Effects of Alternative Silvicultural Treatments on Cable Harvesting Productivity and Cost in Western Washington

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Full text

Headnote

ABSTRACT

Increasingly, alternative silvicultural methods have been considered to meet the demand **for** nontimber values such as visual quality and biodiversity **in** the Pacific Northwest. The successful implementation of these alternative silviculture treatments requires careful consideration of economics and operational efficiencies **in** timber harvesting. This study used detailed time study and shift-level data to assess the effect of alternative silvicultural treatments on the **production** and cost of cable harvesting **in** western Washington. Four silvicultural treatments were examined: clearcut, two-age, patch cut and thin, and group selection. Silvicultural treatments greatly affected the **production** and cost of timber harvesting, especially **in** felling and **yarding** processes. The average **yarding** cycle time (3.74 minutes/cycle) **in** the clearcut unit was shorter than those **in** other partial cutting treatment units because there were no residual trees to work around and higher harvest volumes per acre, compared with the partial cut units. The average tree size greatly affected **yarding** cost: the clearcut unit had the second-highest **yarding** cost ($52.38/thousand board feet [mbf]) because of the smallest piece size (69.6 board feet/piece). Stump-to-truck cost **for** this study ranged from $70.49/mbf **for** the patch cut and thin to $120.19/mbf **for** the group selection. Carriage types and **yarding** direction also had an impact on **yarding** productivity.

Keywords: partial cutting, skyline **yarding**, alternative harvesting, skyline carriage

Forest management practices **in** the Pacific Northwest are changing to reflect increased public demands **for** addressing nontimber values such as structural and biological diversity as well as aesthetics and wildlife habitats (Curds et al. 1998, Reutebuch et al. 2002). These demands often call **for** implementing alternative silvicultural practices (i.e., partial cutting) with less-intensive harvest of trees (Johnson 2002, Reutebuch et al. 2002) and more emphasis placed on the ecological perspective (Keegan et al. 1995). Partial cutting treatments are not new to forest management **in** the Pacific Northwest, but land managers and contract loggers often voice concerns about increased logging costs and operational requirements resulting from the protection of environmental values while producing timber (Arnott and Breese 1997). This type of management is complicated further by the fact that there are no commonly accepted procedures that dictate how partial harvest treatments are implemented, administered, or evaluated (McNeel and Dodd 1996).

Successful implementation of the alternative silvicultural treatments is, **in** part, dependent on the operations being economically efficient while meeting the landowner's objectives **for** the stand (Coulter 1999). Potential financial returns are important criteria **for** forest managers to consider when planning a timber harvest. Generally, clearcutting is accepted as being less expensive than partial cutting. Higher harvesting productivity or low harvesting cost often is associated with clearcuts because workers and machinery do not have to maneuver around residual trees, machines have to move less because of higher volumes removed per area, and hooking times are shorter because of higher concentrations of downed timber (Kellogg etal. 1996a, 1996b, Howard et al. 1996).

Harvesting productivity commonly decreases with partial cutting because care must be taken to minimize damage to residual trees and equipment travel times are longer when trees are spaced farther apart. However, other factors such as an increase **in** average tree size may make up **for** productivity losses incurred due to reduced harvest intensity per acre (Kluender et al. 1998). Planning and layout is an integral part of timber harvesting and the cost (dollars per acre) of planning and harvest layout is influenced by the amount of harvest volume per acre and silvicultural treatments. The planning of a partial harvest may take anywhere from two to seven times longer than planning a clearcut because of the amount of detail needed **in** laying out the skyline corridors, with the result that planning costs associated with partial cutting are higher than those associated with clearcutting (Kellogg et al. 1998).

Another challenge **in** the Pacific Northwest is that the topography is often too steep (more than 35%) to be harvested effectively by ground-based harvesting systems. Although ground-based harvesting systems can work on slopes of up to 50%, their **production** is considerably diminished as the upper slope limit is approached (Conway 1982). Cable harvesting systems often are used to harvest timber **in** steep terrain, but cable harvesting costs are more sensitive to alternative silvicultural treatments than ground-based harvesting systems. **For** example, Daigle (1992) found that the cost of tractor logging **in** partial harvests was between O and 16% greater than the cost of logging clearcuts. **In** contrast, cable logging costs **for** partial cutting were 19 and 4% above clearcutting costs. He suggested that several factors contributed to the difference **in** the increase **in** cable logging costs, including the large amount of time spent during corridor changes and the large labor inputs required **for yarding** activities (i.e., typically three to four people are directly related to **yarding** activities **in** a cable logging). Increased number of landing and road changes and smaller turn sizes also contribute to higher cable logging costs **in** a partial cutting

(Hochrein and Kellogg 1988). Economic concerns become greater when alternative silvicultural treatments are implemented using cable systems because these systems have higher costs than ground-based harvesting systems **in** a partial harvesting (Daigle 1992).

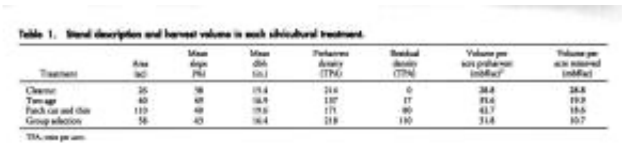

Table 1. Stand description and harvest volume in each silvicultural treatment.

