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Vol. 2 No. 58 October 2001

Contents

Partial cutting in a second-growth stand in British Columbia

Abstract

From 1997–1998, the Forest Engineering Research Institute of Canada (FERIC) conducted a partial cutting study in an immature hemlock stand in coastal British Columbia. The two partial cutting options used were commercial thinning and shelterwood harvesting. The results are presented in this report and include information on productivity and costs of the cable and ground-based harvesting systems used, effectiveness of falling and yarding techniques for the treatments, and information on post-harvest site disturbance, wind damage, and residual tree wounding.

Keywords

Partial cutting, Commercial thinning, Shelterwood cutting systems, Cable logging systems, Skyline systems, Second-growth forests, Immature western hemlock, Tree damage, Site disturbance, Productivity, Costs, Coastal British Columbia.

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Introduction

As harvesting becomes more restricted in the old-growth forests of coastal British Columbia, forest companies are considering methods that are less intrusive than clearcutting to secure public acceptance and sustain fibre supply. An array of harvesting options with variable retention are being evaluated or promoted as alternatives to clearcutting of both old- and second-growth forests. This study investigates the harvesting and economic implications associated with the partial cutting of immature western hemlock stands in coastal British Columbia. Specifically, it examines two partial cutting options for immature forests: commercial thinning and shelterwood harvesting. The results presented are based on data acquired during an operational trial conducted from January 1997 to October 1998 at the Port McNeill Timberlands of Weyerhaeuser Company Limited, on northern Vancouver Island. The study was funded by Forest Renewal BC.

Background

Commercial thinning involves harvesting a portion of the trees from immature stands to both enhance the value of the residual stand and acquire revenue from the material removed. Two removal patterns of commercial thinning are common: systematic and selective. Systematic removal is used in regularly-spaced row plantations commonly found in the southeast United States. Selective thinning, more typical to western North America, can target either the most valuable stems in the stand to maximize revenue (crown thinning), or the least valuable to maximize the residual stand value (low thinning). All thinning activities discussed in this report relate to low thinning.

The shelterwood system temporarily retains from 100 to 400 crop trees per hectare with desired characteristics such as species, form, and windfirmness. Residual trees can either be located in patches or uniformly distributed over the harvest site. Traditional shelterwood harvesting has the purpose of providing a seed source for natural regeneration, or protecting regeneration by reducing vegetative competition, moderating weather extremes (sun or snow), and reducing predation from insects such as the spruce weevil (Westerberg and Hannerz 1994). In addition, shelterwood harvests can preserve aesthetic values on sites with sensitive viewscapes. The shelterwood system was selected for the Port McNeill trial to assess its efficacy at spruce weevil control and wind stability.

Objectives

The specific objectives of the report are to:

- Evaluate productivity, cost and factors influencing combinations of cable and ground-based harvesting systems.
- Document the effectiveness of falling and yarding techniques for the treatments.
- Document extent, severity, and causes of post-harvest site disturbance, wind damage, and residual tree wounding.

Methods

Site and stand descriptions

The 48-ha study block, located on private land owned by Weyerhaeuser, is situated near the community of Port McNeill on Vancouver Island. The biogeoclimatic subzone for this area is Coastal Western Hemlock sub-montane very wet maritime (CWH vm1) (Green and Klinka 1994). Using the Canadian Pulp and Paper Association's terrain classification system (Mellgren 1980), the study block is characterized with a ground strength of Class 3, a ground roughness of Class 2, and a slope of Class 1.

The stand regenerated naturally following cable logging in 1941 and 1944, and evolved to a pre-harvest stand composition of approximately 80% western hemlock (*Tsuga heterophylla*), 15% amabilis fir (*Abies amabilis*), 4% Sitka spruce (*Picea sitchensis*) and 1% western red cedar (*Thuja plicata*) by basal area. Table 1 presents pre-harvest stand conditions for the entire study block and by

Table 1. Pre-harvest stand statistics

Treatment area	Density (trees/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	Average live crown ratio (%)	Average height to diameter ratio	Site index for western hemlock (m at 50 yr)
Control area	1 678	79.0	1 022	29	91.6	32
Cable comm. thinning	1 656	69.3	872	21	96.7	31
Ground-based SW100	1 433	66.7	860	20	96.2	31
Cable SW200	1 111	69.5	926	27	82.2	32
Cable SW300	956	84.1	1 150	30	75.3	33
Entire study block	1 650	70.0	950	n.a.[a]	n.a.[a]	33

[a] Not available.

