Helicopter Logging Productivity on Harvesting Operations in Southeast Alaska, Using Ecologically Based Silvicultural Prescriptions

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ABSTRACT

This study examines production rates and costs for felling and helicopter yarding on eight units harvested in accordance with ecologically based silvicultural prescriptions in southeast Alaska. The prescriptions included harvesting to create gaps, harvesting to leave trees in clumps, individual tree selection, and combinations of these treatments. In combination, the treatments represented five levels of basal area (BA) retention. The levels of retention had irregular spatial arrangements caused by gaps and clumps that ranged from 0% retention (clearcut) to 75% of BA retained. Turn time (TT), as adjusted to a standardized distance, and turn weight were used as the basis for estimating productivity. There were statistically significant differences in adjusted TT, depending on the treatment. Areas with higher levels of removal tended to have lower adjusted TTs. With the exception of one unit with a short yarding distance, average turn weights increased as levels of retention decreased. Weighted average cost per thousand board feet (mbf) harvested was $322. The cost per mbf for cutting and yarding together ranged from $305 to $353.

Keywords: logging costs, partial cut, yarding, Tongass

The Record of Decision of the Tongass Land and Resource Management Plan (TLMP) committed USDA Forest Service Region 10 in Alaska to "ensure that silviculture systems other than clearcutting are considered through an appropriate project level analysis process" (USDA Forest Service 1997). In accordance with this commitment, the Pacific Northwest Research Station and Region 10 cooperatively established an interdisciplinary study to evaluate alternative silvicultural systems. A detailed outline of the alternatives to clearcutting (ATC) project is contained in a study by McClellan et al. (2000).

The ATC study has three replications of eight treatments, designed in total to examine a range of ecological impacts on stream productivity, avian biology, slope stability, and biodiversity conditions. The sites in this study are part of the second ATC replication located on Kupreanof Island in Alaska.

One of the objectives of the ATC project is to evaluate silvicultural systems currently being considered for use by practicing silviculturists in the Alaska region. Helicopter yarding was determined to be the only method suitable for all planned treatments (McClellan et al. 2000). The decision to conduct a helicopter logging study was made shortly before the start of the harvesting operation. The desire to determine if there were cost differences among the silviculture prescriptions created this secondary objective. Thus, this article provides an analysis of the impact of eight different silvicultural prescriptions on helicopter logging cycle times, loads, and costs.

Literature Review

There have been few published time and cost studies of partial cutting operations using helicopters in old-growth Sitka spruce (*Picea sitchensis* [Bong.] Carr.) and western hemlock (*Tsuga heterohylla* [Raf.] Sarg.). Dykstra (1975) suggested a general framework for analysis of helicopter logging studies. In the Dykstra methodology, productive yarding time is defined as a function of yarding distance (YD), volume per turn, and number of logs per turn. Productive time is influenced also by chord slope (percent) and tagline length. The tagline is a long cable suspended below the helicopter to which the load of logs is attached.

The Forest Engineering Research Institute of Canada (FERIC) conducted a study of helicopter production in old-growth Sitka spruce and western hemlock stands in coastal British Columbia (Krag and Clark 1995). In the FERIC project, production times for clearcutting, patch-cutting, and single tree selection were compared. When comparing treatments that created clumps, gaps, and single tree selection, the study determined that average collection and travel time increased as the number of residual trees increased for both aggregated (clumps and gaps) and dispersed (single tree retention) removals. Retention levels (number of trees left standing) were of secondary importance to the distribution of retained stems (i.e., in 25% clearcut versus 25% single tree selection). Average turn weight did not vary significantly until high levels of retention (85%) were reached.

In another publication, Lyons (1998) evaluated helicopter production in northern Washington. He suggested measuring the effect of treatment prescriptions by tracking changes in logging productivity.

Project Area

The second ATC replication site (Portage Bay) is located in the Missionary Valley on northeastern Kupreanof Island and is approximately 12 miles northwest of Petersburg, Alaska (Figure 1). The TLMP designates this area as a timber production site. The terrain

Received January 30, 2006; accepted July 10, 2006.

