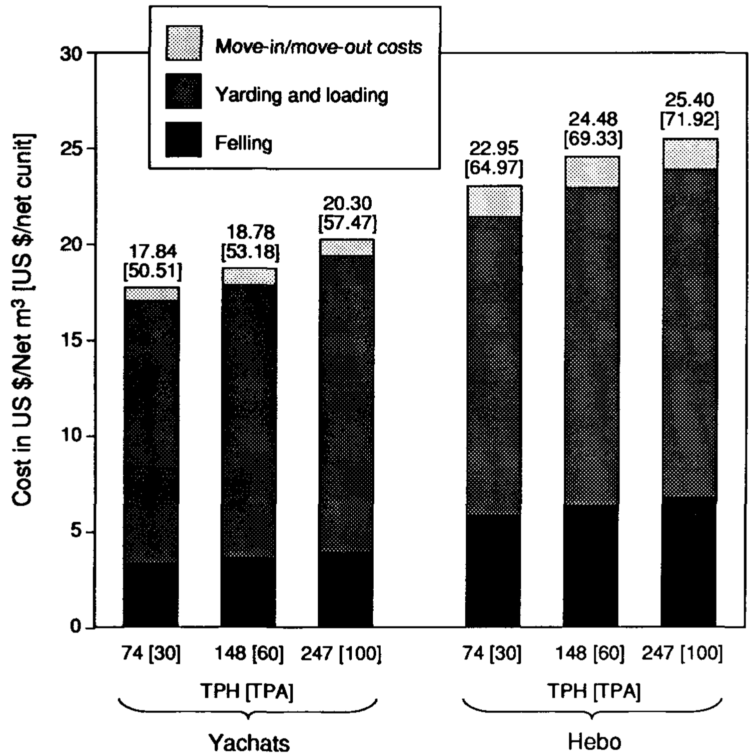

Figure 2. Total harvesting costs.

Table 8. Variables in the yarding regression equation.

Variable	Definition	Yachats		Hebo	
		Average	Range	Average	Range
YARD	Delay-free yarding cycle time in minutes	3.64	1.78-5.83	4.04	1.47-6.79
YDIST	Slope yarding distance in m [ft]	125 [411]	18-250 [60-820]	99 [326]	9-201 [30-660]
LDIST	Lateral yarding distance in m [ft]	7 [23]	0-26 [0-85]	6 [19]	0-26 [0-85]
PRESET	1 = preset turn 0 = otherwise	0.50	0-1	0.83	0-1
LOGS	Number of logs per turn	3.18	1-7	4.75	1-9
SPAN	1 = lower end of multispan 0 = single span or upper end of multispan	0.22	0-1	Not a variable at Hebo; all corridors were single span.	
DAMAGE	1 = live tree(s) scarred by logs or cable during turn 0 = otherwise	0.11	0-1	0.12	0-1
SLOPE	Percent slope where logs are hooked	Not a significant variable		41.4	14-70

DISCUSSION

Felling

The felling regression equation shows a significant difference in the effect of treatment type on felling-cycle time. The delay-free felling-cycle time increased as the number of residual trees increased. This is reasonable because as the number of residual trees increases, the trees designated for cutting are spaced farther apart, resulting in a longer travel time between trees. It also takes longer to locate the trees that are designated for cutting, and requires additional planning time to identify a lay for each tree without felling hangups into residual trees.

Table 3 shows that the average time for "fell" at Yachats was 0.48 minutes longer than at Hebo. The increased felling time is explained by the larger diameter of the trees (4.6 cm [1.8 in.] greater than at Hebo), and the greater use of wedging (36% of trees wedged at Yachats versus 11% wedged at Hebo). These differences resulted in an increase of 0.62 minutes in the felling-cycle time at Yachats, calculated from the felling regression equation.

The coefficient of the SITE variable in the felling regression equation shows that the delay-free cycle time at Hebo was about a minute longer than at Yachats. This is largely the result of the longer limbing and bucking time at Hebo (Table 3), due to bucking the top of each tree and limbing three sides of the tree, which was not done at Yachats. Thus, leaving the top attached to the last log and doing less limbing increased felling production.

The two sites showed similar results in the percent felling cost increase of the 148 and 247 tph [60 and 100 tpa] treatments over the 74 tph [30 tpa] treatment. However, the felling costs at Hebo were much higher than at Yachats (Table 5). For example, felling in the 74 tph [30 tpa] treatment was US $5.64/net m^3 [US $15.97/net cunit] at Hebo and US $3.26/net m^3 [US $9.23/net cunit] at Yachats. The difference in felling costs between the two sites can be explained by several factors: differences between fellers and their felling techniques (bucking the top of the tree and limbing three sides at Hebo but not at Yachats), tree volume differences, and net-to-gross log-scale differences.