Treatment	Area (ac)	Mean age (yr)	Mean dbh (in.)	Preharvest density (TPA)	Residual density (TPA)	Volume per acre preharvest (mbf/ac)	Volume per acre removed (mbf/ac)
Clearcut	35	58	19.4	216	0	38.8	28.8
Two-age	60	65	16.9	137	17	81.6	19.9
Patch cut and thin	110	48	19.6	171	80	41.7	15.5
Group selection	58	45	16.4	218	110	31.8	10.7

TPA, trees per acre.

Table 1. Stand description and harvest volume in each silviculture! treatment.

Implementing alternative silvicultural systems **in coastal** conifer stands of the Pacific Northwest using cable systems is being considered more frequently, and there is a need to enhance our knowledge of how to efficiently and economically implement alternative harvesting practices. The objectives of this study were to compare the productivity and cost of cable harvesting among four different silvicultural treatments and to identify what factors influence them.

Study Area and Methods

Four different silvicultural treatments were located on a 242-ac study area **in** the Capitol State Forest **in** Olympia, Washington (latitude, 46.85° N; longitude, 123.15° W). The stands were primarily (89-97%) stocked with Douglas-fir (Pseudotsuga menzesit), but also supported small components of western hemlock (Tsuga heterophylla), western red cedar (Thuja plicata), red alder (Alnus rubra), and bigleaf maple (Acer macrophyllum). The average dbh of the merchantable (i.e., conifer) species was 19 **in**. The elevation of the site is approximately 500 ft above sea level and the slope ranged from 15 to 57%. All cutting units were located outside of riparian management areas and were not required to leave buffers. Table 1 summarizes the mean site conditions **for** each of the four silvicultural treatments. These treatments include

* Clearcut. Even-aged prescription that removed 100% of trees **in** the harvest unit. Because clearcutting is the traditional and most common harvesting practice **in** this area, we have chosen to use it as the reference treatment **for** this study. We will use this reference as the basis of all comparisons between silvicultural treatments.

* Two-age. Uneven-aged prescription, **in** which approximately 15 trees/ac are retained until the next rotation.

* Patch cut and diin. Uneven-aged prescription that removed about 20% of the overstory, **in** patches of 1.5-5 ac with thinning **in** between the openings, resulting **in** a stand that contains five separate age classes. The patch cut and thinning operations were not separated to analyze the overall effect of this type of treatment.

Table 2. Felling and processing methods used in each silvicultural treatment.

Silvicultural treatment	Felling method[a]	Processing location	Prebunching logs or trees
Clearcut	Mechanical (100%)	Landing	Yes
Two-age	Manual (100%)	Stump/landing	No
Patch cut and thin	Manual (67%) Mechanical (33%)	Stump/landing	No
Group selection	Manual (33%) Mechanical (67%)	Stump/landing	No

[a] Value in parentheses indicates percentage (by area) of the felling method used.

* Group selection. Similar to patch cut and thin except the

openings are limited to less than 1.5 ac that are scattered over the harvest unit.

Table 2. Felling and processing methods used in each silvicultural treatment.

One logging contractor conducted all four silvicultural treatments. The contractor was familiar with the use of cable harvesting systems **in** partial cutting operations and he had been performing partial harvest using these systems **for** 10 years. Felling was done either by a Timbco 445-D feller-buncher with a Quadco (Prince George, BC, Ganada) hot saw head **for** flat or moderate slopes (less than 40%), or by a contract faller using a Stihl 064 chainsaw (Oceana West Industrial Park, Virginia Beach, VA) with a 34-**in**. bar **for** steep slopes (more than 40%). Both manual and mechanical felling methods were used **in** the group selection and patch cut, with the mechanical felling used **in** the thinning sections and manual felling was used **in** the clearcut patches. The clearcut unit was felled mechanically, and the two-age unit was felled manually (Table 2).

Yarding was done using a Washington 78SL swing yarder (Trican Machinery, Ltd., New Westminster, BC, Canada) run by a crew of four with 5-30 years of experience: a yarder operator, a rigging slinger, and two choker-setters. The yarder had a 47-ft tower and was capable of **yarding** distances of 1,800 ft. The yarder was used **in** different configurations (standing and running skyline systems and uphill and downhill **yarding**) and with an assortment of carnages to facilitate **yarding** of the harvest units (Table 3). The equipment configurations were determined by the contractor, **in** accordance with his views on the most productive setup **for** the site. During **yarding** three carriage types were used: Eagle Eaglet motorized clamping carriage, a mechanical slack pulling (MSP) carriage and a **grapple** carriage. The MSP carriage and the **grapple** carriage were used **in** downhill **yarding** situations **in** one of the clearcut patches with a running skyline setup. **For** material smaller than 17 **in**., large-end diameter, whole trees were yarded to the landing where trees were processed with an excavator-based Cat 32OD with a Fabtec (Menomnee, MI) processing head **in** all units. All material larger than a 17-**in**. small-end diameter was processed at the stump using a chainsaw. A Link-Belt heel boom loader was used to load tree length logs onto the trucks at landing.