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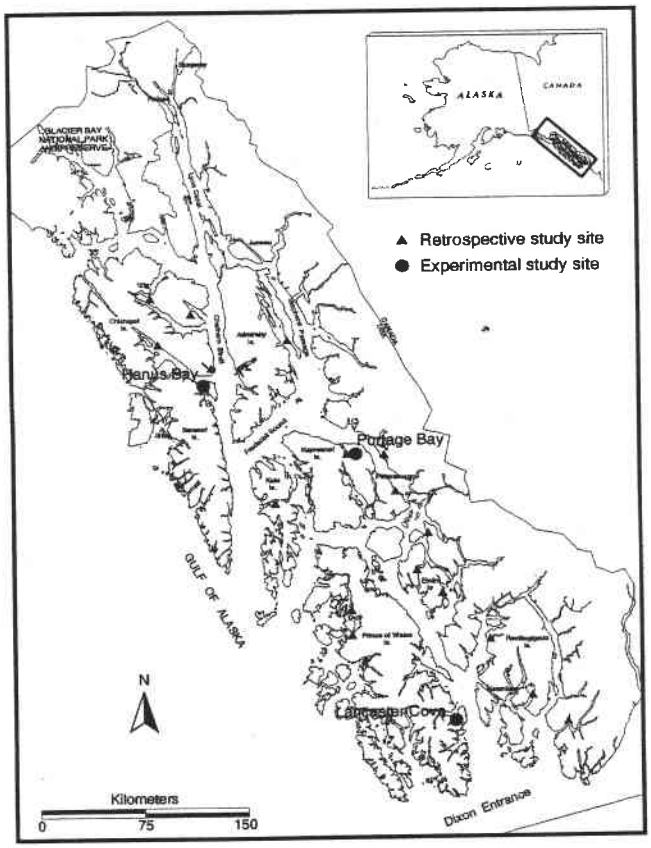

Figure 1. Map of southeast Alaska showing location of Portage Bay ATC site.

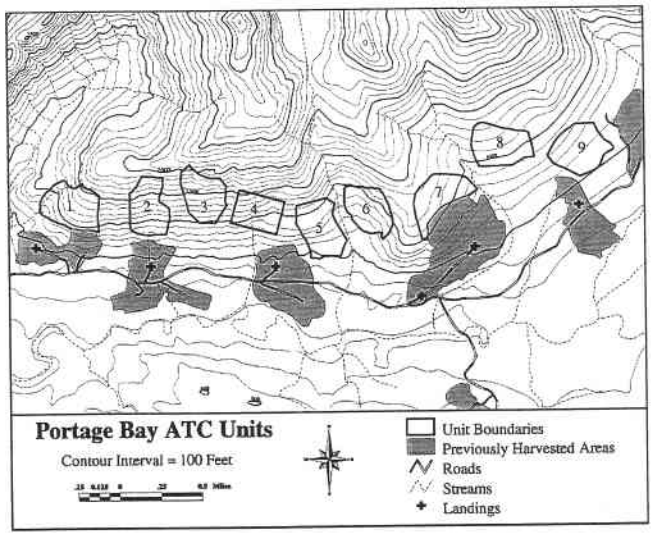

Figure 2. Replication two, ATC units at Portage Bay, Alaska.

in the area is characterized as steep, north-facing mountain slopes with a few glacial cirque lakes and alpine ridgeline. The existing road system connects the study units with the Portage Bay log transfer facility. A contour map showing the positions of treatment units is provided as shown in Figure 2.