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ISSN 1493-3381

the individual treatment areas. Figure 1 illustrates pre-harvest stand conditions on one of the treatment units.

The block was subdivided into five compartments (Figure 2). A control area was to remain untreated, two compartments were to be commercial thinned to a residual stocking of 450 trees/ha using two different harvesting methods (ground-based harvesting and cable yarding), and two other units were to be thinned as uniform shelterwood treatments of 200 and 300 trees/ha residual density using cable yarding. Final harvest for all four partial cuts was proposed at a breast height age of 73 years (20 years following treatment). A major wind event occurred part way through the trial and the density prescriptions for all the treatment units were subsequently modified. The ground-based commercial thinning unit, which was only partially felled prior to the windstorm, was changed from 450 trees/ha commercial thinning to 100 trees/ha uniform shelterwood (now SW100). The cable yarding area, prescribed at 450 trees/ha, was partially harvested before the storm. It was partitioned into two sub-units following the storm, one requiring windfall recovery and the other requiring both log and windfall recovery. Ground-based harvesting equipment was used on both sub-units for the final harvesting and cleanup activities. Post-harvest densities on all treatment units were lower than those initially prescribed due to the windfall.

Figure 1. Pre-harvest second-growth stand on SW300 treatment area.

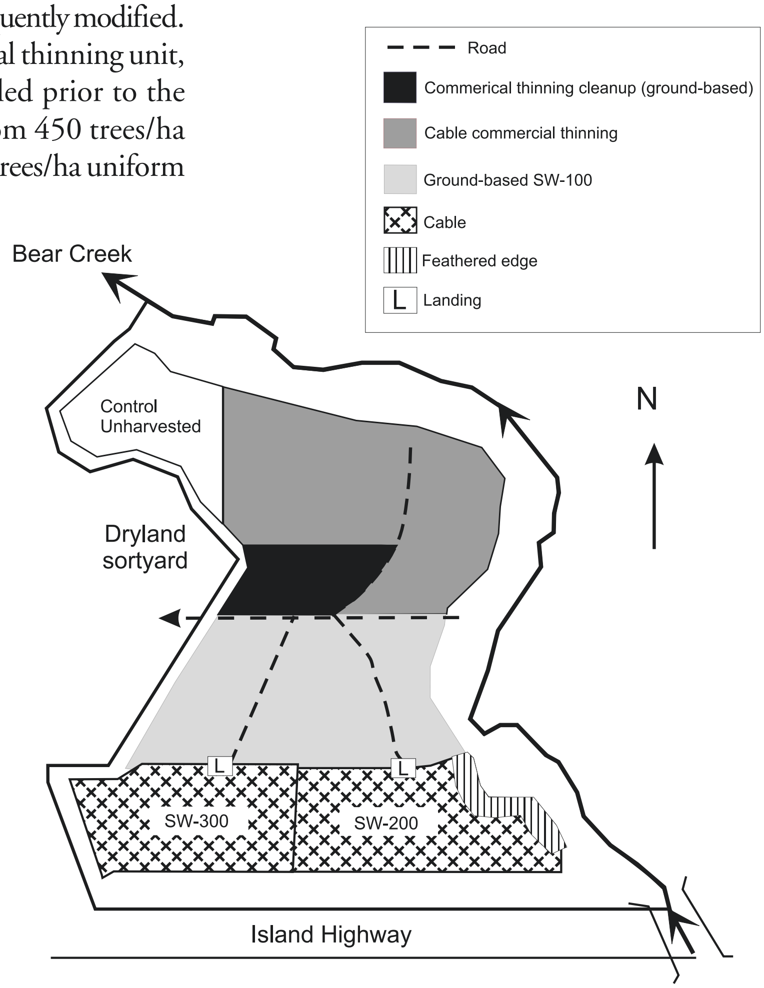

Figure 2. Map of study area.

Harvesting system and equipment descriptions

Two falling methods were used on the study block. Manual falling was used for the commercial thinning and SW100 areas. Mechanical falling using a Timbco 415 feller-processor equipped with a Pierce 220 head (Figure 3) was used on the SW200 and SW300 areas. The manual fallers had extensive experience with all aspects of commercial thinning. The operator of the

Figure 3. Timbco 415 harvester falling on the SW200 treatment unit.

Figure 4. Diamond D210 swing yarder with Maki II motorized carriage.

Figure 5. Hydraulic loader pre-bunching logs for yarder.

Figure 6. Ranger 667 skidder used to forward and sort yarded logs.

Timbco, although experienced with hydraulic excavator-based machinery, was new to mechanical falling in a partial cut.