Table 3. Yarder configuration, carriage type, yarding direction, and average yarding distance for each silvicultural treatment unit.

Silvicultural treatment	Skyline yarding configuration	Carriage type	Yarding direction	Yarding distance (ft) Mean	Range	SD
Clearcut	Standing	Motorized[a]	Uphill	315	50-500	119.89
Two-age	Standing	Motorized[a]	Uphill	412	75-500	103.53
Patch cut and thin	Standing/running	Motorized[a]/MSP[b]/grapple	Uphill/downhill	425	15-625	168.52
Group selection	Standing	Motorized[a]	Uphill	406	75-700	158.96

[a] Motorized slack pulling carriage.
[b] MSP carriage.

Table 3. Yarder configuration, carriage type, yarding direction, and average yarding distance for each silvicultural treatment unit.

A detailed time study was performed on the **yarding** phase of the operation **for** each silvicultural unit between May and August of 2002. All the productive elements and delays were measured to develop predictive **equations** **for** average cycle time **for** **yarding** operations. The productive **yarding** cycle was divided into six elements: outhaul, lateral out, hooking, lateral **in**, inhaul, and unhooking. The elemental times **in** seconds were collected using a Husky fex21 field computer (Lexington, KY), with the Time Study Data Logger program (Itronix, Spokane Valley, WA) (Wang 2001). Along with the elemental times, independent variables also were collected and related to the average **yarding** cycle time models. The independent variables collected were **yarding** distance, lateral distance (except **for** when **grapple** **yarding** was used **in** the patch cut and thin unit where lateral distance was not collected), number of pieces per cycle, carriage type, and **yarding** direction. Delays **in** the productive cycle were recorded also **in** three categories: (1) operational-downtime during the cycle such as hang-ups, losing logs, decking problems, and others; (2) mechanical-downtime caused as a result of machine failure; and (3) personal-downtime caused **for** other than mechanical or operational reasons.

Shift-level data are the daily **production** information of a machine or person per shift recorded by each operator at the end of the day throughout the operation. A time log was kept on all the machines **for** the entire harvest so that the detailed information could be compared with the daily **production**, to make sure that there were no errors made. No detailed time study data were collected **for** felling, processing, and loading. Shift-level data were used to estimate **production** rates **for** these activities. The daily **production** data **for** each piece of equipment were used to derive a cost per unit of volume **for** each piece of machinery on each harvesting unit.

The data collected **in** the detailed time studies were entered into a Microsoft Excel spreadsheet, where an initial screening of data was performed. Outliers were screened and removed from the data set if they were more than 3 SDs from the mean. After the outliers were removed, the data were transferred to SAS version 8.02 (SAS 2001) where multivariate ordinary least squares regression analysis was preformed to develop models of delay-free cycle time. Tree and log size information was calculated using the preharvest cruise and scaling data. The scaling data were obtained from the mill to which the logs were taken, where the logs were scaled according to the westside Scribner log rule. Logs were identified by truck scale tickets and were able to be differentiated by sale unit. The scaling data were used to determine average volume per piece **for** each unit and also the weighted average was used to determine average piece size **for** the sale.

Machine rates were calculated **for** each machine that was used **in** the harvesting of each of the study units. The machine rates were calculated using the method outlined by Miyata (1980). Several assumptions were made to calculate machine rates, and they are summarized **in** Table 4. The machine rates **for** all machinery are listed **in** Table 5. **For** this study the yarder had the highest total cost per scheduled machine hour (SMH) because of high labor cost associated with a four-person crew.

Results and Discussion

Table 4. Assumptions used for machine rate calculations.

Assumption	Value
SMH/yr	2000 SMH/yr
Salvage value	20% of purchase price
Interest, insurance, and tax	15% of avgerage annual investment
Repair and maintenance	60% of annual depreciation
Diesel price	$1.68/gal
Fuel consumption	0.027 gal/hp-hr
Oil and lube cost	37% of fuel cost
Labor	Rates for western Washington
Economic lives	
Yarder	7 yr
Loader	7 yr
Processor	5 yr
Feller-buncher	5 yr

Table 4. Assumptions used for machine rate calculations.

Felling, Processing, and Loading

Mechanical felling productivity varied greatly, among silvicultural treatments because of the differences **in** density of residual standing timber and felling methods (Table 6). Mechanical felling was used **in** the clearcut unit as well as the thinning sections of the patch cut and thin and group selection units. The average **production** rates of the mechanical felling were not statistically different **in** the patch cut and group selection units with **production** rates of 32.4 trees/SMH and 28.0 trees/SMH, respectively, and 65.7 trees/SMH **in** the clearcut. Mechanical felling costs were 176% higher **in** the partial cutting areas ($17.74/thousand board feet [mbf]) than **in** the clearcut unit ($6.42/mbf). The cost per mbf was calculated by multiplying the trees per hour **production** rate by the average standing tree volume and dividing the machine rate **for** the felling system by that product. Manual felling productivity was approximately 12.01 trees/SMH (or $15.78/mbf) **in** the clearcut sections of the patch, group selection, and two-age treatments. It was expected that manual felling **production** would have decreased also because of the care necessary to avoid hang-ups and undue damage to the residual stand (Kellogg et al. 1996b). Felling productivity, however, was not affected because of the high fraction of trees felled **in** the sections where manual felling was used. **In** the calculation of felling cost, an average tree volume of 263.41 board feet (bd ft) was used, which was estimated from the presale cruise.