The study area has been divided into eight harvest units. Each harvest area has been prepared so that it is representative of a retention or harvesting strategy and a level of basal area (BA) retention. The harvesting strategies include individual tree selection (ITS), gaps, clumps, and clearcut. Gaps are small openings created by

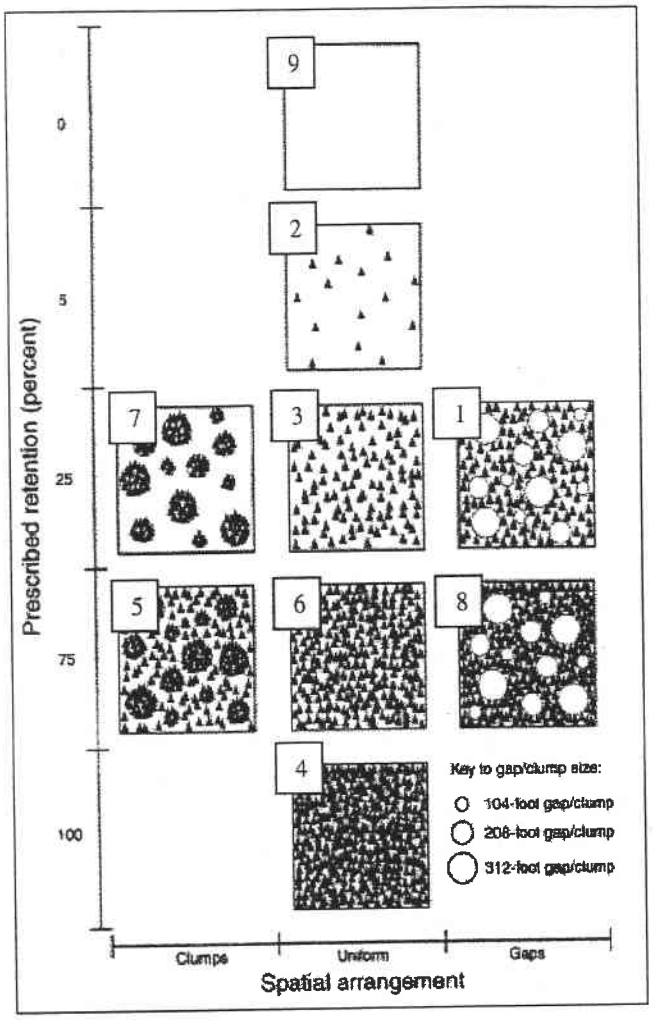

Figure 3. Schematic representation of ecological prescriptions ATC project (McClellan et al. 2000). The numbers next to each box refer to the harvest unit.

removal of timber. Clumps are small groups of trees left between areas of clearcut timber. All merchantable timber 9 in. dbh and larger was removed from the clearcut unit and patch clearcut areas. All timber less than 9 in. dbh was left standing in the woods. In addition, two of the treatments included thinning in the matrix surrounding the gaps or within the residual clumps. The degree of thinning in the matrix was designed so that the weighted average (area basis) BA for the unit was at a specified value. Figure 3 presents a schematic version of the treatments. A control unit was designated so that future conditions in the control and harvested areas can be compared.

Logging Crew Organization

The equipment used in this operation consisted of a Sikorsky 61N helicopter with a target payload of 7,500 lb when operating at elevations between sea level and 3,000 ft. Support equipment included an on-site service trailer with fuel, one support helicopter for shuttling fallers and helihookers, and one loader for decking material and loading trucks on the landing. Logs were decked but not sorted on the landing. Occasionally, the capacity of a specific landing was reached and logs were flown to an alternative landing. The ground crew consisted of four to nine individuals and a foreman. On any given day, one-half of the personnel were in the units setting

chokers and hooking the turns. The second half of the crew was on the landing unhooking the turns, coiling the chokers, limbing, and painting and branding logs.

An important caveat to consider is that the labor retained to harvest and set chokers had limited training and experience with helicopter-based operations. Throughout the study there was constant turnover of crewmembers, so that few of the workers on the ground gained significant experience in this type of operation.

Data Collection

Our objective was to create a data set that allowed analysis in accordance with Dykstra's (1975, 1976) concept of productive yarding time. Dykstra's original approach assumed direct timing of the yarding cycle components (travel time from landing to cutting unit, choker hookup, travel time to landing, and log drop at the landing). Because of a lack of personnel, the data collection process for this project did not use a direct timing of components approach. The following sections describe how data were converted to the format specified by Dykstra.