Felling Sensitivity Analysis

To more evenly compare felling costs between the two sites, we removed differences between the two fellers in felling speed and felling techniques. This was done by using the diameter and number of logs per tree at Hebo in the felling regression equation for the 74 tph [30 tpa] treatment at Yachats. The resulting delay-free cycle time was 2.41 min, with a cost of US $4.33/net m^3 [US $12.27/net cunit] for the 74 tph [30 tpa] treatment at Hebo (compared to US $3.26/net m^3 [US $9.23/cunit] at Yachats).

The remaining difference in felling cost between the two sites can be explained by differences in tree volume and the net-to-gross timber scale. Tree volume averaged 0.76 m^3 [26.7 ft^3] at Yachats, but only 0.48 m^3 [16.8 ft^3] at Hebo. The lower volume per tree resulted in a lower production rate per hour: 9.123 gross m^3/hr [3.222 gross cunits/hr] at Hebo compared to 11.313 gross m^3/hr [3.995 gross cunits/hr] at Yachats for the 74 tph [30 tpa] treatment (if differences in fellers and felling techniques are removed as previously described). Finally, the net-to-gross timber scale was lower at Hebo than at Yachats (0.88 versus 0.94), further increasing the felling cost per net unit of volume at Hebo.

Yarding

To compare yarding cycle times at the two sites, we used values averaged for all treatments over both sites for the independent variables in the two regression equations. The resulting cycle time was 16% longer at Hebo (4.15 min) than at Yachats (3.58 min). This is primarily due to differences in the skyline set-up at each site. At Hebo, because mobile tailholds on a road outside the site and across a ravine were used, the height of the skyline averaged 18 m [60 ft] above the ground. At Yachats, tailtrees and intermediate supports were used, and the skyline averaged 9 m [30 ft] above the ground. The higher skyline at Hebo resulted in longer "drop" and "lateral in" times, which increased the yarding cycle time.

The parallel skyline road pattern at Hebo was more efficient than the fan-shaped pattern at Yachats. The Hebo site averaged 0.65 ha [1.6 acres] yarded for each skyline road, compared to 0.40 ha [1.0 acre] at the Yachats site. Often the terrain and truck road location influence the skyline yarding pattern, however, at some sites, either pattern may be feasible. Our study indicates that in situations with a choice of layout patterns and comparable skyline rigging distances, a parallel skyline road pattern would result in higher yarding production than a fan pattern

Table 9. Yarding production rates and costs for yarding and loading.

Site and treatment	Average logs per turn turn (no.)	Production rate[a] in m^3/hr [cunits/hr]	Cost/net volume in $/$m^3$ [$/cunit]	Cost > 74 tph [30 tpa] (%)
Yachats				
74 tph [30 tpa]	3.37	14.693 [5.189]	13.73 [38.87]	0
148 tph [60 tpa]	3.22	14.039 [4.958]	14.37 [40.68]	4.7
247 tph [100 tpa]	2.96	12.906 [4.558]	15.63 [44.25]	13.8
Hebo				
74 tph [30 tpa]	4.99	16.200 [5.720]	15.66 [44.33]	0
148 tph [60 tpa]	4.68	15.190 [5.364]	16.69 [47.27]	6.6
247 tph [100 tpa]	4.54	14.736 [5.204]	17.21 [48.73]	9.9

[a]Gross scale volume; includes all delay time.

Notes:
1. Owning, operating, and labour cost for yarding and loading was US $190.27/hr at Yachats and US $223.39/hr at Hebo.
2. Effective hour was 38.70 min/hr at Yachats and 40.14 min/hr at Hebo.
3. Average delay-free cycle time from regression was 3.65 minutes at Yachats and 4.03 minutes at Hebo.
4. Gross volume per log was 0.411 m^3 [14.5 ft^3] at Yachats and 0.326 m^3 [11.5 ft^3] at Hebo.
5. Net-to-gross timber scale was 0.94 at Yachats and 0.88 at Hebo.
6. A conversion factor of 274 ft^3/MBF was used to convert original board foot volume data to cubic feet [9].

because fewer roads are needed and a smaller proportion of total yarding time would be spent in skyline road changes.

Although the parallel skyline road pattern at Hebo was more efficient, the method used for rigging the skyline corridors was less efficient than at Yachats; road-change times averaged 50% longer at Hebo (Table 7). This was due to several factors. First, the tailholds at Hebo were located about 275 m [900 ft] from the study site boundary, making the required rigging length about 2.5 times longer at Hebo than at Yachats. Second, there was some difficulty achieving proper alignment with the corridor as the skyline was raised at Hebo. Landing changes, on average, took slightly longer at Yachats than at Hebo. The sample size was very small at Yachats, however, with only two landing changes and large variability in times (Table 7).