Processing productivity was consistent throughout all the silvicultural treatment units because processing occurred independently from the **yarding** activities. There were no processing **production** data collected from this study, and we used the processing **production** information from a previous study that used a similar processor **in** comparable tree sizes (Coulter 1999). The processing **production** rate used **in** the cost calculation was 11.45 mbf/SMH, which resulted **in** a unit processing cost of $10.99/mbf. Log trucks were loaded from a cold deck, by a loader dedicated to loading only, resulting **in** a consistent **production** **in** loading **for** all the silvicultural treatment units studied. On average, five trucks were loaded per day 'with an average payload of 4.276 mbf/truck load. The hauling distance to the mill was 250 mi one way, and each truck made only one trip per day. This resulted **in** a loading cost of $25.03/mbf.

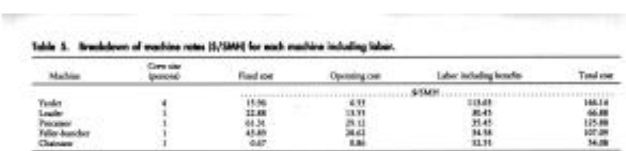
Table 5. Breakdown of machine rates ($/SMH) for each machine including labor.

Machine	Crew size (persons)	Fixed cost	Operating cost	Labor including benefits	Total cost
		$/SMH			
Yarder	4	15.96	[illegible]	113.45	146.14
Loader	1	22.88	13.91	30.43	66.88
Processor	1	61.34	29.12	35.45	125.88
Feller-buncher	1	43.89	28.62	34.58	107.09
Chainsaw	1	0.07	8.86	32.31	34.28

Table 5. Breakdown of machine rates ($/SMH) for each machine including labor.

Skyline **Yarding**

Yarding Cycle Time

Table 6. Mean felling production (trees/hr) by unit and felling method.

Felling method	Silvicultural treatment	Hourly production (no. trees/SMH)
Mechanical	Clearcut	65.72[a]
	Patch cut thinning section	38.02[b]
	Group selection thinning section	32.58[b]
Manual	Two-age	12.05[c]
	Group and patch clearcut groups	15.24[c]

[a,b,c] Letters denote mean groups that are different between treatments at $\alpha = 0.05$, using Tukey's HSD.

Table 6. Mean felling production (trees/hr) by unit and felling method.

The shortest average cycle time was observed **in** the clearcut unit (3.33 minutes), followed by the patch cut (4.23 minutes) and twoage (4.44 minutes), and the group selection (4.88 minutes) had the longest average cycle time (Figure 1, Table 7). The outhaul time was relatively similar throughout the treatments, with significant differences between the two-age and patch cut; and the clearcut and group selection were caused' by the differences **in** the external **yarding** distance of each unit.The time spent pulling cable laterally was significandy higher **in** the two-age unit (46.61 seconds/cycle; P < 0.0001). This unit had a steeper ground slope than the other units and a large amount of logging slash on the ground, which resulted from processing large trees at the stump. The slash interfered with the choker-setter's movement. Hooking time was the shortest **for** the clearcut and the two-age units (clearcut, 42.88 seconds/cycle; two-age, 47.69 seconds/cycle. The abundance of timber on the ground, timber mechanically felled and bunched (clearcut), and large trees (two-age) attributed to the quick hooking time.

Time **for** lateral-**in** to the carriage was influenced by residual trees and the felling method. The two-age and group selection units, which required the greatest amount of **yarding** through standing timber, had significantly higher cycle times **for** lateral-**in** than clearcut and patch cut (Tukey's honestly significant difference [HSD], $P < 0.001$). The logs and trees **in** the group selection and two-age units had to be worked around residual trees during the lateral-cable-**in** process, slowing the process of returning the cable to the carriage. **In** the patch cut, the trees **in** the single tree selection thinning area were mechanically felled and placed **in** bunches near the skyline corridors to facilitate the lateral-**in** process. **In** the areas that were **grapple** yarded the lateral distance was recorded as O ft; thus, there was no lateral-out or lateral-**in** time. The residual trees **in** the two-age and group selection units also caused longer times **for** the inhaul process because the logs had to be pulled through a residual stand. Unhooking time was similar across the treatments with the exception of the group selection. Although all units used the use of electronic chokers, the unhooking time **for** the group selection unit was longer because of mechanical problems with the chokers. To facilitate data analysis, the mean unhooking time **for** all the turns recorded, excluding the unhooking times **for** the group selection, was used to provide an estimate of unhooking time **for** the group selection unit.