Documentation available for data collection and reduction in this study consisted of the following:

Cutter report. A report prepared daily by each cutting crew that included the number of trees and logs cut from a specific cutting unit. The cutter report was supplemented by observational data collected by project members to provide a more detailed view of on-the-ground conditions.

Cycle sheet. This report, maintained by the helicopter pilots, contained information relative to each turn. Specific information included: turn number, number of logs per turn, weight per turn in thousand pound units, and a code to record the reason for any aborted lifts. It should be noted that the load weight included the weight of limbs, cables, and hook, as well as the weight of the merchantable logs. All data in this record were referenced to ATC unit number and landing. Cycle time recorded on this report was for multiple turns (a "cycle" as used by the helicopter crew was the time between successive refueling stops). Although an average turn time (TT) could be calculated, it was not possible to determine the specific time for each turn in accordance with Dykstra's (1975, 1976) suggested methods.

Daily flight report. The pilot's daily flight report included the following numeric information: number of turns per cycle, number of logs per cycle, weight lifted per cycle, turns per cycle, cycle time, and flight time. These items were totals copied from the cycle sheet. Additional items recorded on the flight report included down time, reasons for down time, and time spent using the support ship.

YD. Twenty points were spatially located in each cutting unit using a global positioning systems (GPS). GPS coordinates were collected also for each landing. On a daily basis, maps were supplied to the crewmembers. Helihookers located GPS coordinates closest to load pickup points and landing drop points on the supplied maps. A single GPS coordinate was used for a group of turns and represented the approximate centroid of an area from which timber was harvested around that point. Because the crews worked in the same area for several hours, time of day was used to match the GPS coordinates to the harvested units. Average YD was calculated as the straight-line distance between the pair of GPS coordinates.

As noted previously, the cycle times collected by the pilots represent multiple turns. Initially, average time per turn was calculated by dividing cycle time by the number of turns. The calculated average TT is a function of all the factors included in Dykstra's (1975, 1976) concept of productive yarding time, including YD. For the purposes of this study, we assumed that there was a linear relationship between YD and average cycle time. Implicit in this assumption is that acceleration and deceleration, which are nonlinear components of total travel time, are either not significant or they can be incorporated adequately into the constant term of the regression equation. Thus, a simple linear regression of time versus distance was used as the basis for adjusting all YDs to a standard distance. The selected standard was the weighted average distance for all YDs (2,097 ft). This relationship was highly robust and yielded the following equation:

$$TT = 2.194 + 0.00032\ YD$$

where TT is in minutes and YD is in feet. The value of $R^2 = 0.224$, the Student's t-value for the YD coefficient = 68.467, and the regression SE = 0.3704.

Given this equation, we assumed that the coefficient 0.0032 represented the linear relationship between distance in feet and TT in minutes and that the constant term 2.194 incorporated all nonlinear elements including acceleration, hooking, and unhooking time. Based on this relationship, all TTs were adjusted to the average YD by adding time to any distance below the average and subtracting time from any distance above the average. In the following analysis, this time-related variable is referred to as adjusted time. Using this approach, the average adjusted time was equal to the original average TT. The SD of adjusted TTs was less than that for TT.

Analysis

The observed harvesting operation had two distinct stages. Stage 1 included felling and bucking. Stage 2 was helicopter yarding. Cutting reports were prepared on a daily basis and allowed calculation of the average number of trees cut on an hourly and daily basis. Visual observations were available relative to the relationship between timber size and terrain conditions such as slope and roughness and their possible relationship to productivity. Although average rates can be calculated, the data were not collected in a manner that facilitated any additional meaningful statistical analyses. We have elected to include costs for cutting in this study for reference purposes.

The information from the flight reports was processed to calculate average TT, adjusted TT as described previously, load weight, and YD. The harvesting unit from which each load originated was determined from the helicopter pilots' cycle sheets. Analysis of variance (ANOVA) was used to perform the statistical testing. Duncan's multiple-range tests were used to determine differences between group means. Variables subject to ANOVA included adjusted TT and average load weight. We used release 12.0.1 of the Statistical Package for the Social Sciences (SPSS, Inc. 2003) for the statistical analyses.