The primary harvesting system selected for the cable treatments was a standing skyline cable system using a Diamond D210 swing yarder and a Maki II motorized slack pulling carriage (Figure 4). Narrow skyline corridors (3–4 m wide) were located 30–40 m apart, depending on the location of backspar trees. A small Link-Belt hydraulic log loader (Figure 5) was used to align and bunch logs prior to cable yarding. Logs yarded to the roadside were moved by a Ranger 667 rubber-tired grapple skidder (Figure 6) to roadside decks. These decks were sorted according to five grades. A self-loading highway-sized log truck then transported the logs as pure grade-classified bundles to either the sortyard or booming ground.

Although the cable system was considered to be the most appropriate method for harvesting because of site disturbance concerns (high rainfall and deep organic soil layers), Weyerhaeuser wanted to test the feasibility of a ground-based thinning system. Therefore, one area (SW100) was assigned a combined loader-forwarding/grapple-skidding treatment for comparison with the cable system.

Pre-harvest surveys and development

In July 1996, a reconnaissance survey and a pilot cruise of the proposed block were undertaken to characterize the stand and identify boundary locations for the treatment compartments. In August 1996, a contractor appraised the study block for windthrow potential and to suggest management strategies for the treatment units. Weyerhaeuser engineering crews located, traversed, and mapped the block boundaries, treatment unit split lines, riparian buffers, wind protection buffers, and haul road locations. During July and August of 1996, an operational cruise was conducted with 30 fixed-radius plots (5.64 m in radius or 0.01 ha in area) systematically located on a grid pattern over the study block. Five permanent sample plots (PSPs) were also established and surveyed, one in each treatment unit. The plots were located by randomly selecting a distance between 50 and 150 m along the longest diagonal vector between block corners and referenced to the block boundaries. Because the railroad grades used for the first harvest were still evident in the study block and appropriately located for the thinning entry, they were rebuilt for truck access.

Harvest monitoring

Logs from each treatment unit were sorted, decked and hauled in homogeneous loads. The production was weighed and sample loads were scaled to provide a volume to weight conversion factor. The volumes for each treatment unit were later used to determine harvest phase productivity.

Machine rates for the equipment monitored were determined using a machine costing spreadsheet (Appendix I). These calculated rates do not include supervision, equipment mobilization, or profit allowances and differ from actual rates paid to the contractors working on the study. Production costs were then determined by multiplying machine productivity by the appropriate machine rates.

Manual felling times were acquired from the faller's time records. The Timbco 415 feller-processor had its own onboard computer that tracked machine usage. The operator provided printouts from the onboard computer on a daily basis and explained the reasons for any machine delays. Shift-level timing was done for the hydraulic log loader while bunching logs in the cable thinning, SW200, and SW300 blocks. When operations resumed in 1998, shift-level data provided by the contractor were used to determine productivities for the SW100 block and the windfall cleanup work. Both detailed and shift-level timing techniques were used to monitor cable yarding activities on three study blocks (cable thinning, SW200, and SW300). A hand-held datalogger was used for detailed timing of individual yarding cycle elements over different yarding distances and rigging configurations. Shift-level data were collected using a Servis recorder mounted on the cable yarder. In-shift delays and daily log counts were noted on the Servis recorder charts by the machine operator. Productivity by phase and block were determined using the scaled log volumes.

No timing data were recorded for the skidder and shift lengths recorded for the yarder were applied to the skidder. The log truck was only required to service the block intermittently. Costing assumptions for the hauling were based on truck productivity when it worked for complete shifts in the thinning, and those productivities were extrapolated over the total production.

Post-harvest surveys

A network of fixed radius plots (5.64 m or 0.01 ha) was systematically established on each of the treatment units. The same plots were used to survey for post-harvest wind damage, residual volume, site disturbance and tree wounding. Immediately following the completion of all harvesting and windfall recovery on the treatment units in October 1998, a combined survey was initiated to measure residual tree volumes, site disturbance, and tree wounding.

Results

Harvest operations

Over the two years in which harvesting occurred, 18 525 m^3 of logs were recovered from the study block (Table 2). The logs

Table 2. Study block production summary

Treatment area	1997 volume (m^3)	1998 volume (m^3)	Total volume (m^3)
Right-of-way	845	0	845
Commercial thinning	1 890	4 755	6 645
SW100	0	4 025	4 025
SW200	3 103	1 017	4 120
SW300	2 212	678	2 890
Total	8 050	10 475	18 525

recovered from widening of the original railway grades and construction of the new road (845 m^3) were tallied separately.