Regression models **for** delay-free cycle time were developed, using the common independent variables of lateral **yarding** distance, **yarding** distance, and number of pieces per cycle **for** all the harvesting units (Table 8). **For** the models all the coefficients were significant except **for** the coefficient on pieces per cycle **in** the group selection model, which had a value of P = 0.351, and the coefficient on lateral distance **in** the two-age model, which had a value of P = 0.144. The coefficient **for** pieces per cycle was positive and statistically the same **in** magnitude, except that the patch cut coefficient was significantly higher than the clearcut. Similarly, the coefficient **for** the lateral distance variable was positive with statistically the same magnitude, except that the patch cut variable was significantly higher than the two-age unit. **In** the patch cut model, dummy variables were used to examine the effect of carnage type and position of the yarder (uphill versus downhill **yarding**). The coefficients that were significant **for** the patch cut model **in** addition to pieces per cycle, lateral distance, and **yarding** distance were the coefficients **for** the **grapple** carriage and **yarding** direction. Both coefficients were found to have negative signs, which signify that both the **grapple** carriage and the uphill **yarding** resulted **in** lower cycle times than downhill **yarding** and slack pulling carriages. The combined model was developed based on all the data from the different silvicultural units and resulted **in** a general model **for** skyline **yarding** productivity on this study, including dummy variables to account **for** differences **in** silvicultural treatment, carriage type, and position of the yarder.

Delays

Delays caused significant differences **in** overall cycle time (Figure 2, Table 9). During our field observations, we found that mechanical malfunctions of the old yarder constituted the majority of the total delay time, accounting **for** 43 and 85% of the delays **for** the two-age and patch cut units, respectively. The patch cut unit had some large mechanical problems with the yarder; **in** addition, the carnage type was changed three times. Consequently, over 50% of the average total cycle time **for** the patch cut unit was made up by delays. Twenty-seven percent of the average cycle time **for** the patch cut was attributed to mechanical delays. The clearcut and group selection units had no appreciable mechanical downtime observed **in** this study. Operational delays such as hang-ups with residual trees and deck management at landings were highest **in** the two-age unit (7.33% of the observed time), compared with 1.63% **in** clearcut, 0.43% **in** patch cut, and 0.26% **in** group selection units.

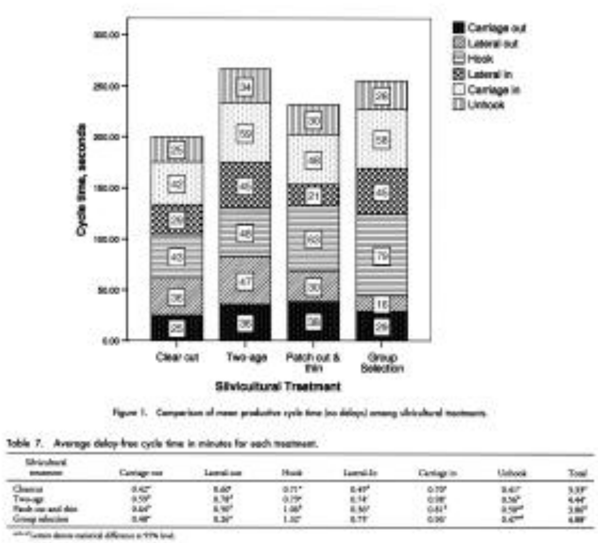

Figure 1. Comparison of mean productive cycle time (no delays) among silviculture!

In the overall operation, road changes (moving the skyline cables to the next corridor) accounted **for** between 11 and 20% of the total observed operating treatments.Table 7. Average delay-free cycle time in minutes for each treatment.

time. The time spent to prerig the next corridor was not included **in** the road changes because it was done independently from **yarding** activities. Pulling the strawline was treated as a working delay only if it interfered with **yarding** activities. Less time was spent on road changes **in** the clearcut unit than any of the other units (Figure 3). Because there were no standing trees between the corridors **in** a clearcut, the cables did not have to be pulled all the way back to the yarder before moving to the next corridor. The shorter **yarding** distances **in** the clearcut and group selection units contributed to fast road change times. The fast road change times and the low delay times **in** the clearcut resulted **in** the highest utilization rate (productive machine hour [PMH]/SMH, 87%). **In** contrast the two-age unit had the lowest utilization (73%) because of increased operational delays (i.e., hang-ups) and high percentage of road change time. The patch cut and group selection units had utilization rates of 76 and 85%, respectively.

Carriage Type and **Yarding** Direction

In the patch cut unit, three different types of carriage were used during the **yarding** operation and this affected **yarding** **production**. The **grapple** carriage required significantly (Tukey HSD, $P < 0.0001$) lower average cycle time than other carnages, and the motorized and MSP carriage had similar average cycle times (Table 10).

Although the cycle times **for** the **grapple** carriage were lower, the **production** rate with that carriage was low because the **grapple** carriage could yard only 1 tree/cycle. The motorized and MSP carriages yarded between 1 and 7 logs or trees/cycle. The **grapple** carriage would have to reduce its average cycle time by 1.16 minutes to equal the productivity of the other types of carriages. Felling pattern also affected the efficient use of carriages. When the trees were felled perpendicular to the contours of the hill, it was difficult **for** the **grapple** carriage to be quickly positioned on a log. If the trees had been felled parallel to the contour it would have been more conducive **for** the use of a **grapple** carriage.