Results

In all the presented tables, basic statistical information relative to standing timber and harvest volumes from the units is available from multiple sources. We used data from the cutter report and helicopter

Table 1. Unit information relative to the felling and bucking phase.

Unit	Prescription and explanation[a]	Unit area (ac)	Preharvest ecological cruise volume[b] (mbf/ac)	Functional description	Calculated percent of preharvest volume removed (%)	Rate of harvest[c] (trees/hr)	Recorded comments and observations
1	BA retained 25% gaps of 104, 208, and 312 ft diameter, surrounding matrix cut with ITS	38	66.9	Small clearcut, heavy ITS	81	23	
2	BA retained 5% ITS	28	70.2	Functional clearcut	109	27	Rock outcroppings rough; larger timber
3	BA retained 25% ITS	31	71.1	Near clearcut	68	23	
4	BA retained 100% control, undisturbed	41		Control	0	Control	Control
5	BA retained 75% clumps of 104, 208, and 312 ft diameter, surrounding matrix cut with ITS	37	41.1	Light ITS	33	16	Heavy residual stand
6	BA retained 75% ITS spread evenly across 25% BA	41	50.6	Light ITS	23	15	Heavy residual stand; longest YD
7	BA retained 25% clumps of 104, 208, and 312 ft diameter remaining	35	32.8	Near clearcut	85	30	Larger timber
8	BA retained 75% gaps of 104, 208, and 312 ft diameter	43	38.8	Small clearcuts	29	31	Larger timber
9	BA retained 0% clearcut by cutting all trees over 9 in. diameter	40	36.0	Complete clearcut	100	23	Least slope; smaller timber; shortest YD

[a] BA = basal area and ITS = individual tree selection. BA retention values in this column were targets that may not have always been achieved. All trees less than 9 in. dbh were left standing in all units. Trees over 9 in. dbh were left evenly spaced in units with ITS.
[b] Volume in trees greater than 1 in. dbh.
[c] Information gathered from cutting report.

Table 2. Unit information relative to the helicopter-yarding phase.

Unit	Estimated volume removed[a] (mbf/ac)	Percent removed[b] (%)	Average YD (ft)	Unadjusted average TT (min)	Distance-adjusted average TT[c] (min)	Average load weight per turn (lb)	Lifting aborts/100 mbf logged (aborts/100 mbf)	Production per adjusted time[a] (mbf/hr)
1	54.3	81	1,711	2.58	2.71	6,551	1.5	13.186
2	76.5	109	1,887	2.95	3.02	6,828	1.0	12.332
3	48.3	68	2,831	3.11	2.88	6,464	1.5	12.243
4	N/A	N/A	N/A	N/A	N/A	N/A	Control	Control
5	13.6	33	2,105	2.88	2.88	5,892	1.3	11.159
6	11.4	23	3,187	3.25	2.90	6,339	1.8	11.923
7	28.0	85	2,023	3.07	3.09	6,834	1.7	12.063
8	11.1	29	3,121	3.08	2.76	6,214	1.5	12.280
9	35.9	100	1,487	2.51	2.71	6,501	0.8	13.084
Weighted average			2,097					

[a] An average weight of 11,000 lb/mbf was used based on gross scale and total weight supplied by the helicopter operator.
[b] Percentage value based on volume from the helicopter report and total volume from the sale prospectus.
[c] Average TTs at the weight average YD of 2,097 ft.

cycle sheets whenever possible. Data from other sources are identified as such when presented.

Cutting Data

Table 1 presents data relative to the felling and bucking phase of the operation. Quantitative data is presented to describe basic stand conditions and number of trees harvested per man-day. Observations relative to terrain conditions, sequence of harvesting, and timber conditions are presented also in later tables for reference purposes.

Helicopter Yarding

Table 2 contains basic information relative to the helicopter-yarding phase of the operation, including production rates (thousand board feet [mbf] per hour). The total load weight and total scale data provided by the flight operators were used to calculate the factor of 11,000 lb/mbf.