Planning and development phases

The planning and development phases are typically more expensive for partial cuts than clearcuts because costs are accrued against the volume harvested, not against the entire block volume that was developed. However, in this case the costs were relatively low at $1.46 and $1.16/$m^3$ for the planning/layout and road construction phases, respectively (Table 3).

Road development benefited from the legacy of old railroad grades that were located appropriately for the second harvest. About 1 km of the 1.27 km of road constructed on the block was rebuilt railroad grade which simply involved clearing stumps and placing about 20 cm of gravel surfacing on the old grade.

Harvesting phase

Falling and bucking

Both manual and mechanical falling and bucking methods were observed during the study and are summarized in Table 4. Mechanical falling was more costly because the feller-processor cost $180 per scheduled machine hour (SMH) compared to the manual faller at $65/SMH, and the productivity rates of the feller-processor were not very different from those for the manual fallers.

In addition to the higher costs for mechanical falling in a partial cutting treatment, other shortcomings were observed with the feller-processor:

- The machine caused some site disturbance and root damage.
- The machine cab restricted visibility of the tree canopies and, consequently many trees with poor crowns were retained.

Table 3. Planning and development costs

Participants	Tasks	Planning and layout		Road development	
		Total cost ($)	Production cost ($/$m^3$)	Total cost ($)	Production cost ($/$m^3$)
FERIC	reconnaissance	1 570	0.08		
	operational cruise	11 200	0.60		
Consultant	windthrow hazard assessment	1 000	0.05		
Port McNeill Division	boundary/road location	5 980	0.32	5 980	
	mapping	1 900	0.10	1 900	
	cutting permit preparation	2 200	0.12	2 200	
	cruise compilation	2 500	0.13		
	gravel truck			11 700	0.63
	compactor			2 040	0.11
Millstone	yarding corridor layout	940	0.05		
	loader			6 336	0.34
	skidder			1 386	0.08
Total cost		27 290	1.46	21 462	1.16

Treatment	Felled volume (m³)	Productivity				Production cost ($/m³)
		(m³/h)	(m³/shift)	(stems/h)	(stems/shift)	
Manual falling						
Commercial thinning	5 451	7.4	48.2	18	117	8.71
SW100	3 882	9.3	60.4	n.a.[a]	n.a.[a]	6.96
Mechanical falling						
SW200	3 102	15.2	103.4	16	109	13.93
SW300	2 212	10.5	71.4	16	109	20.17

Table 4. Falling: Shift-level productivity

[a] Not available.

- The felling head used on the Timbco harvester was not well-suited for falling clusters of stems on single root systems so most clusters were left standing.
- The technique used to work the falling face was problematic and wounded many of the residual trees.
- The boom of the machine, located on the operator's left side, restricted his vision and a small hydraulic log loader was needed to realign the processed logs before yarding.

Loader forwarding

Over the course of the study, two methods of loader forwarding were used. On the blocks that were cable harvested, the loader aligned and piled logs for yarding, while on the SW100 block the loader moved the logs to roadside or, in some cases, to skid trails. Productivities varied by both residual density and falling practice used (Table 5). Of the two manually felled blocks (Commercial thinning and SW100), loader forwarding was most productive on the SW100 block with fewer residual trees. Similarly, on the mechanically felled blocks, the loader did better with fewer residual trees. This result is logical because the operator must take more care in denser residual stands to avoid wounding trees. The forwarding productivity on the SW300 block was the lowest of the four treatments and this can be attributed to a decision to forward all the logs from the last three skyline corridors either to the landing or to the last active yarding corridor. Although this strategy saved three road changes for the yarder and reduced the cable harvesting costs for the block, it resulted in low productivity for the loader-forwarder.

Cable harvesting

Harvesting on three of the four treatment units involved cable yarding. Table 6 summarizes the results of shift-level monitoring. Overall, the cable yarder spent 89% of the time engaged in productive activities. The move and rig element included all the tasks associated with moving from one yarding corridor to the next. This time element averaged 4.7 hours per move over the 28 corridor changes observed on the three

Table 5. Loader forwarding: shift-level productivity

Treatment area	Volume harvested (m³)	Productivity		Production cost ($/m³)
		(m³/SMH)	(m³/PMH)	
Commercial thinning	2 141	16.4	19.7	5.05
SW100	4 025	26.3	27.0	3.15
SW200	3 102	18.5	19.9	4.47
SW300	2 212	10.8	11.3	7.66