For the three treatments studied, yarding production increased as thinning intensity increased (Table 9). This was directly related to an increase in the average number of logs per turn as thinning intensity increased. As production increased, the cost per unit volume decreased, making the 74 tph [30 tpa] treatment the least costly treatment to yard. Yarding production was higher at Hebo, but yarding costs were lower at Yachats (Table 9). The Thunderbird TMY 40 yarder used at Hebo has a more powerful engine (132 kW [177 horsepower]) than the Koller K501 yarder used at Yachats (84 kW [112 horsepower]), enabling it to haul on average about 1.5 more logs per turn under the conditions studied at the two sites. Single-span skylines were used at Hebo, while there was a mixture of single-span and multispan skylines at Yachats. Owning, operating, and labour costs for yarding and loading were higher at Hebo (US $223.39/hr) than Yachats (US $190.27/hr). The higher yarding costs at Hebo, however, are primarily due to the lower volume per log and the lower net-to-gross scale at Hebo, rather than to the higher hourly owning, operating, and labour costs.

Yarding Sensitivity Analysis

To more evenly compare yarding costs between the two sites, we removed differences in tree volume, net-to-gross scale, and crew operation (PRESET, DAMAGE) by using values averaged over both sites. First, yarding cycle time was calculated with values averaged over both sites for the independent variables in the regression equations, except for the number of logs per turn. We believe that the number of logs per turn was affected by the logging techniques used, including skyline deflection (affected by terrain, rigging length, and single span versus multispan), the number of chokers used per turn, and attributes of the yarder (such as tower height and engine power). Since these logging techniques were different at each site, we used the average number of logs for each individual site to calculate yarding cycle time from the regression equation. The resulting cycle times were 3.43 min at Yachats and 4.30 min at Hebo.

These cycle times were then used to calculate yarding costs with values averaged over both sites for delay time, volume per log, and net-to-gross scale. The resulting costs for all treatments combined were similar, even with the differences in logs per turn and owning, operating, and labour costs: US $15.36/net m^3 [US $43.50/net cunit] at Yachats and US $15.14/net m^3 [US $42.86/net cunit] at Hebo. Thus the larger yarder used at Hebo had a slightly higher owning and operating cost, but yarding production was also slightly higher, resulting in similar thinning costs for the two sites.

If the number of logs yarded per turn was the same for both yarders (3.97 logs per turn was the average of both sites), and other variables were standardized as presented above, the resulting cost for all treatments combined would be US $12.86/net m^3 [US $36.41/net cunit] at Yachats and US $17.68/net m^3 [US $50.05/net cunit] at Hebo, a difference of 37%.

Move-in and Move-out Costs

Move-in and move-out costs per unit volume were almost twice as high at Hebo as Yachats (US $1.65/net m^3 [US $4.67/net cunit] compared to US $0.85/net m^3 [US $2.41/net cunit). There are several factors that account for this. First, the total volume harvested at Hebo was less than at Yachats because fewer acres were thinned and the trees were smaller, yielding less volume per tree. The smaller volume at Hebo resulted in higher move-in and move-out costs per unit volume, since the cost to move logging equipment to the site, set it up, tear it down, and move it out is constant for a given location, but the cost per unit volume decreases as the volume harvested increases. Second, the loader at Hebo was crawler-mounted, requiring lowboy transport to and from the site, which was more expensive than moving the rubber-tired loader at Yachats to and from the site. Third, set-up and tear-down costs, based on the average road-change time at each site, were higher at Hebo because the average road-change time was longer. Fourth, the equipment used at Hebo was more expensive than Yachats, resulting in slightly higher owning and operating costs.

CONCLUSIONS

Regression analyses showed that the type of treatment was significant in predicting felling cycle time but not yarding cycle time for the three treatments studied.

As thinning intensity increased, felling and yarding production increased and costs decreased. For felling, this was related to shorter felling cycle times as thinning intensity increased; for yarding, the number of logs per turn was higher as thinning intensity increased. Overall, the 74 tph [30 tpa] treatment had the highest production rate and was the least costly to harvest; costs of the other two treatments averaged 6.0% (148 tph [60 tpa]) to 12.3% (247 tph [100 tpa]) more. These differences are probably small enough to allow choosing the most appropriate silvicultural prescription to meet desired management objectives.

Differences in logging techniques between the two sites also affected production rates and costs. Leaving the top attached to the last log and limbing only the top side of the tree increased the felling production rate at Yachats, compared to bucking the top off and limbing three sides at Hebo. Long rigging distances that extended outside the logging unit increased road change times and created skyline alignment problems with the thinning corridors at Hebo. The parallel skyline road layout used at Hebo, however, required fewer roads per hectare and resulted in a smaller proportion of time spent in road changes than did the fan-shaped layout at Yachats.

Finally, both felling and yarding production rates and costs were affected by site differences in tree volume. Production rates increased and costs decreased with larger trees harvested, higher average volume per log, and higher net-to-gross log scale.

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