Group means for adjusted TT were tested using ANOVA and were partitioned into groups using Duncan's multiple-range test. There was a highly significant difference between adjusted TTs. Table 3 presents the significant grouping resulting from using Duncan's test. The eight units were combined into five significantly different groups. Lowest average adjusted TT occurred on the clearcut block. There does not appear to be any meaningful relationship between the various gap, cluster, or ITS treatments.

Group means for average lifted weight per turn were analyzed. There was a highly significant difference between the turn average lift weights. Average values for this variable are presented in Table 2, with significant groupings for the variable as determined from Duncan's test shown in Table 4. The eight units represent five significantly different and independent groups. In all cases, average weight per turn from the units with high levels of BA retention was lower than those from areas with a high level of volume removal.

Table 3. Duncan's multiple-range test on adjusted average TTs.[a]

Unit	Ecological description and target retention (BA%[b])	Volume removed[c] (%)	N[d]	Subset for alpha = 0.05				
				1	2	3	4	5
9	Clearcut (0%)	100	2,443	2.7062				
1	Gaps, heavy ITS in matrix (25%)	78	3,481	2.7124				
8	Gaps (75%)	27	846		2.7564			
3	ITS (25%)	68	2,558			2.8786		
5	Clumps, light ITS in matrix (75%)	32	944			2.8786		
6	ITS (75%)	23	853			2.8987		
2	ITS (5%)	104	3,467				3.0203	
7	Clumps (25%)	82	1,583					3.0924

[a] Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size = 1475.642. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
[b] The BA% is the BA retained as a percent of initial basal area.
[c] Percentage value based on volume from the helicopter report and total volume from the sale prospectus. In unit 2 the cruise volume was less than the removed volume.
[d] N = number of observations.

Table 4. Duncan's multiple-range test on average turn weight.[a]

Unit	Ecological description and target retention (BA%)	Volume removed[b] (%)	N	Subset for alpha = 0.05				
				1	2	3	4	5
5	Clumps, light ITS in matrix (75%)	32	944	5,892				
8	Gaps (75%)	27	846		6,213			
6	ITS (75%)	23	853			6,339		
3	ITS (25%)	68	2,558				6,464	
9	Clearcut (0%)	100	2,443				6,500	
1	Gaps, heavy ITS in matrix (25%)	78	3,481				6,550	
2	ITS (5%)	104	3,467					6,828
7	Clumps (25%)	82	1,583					6,833

[a] Means for groups in homogeneous subsets are displayed. Uses harmonic mean sample size = 1475.642. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
[b] Percentage value based on volume from the helicopter report and total volume from the sale prospectus. In unit 2 the cruise volume was less than removed volume.

Table 5. Estimated direct cost for cutting and yarding.

Unit	Prescription	Functional description	Calculated percent stand volume removed[a] (%)	Recorded comments and observations	Total yarding cost[b] ($/mbf)	Cutting cost ($/mbf)	Total cost ($/mbf)
1	Gaps BA retained 25%	Small clearcut, heavy ITS	78		277.51	27.53	305.04
2	ITS BA retained 5%	Functional clearcut	104	Rock outcroppings rough; larger timber	296.71	24.76	321.46
3	ITS BA retained 25%	Near clearcut	65		298.88	30.92	329.80
4	Control BA retained 100%	Control	0	Control unit			
5	Clumps BA retained 75%	Light ITS	32	Heavy residual stand	327.90	25.27	353.17
6	ITS BA retained 75%	Light ITS	23	Heavy residual stand; longest YD	306.89	24.33	331.22
7	Clumps BA retained 25%	Near clearcut	82	Larger timber	303.32	29.85	333.17
8	Gaps BA retained 75%	Small clearcut, no adjacent volume	27	Larger timber	297.97	17.06	315.03
9	Clearcut BA retained 0%	Complete clearcut	95	Least slope; smaller timber; shortest YD	279.66	38.03	317.69
Weighted average value							322.00

[a] Percentage value based on volume from the helicopter report and total volume from the sale prospectus.
[b] Based on helicopter cost of $3,500/hr.