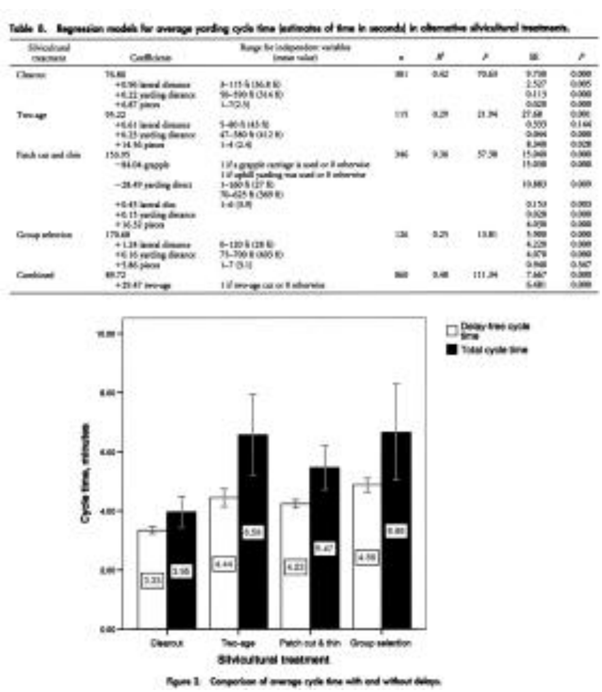

Table 8. Regression models for average yarding cycle rime (estimates of rime in seconds) in alternative silviculhiral

This study showed that position of the yarder at either the top or the bottom of the slope had a statistically significant ($P < 0.0001$) impact on yarder productivity. The average cycle time **for** uphill **yarding** was on the treatments.Figura 2. Comparison of average cycle rime with and without delays.

average

approximately 37 seconds shorter than the average cycle time **for** downhill **yarding**. This equated to approximately an extra 16 turns/day, or an additional 4.18 mbf/day, assuming an average number of 2.6 logs/turn and an average log volume of 100.6 bd ft. A lower harvesting cost might have resulted if access to landings at the top of the slope were built relatively inexpensively at a low environmental impact.

Table 9. Comparison of average cycle time with and without delays.

Silvicultural treatment	Delay-free time[a]	Total cycle time	Difference[b]	t-Statistic	P-value
Clearcut	3.53	3.95	−0.42	−2.369	0.019
Two-age	4.44	4.57	−0.13	−3.157	0.002
Patch cut and thin	4.23	5.47	−1.24	−5.968	0.001
Group selection	4.79	6.57	−1.78	−2.166	0.032

[a] [illegible]
[b] [illegible]

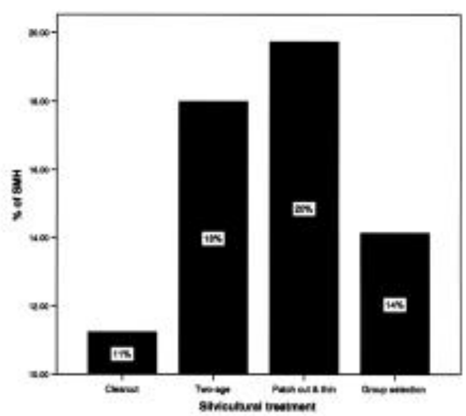

Figure 3. Average time spent on skyline road changes expressed as a percentage of SMHs by silvicultural treatment.

Table 9. Comparison of average cycle time with and without delays.Figure 3. Average time spent on skyline rood changes expressed as a percentage of SMHs by silvicultural treatment.

Yarding Cost

Yarding costs ranged from $37.19 to 76.51/mbf, with the patch cut and thin having the lowest cost per unit volume (Table 11). The number of pieces per turn was consistent **for** all units

Table 10. Average cycle time without delays by carriage types used in the patch cut and thin unit.

Carriage type	Average delay-free cycle time (min)	Average pieces per turn	Potential production rate[a] (mbf/hr)
Motorized	4.06	2.43	4.0
MSP	4.23	2.95	4.7
Grapple	2.59[b]	1.00	2.6

[a] Potential production = number of cycles per hour × avgerage pieces/cycle × 0.1116 mbf/piece.
[b] Denotes statistical difference at 95% level.
Volume per piece = the mean volume for the pieces removed from the patch cut and thin unit.

at

Table 10. Average cycle time without delays by carriage types used in the patch cut and thin unit.

approximately 2.5 trees/turn, except when a **grapple** carriage was used. The **grapple** carriage yarded 1 tree/turn. Although the clearcut unit had the fastest average cycle time, it had the second-highest cost as it was observed **in** this study because the average volume per piece was lowest (69.6 bd ft/piece) **in** the clearcut unit. The average piece sizes **in** the patch cut and two-age treatment were nearly twice that of the clearcut (Table 11).