Cutting and Yarding Costs

The calculated cutting and yarding costs are presented in Table 5. We calculated the costs based on estimated volumes from the flight report using adjusted total time and weight per turn. As previously stated, all weight values from the flight reports were converted to mbf using a factor of 11,000 lb/mbf of logs. Total cutting and yarding costs ranged from $305 to $353/mbf. Weighted average cost, using block volume as the weighting factor, was $322/mbf. The average unweighted harvesting cost for all ITS units was $342.19/mbf as opposed to $320.36/mbf for other gap and clearcut systems.

Discussion

Obtaining perfect design and control of experiments conducted in natural stands is always difficult. In this project, the problem was compounded by the fact that the real objective was to evaluate the impact of silvicultural treatments on future environmental conditions and not the evaluation of the impact of the prescriptions on

helicopter logging costs. The reported study was designed to measure productivity resulting from silviculture prescriptions. However, productivity also is a function of crew training, experience, equipment, and efficiency and appropriateness of measurement methods.

Regardless, the statistical analyses of adjusted TT and load weight per turn were determined significant. As might be expected, the lowest adjusted TT occurred on the clearcut unit. When considering levels of retention or harvest, however, it is difficult to perceive any consistent relationship among the other treatment units. We are forced to conclude that other factors had a greater impact on productivity than the silviculture prescriptions themselves.

The analysis of average turn weights in Table 4 shows that the units with heavy levels of removal had greater average load weights than those for the lower levels of removal. This result is in general agreement with the statement by Krag and Clark (1995) that "turn weight did not vary significantly until levels of stand retention were 85 percent of stand volume."

Unit 9 is something of an anomaly when average turn weights are inspected. Under normal circumstances, a clearcut unit would be expected to have the highest turn weight, but this is not the case. The unit had the shortest YD and some of the smaller timber. Individuals with extensive helicopter logging experience have noted that for short YDs, the time between pickup cycles is so short that the choker setters have insufficient time between turns to select logs to obtain near maximum loads. Given the short YD and small timber, it was likely difficult for the ground crew to make up optimal loads.

The cost information in Table 5 is in general agreement with the foregoing measures of productivity. Unit 5, with a clump and ITS prescription and a target removal of 25% of BA, was the most expensive ($353/mbf) unit to operate. The second most expensive ($333/mbf) was unit 7. The level of removal for this unit was 82% of stand volume. Functionally, this unit was a "near clearcut." Volume per acre for this unit was low, but trees were larger. The trees were scattered and this made it difficult for the crew to build optimal loads. The third most expensive unit ($331/mbf) was unit 6, which had an ITS prescription designed to remove 25% of the volume.

The cost results indicate that helicopter logging continues to be an expensive method for harvesting timber. Use of helicopters will be limited to areas from which only high-value timber can be harvested (e.g., for export) or to areas where resource protection is the primary concern.

If future projects are undertaken to investigate the impact of silviculture prescriptions on logging cost, it is suggested that procedures recommended by Dykstra (1975, 1976) be used. Specifically, all time-related data must be collected so that cycle times (round-trip from landing to stump and return) are broken into components.

Management Implications

The units used in this analysis of helicopter logging were designed to test ecologically based silviculture prescriptions as an alternative to clearcutting. This study has been conducted to review the costs associated with helicopter logging and to determine whether significant differences could be detected among the various silvicultural prescriptions. There are many ecological or other nonmonetary benefits that may result from some of these prescriptions that have not been considered in this analysis.

One of the authors of this study has spent the past 10 years working on the Tongass National Forest and was actively involved with the TLMP of 1997. Many of the standards and guidelines of the plan can be implemented by the use of helicopter logging. However, it is obvious that the value of domestically processed timber does not support the added cost of helicopter logging as reported in this study. It is an excellent logging tool but helicopter logging is too expensive for operation in all but the highest-valued stands in Alaska or sales that receive export waivers for processing logs.

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