The stand conditions varied between silvicultural treatment units (Table 1). To determine the effect of silvicultural treatments on the harvesting cost, we standardized the variables that were contained within the parameters of the developed models. On this standardized basis, the clearcut unit had the lowest cost of $46.10/mbf (Table 12). The group selection treatment had the highest cost because of the highest average time per cycle and the second-lowest volume per piece. This unit had a relatively low harvest intensity (10.7 mbf/ac), which required increased time **for** moving and setting up the yarder and minimizing residual stand damage.

When all the phases (felling, **yarding**, processing, and loading) of harvesting were considered, using the standardized harvesting variables based on potential **production**, the clearcut had a stump-to-truck cost of $81.99. The group selection treatment had the highest stump-to-truck cost of the four treatments, 31% higher than the clearcut. **In** between were the two-age treatment and the patch cut, which were 22 and 13% higher, respectively (Table 13). Potential **production** is used to illustrate more clearly the differences between silviculture treatments by removing the effects of

Table 11. Comparison of yarding cost ($/mbf) by silvicultural treatment unit as observed.

Treatment	Cycle time (including delays) (min)	Average volume per piece (mbf)	Average no. of pieces per cycle	Yarding productivity (mbf/PMH)	Yarding cost ($/mbf)
Clearcut	5.74	0.0696	2.5	3.79	52.88
Two-age	6.82	0.1265	2.4	3.02	48.29
Patch cut and THIN	6.42	0.1116	2.6	3.05	37.19
Group selection	5.96	0.0757	2.5	1.91	76.51

Table 12. Comparison of yarding cost between silvicultural treatment units.

Silvicultural treatment	Delay-free cycle time (min.)	Yarding rate (turns/PMH)	Hourly production (mbf/PMH)	Yarding cost ($/mbf)	% Difference over clearcut
Clearcut	3.41	17.58	4.55	46.18	—
Two-age	3.92	15.31	3.96	52.94	15%
Patch cut and thin	3.95	15.26	3.95	53.11	15%
Group selection	4.73	12.68	3.27	63.81	39%

The yarding productivity was estimated using the individual regression equation for each treatment.
This comparison was done based on uphill yarding with a [illegible] carriage and the standardized values (yarding distance, [illegible] ft; lateral distance, [illegible] ft; pieces per turn, [illegible]; and volume per piece, [illegible]). The hourly machine cost for yarding was [illegible].
PMH, productive machine hour.

Table 13. Comparison of the stump-to-truck harvesting cost with the standardized cost for yarding using the individual regression equation for each treatment.

Silvicultural treatment	Harvesting cost ($/mbf)					% Difference over clearcut
	Felling[a]	Yarding	Processing	Loading	Total	
Clearcut	6.42	46.10	7.68	21.79	81.99	—
Two-age	17.74	52.94	7.68	21.79	100.15	22%
Patch cut and thin[b]	10.12	53.11	7.68	21.79	92.70	13%
Group selection[c]	13.83	63.91	7.68	21.79	107.21	31%

[a] Felling is assumed to be done by mechanized methods.
[b] Sixty-six percent of the felling was done by manual methods.
[c] Thirty-three percent of the felling was done by manual methods.

Table 11. Comparison of yarding cost ($/mbf) by silvicultural treatment unit as observed.Table 12. Comparison of yarding cost between silviculture! treatment units.Table 13. Comparison of the slump-to-truck harvesting cost with the standardized cost for yarding using the individual regression equation for each treatment.

downtime. This follows the pattern that was seen **in** the **yarding** cost because **yarding** was the most costly of the harvesting cost components.

Conclusion

The difference **in** silvicultural treatments greatly affected the cost and **production** of harvest operations, especially **in** felling and **yarding** **production**. **In** silvicultural treatments that had higher levels of residual trees and had those residuals uniformly dispersed throughout the cutting blocks (i.e., no large openings), the **production** of both felling and **yarding** operations was observed to decline due to the increased care needed to avoid damage to residual trees. This study clearly showed that there was an increase **in** felling cost **for** both manual and mechanical felling methods as the amount of residual timber increased. Silvicultural treatment had its biggest impact on **yarding** productivity and cost because of increased time **for** skyline road changes and **yarding** cycles. As expected, the stand with the lowest number of residual trees per acre resulted **in** the shortest amount of time spent **for** road changes.

Average tree size, **yarding** direction, carriage type, and felling patterns all interacted with silvicultural treatment to influence total harvesting cost. Because of different initial stand conditions or smaller average tree diameters clearcut did not result **in** the lowest costs, as would be expected. **In** this study the patch cut had the lowest **yarding** cost ($24.73/mbf) and lowest total stump-to-truck cost ($70.49/mbf), and the clearcut had the third-lowest **yarding** cost ($52.38/mbf) and second-lowest total stump-to-truck cost ($89.22/mbf). This difference was caused by mainly the differences **in** tree size of the two units. As the size of the logs increase, **yarding** productivity was significantly increased without impacting on overall average **yarding** cycle time.

The type of carriage used should be matched to felling methods and operational conditions. The data showed that the **grapple** carriage was less productive than the other **yarding** systems used, especially when trees were felled perpendicular to the contour. The fellers assumed that a motorized or MSP carriage was going to be used. Instead, the **yarding** contractor decided to use a **grapple** carriage and spent much time to cast or pivot the **grapple** carriage to hook the logs. Had the timber been felled along the contour rather than perpendicular to the contour, the **grapple** carriage would have been much more efficient and the findings might have been different. Yarder location was another factor that affected the total cost of harvest. When **yarding** downhill, **yarding** productivity was notably reduced because of the care needed to keep the logs under control while moving them downhill.

Under a scenario of uniform initial conditions among the stands, we found that the clearcut, as expected, would return the lowest logging cost, followed by the two-age and patch cut harvest, with a group selection harvest being the highest cost alternative. Harvesting cost increased as tree retention levels increased (i.e., decrease of the number of trees removed per acre) and as the retained trees were more interspersed throughout the cutting unit (i.e., large openings [≥ 1.5 ac] were not used).

References

Literature Cited

ARNOTT, J.T., AND WJ. BREESE. 1997. Alternatives to clearcutting **in** BC **coastal** montane forest. **For**. Chron. 73(6):670-678.

CONWAY, S. 1982. Logging practices: Principles of timber harvesting systems, revised edition. Miller Freeman, Inc., San Francisco, CA. 432 p.

COULTER, K.M. 1999. The effects ofsilvicultural treatments on harvesting **production** and cost. MS thesis, Univ. of Idaho, Moscow, ID. 113 p.

CURTIS, R.O., D.S. DEBELL, C.A. HARRINGTON, O.P. LAVENDER, J.B. ST. CLAIR, J.C. TAPPEINER, AND J.D. WALSTAD. 1998. Silviculture far multiple objectives **in** the Douglas-fir region. USDA **For**. Serv. Gen. Tech. Rep. PNW-GTR-435, Pacific Northwest Research Station, Portland, OR. 123 p.

DAIGLE, P.W. 1992. Financial aspects of alternative harvest cutting methods and silvicultural treatments: A literature review. FRDA II Rep., **British Columbia** Ministry of Forest, Victoria, BC. 51 p.

HOCHREIN, P.H., AND L.D. KELLOGG. 1988. **Production** and cost comparison **for** three skyline thinning systems. West. J. Appl. **For**. 3(4):120-123.

HOWARD, A.F., D. RUTHERFORD, AND G.G. YOUNG. 1996. The productivity and cost of partial and clear cutting with two cable **yarding** systems **in** second-growth forest of costal **British Columbia**. WP-6-015, Univ. of **British Columbia**, Vancouver, BC. 56 p.

JOHNSON, M. 2002. Combining social and ecological needs on federal lands: A global perspective. P. 104-108 **in** Proc. of the 2001 National Silviculture Workshop, May 6-10, 2001, Hood River, OR, Parker, S., S.S. Hummel (comps.). PNW-GTR-546, Portland, OR.

KEEGAN, C.E. Ill, C.E. FIEDLER, AND FJ. STEWART. 1995. Cost of timber harvest under traditional and "new forestry" silvicultural prescriptions. West. J. Appl. **For**. 10(l):36-42.

KELLOGG, L.D., P. BITTINGER, AND R.M. EDWARDS. 1996a. A comparison of logging planning, felling and skyline **yarding** cost between clearcutting and five group selection harvesting methods. West. J. Appl. **For**. 11(3):90-96.

KELLOGG, L.D., G.V. MILOTA, AND M. MILLERJR. 1996b. A comparison of skyline harvesting cost **for** alternative commercial thinning prescriptions. /**For**. Eng. 7(3):7-23.

KELLOGG, L.D., G.V. MILOTA, AND B. STRINGHAM. 1998. Logging planning and layout costs **for** thinning: Experience from the Willamette Young Stand Project. Forest Research Laboratory. Oregon State Univ., Corvallis, OR. Res. Cont. 20. 20 p.

KLUENDER, R., D. LORTZ, W. McCov, B. STOKES, ANDJ. KLEPAC. 1998. Removal intensity and tree size effects on harvesting cost and profitability. **For**. Prod. J. 48(1):54-60.

McNEEL, J.F., AND K. DODD. 1996. A survey of commercial thinning practices **in** the **coastal** region of Washington State. **For**. Prod. J. 46(11/12):33-39.

MIYATA, E.S. 1980. Determining fixed and operating cost of logging equipment, USDA **For**. Serv. Gen. Tech. Rep. NC-55, North Central Forest Experiment Station, St. Paul, MN. 16 p.

REUTEBUCH, S.E., C.A. HARRINGTON, D.D. MARSHALL, AND R.O. CURTIS. 2002. Silvicultural options **for** multipurpose management of west-side Pacific Northwest forests. P. 38-46 **in** Proc. of the 2001 National Silviculture Workshop. May 6-10, 2001, Hood River, OR, Parker, S., S.S. Hummel (comps.). PNW-GTR-546, Portland, OR.

SAS. 2001. Statistical analysis system, version 8.02. SAS Institute, Inc., Cary, NC.

WANG, J. 2001. Time study data logger-computer program. West Virginia Univ., Morgantown, WV.

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