Table 6. Cable yarding: shift-level time distribution

Time	Commercial thinning (h)	Commercial thinning (%)	SW200 (h)	SW200 (%)	SW300 (h)	SW300 (%)	Weighted overall average (%)
Scheduled time (h)	251.3	100.0	279.9	100.0	197.6	100.0	100.0
Mechanical delays (h)	6.0	2	0.3	0.1	4.0	2.0	1.4
Weather delays (h)	0.0	0	12.0	4.3	10.8	5.4	3.1
Rigging delays (h)	9.0	4	8.3	3.0	11.8	6	4.0
Operating delays (h)	6.0	2	12.0	4.3	2.0	1.0	3
Moving and rigging (h)	50.0	20	44.8	16.0	35.5	18.0	18
Yarding (h)	180.3	72	202.5	73	133.5	68	71

treatment units. The largest non-productive shift element was rigging delays (4%) which included the time required to splice broken or worn running lines and eyes, etc. The yarder had good mechanical availability (99%), reflecting the fact that it was new when it arrived at the study block.

Cable harvesting productivity ranged widely between the commercial thinning and shelterwood blocks (7.5 and 11.2 m^3 per scheduled hour, respectively) (Table 7). The average piece size on the commercial thinning block was the smallest at 0.25 m^3 compared with 0.34 and 0.27 m^3 on the SW200 and SW300 blocks, respectively. Less volume per hectare was removed from the commercial thinning block, requiring more frequent corridor changes for the yarder. In the SW300 unit, the log loader bunched more logs along fewer corridors, allowing the crew to avoid three corridor changes.

Table 8 summarizes the results of 553 cycles that were timed in detail. The results are presented by treatment and by the number of chokersetters working during the observation period. Even though detailed-timing results often overestimate when used to extrapolate production outcomes, they do indicate the relative proportion of individual elements to overall cycle times and this can be useful when analyzing alternative scenarios.

Skidding and sorting

The skidding and sorting phases were not observed in detail but the operating shifts for the machine were tallied. These hours for the skidder at a rate of $63 per scheduled hour (Appendix I) were applied against delivered log volumes to determine skidding and sorting phase costs for each treatment area (Table 9). Skidding and sorting costs ranged from $3.44 to $8.25/$m^3$, reflecting the productivity of the harvest system feeding the skidder, not the capability of the skidder.

Loading and hauling

Hauling productivity was not monitored directly due to the intermittent and

Table 7. Cable yarding: shift-level productivity and cost

Treatment	Volume harvested (m^3)	Logs harvested (no.)	Productivity (m^3/SMH)	Productivity (m^3/PMH)	Productivity (Logs/PMH)	Production cost ($/$m^3$)
Commercial thinning	1 890	7 597	7.5	10.5	42.2	33.17
SW200	3 103	9 130	11.1	15.3	45.1	22.41
SW300	2 212	8 189	11.2	16.6	61.3	22.21

independent truck schedule used for this phase. Instead, an average hauling productivity of 20.7 m^3 per scheduled hour was calculated and applied against an hourly cost of $91 (Appendix I) to yield an average hauling cost of $4.40/$m^3$. The same average hauling cost was applied to each treatment unit (Table 10).

Overall harvest costing

Table 9 illustrates the overall harvesting costs for the four treatment units. The costs presented are not the actual costs incurred by the harvesting contractors or Weyerhaeuser, and they pertain only to initial harvesting activities, not windthrow recovery. Note that some of the phase costs (e.g., falling and cable yarding) presented in Table 9 vary widely between blocks.

Post-harvest stand and site damage

Wind damage

As harvesting activity progressed during the study period, the study area was frequently buffeted by strong winds. Athough a few trees blew over while the study area was active, the frequency of windfall was not alarming and no surveys were initiated to tally windfall occurrences.

Harvesting was halted at the end of June 1997 due to poor market conditions. At this time both shelterwood blocks were completed, the cable commercial thinning block was felled but only 60% yarded, and the ground-based commercial thinning block was partially felled (35%). Subsequent windthrow

Table 8. Cable yarding: detailed-timing results

	Commercial thinning		SW200		SW300	
Chokersetters (no.)	1	2	1	2	1	2
Cycles (no.)	151	54	120	84	65	79
Avg logs (no./turn)	6	6	6	6	6	6
Avg yarding distance (m)	91	265	93	91	131	156
Avg time/cycle						
Unhook (min)	0.69	1.38	0.71	0.55	0.63	0.65
Outhaul (min)	0.79	0.94	0.86	0.84	0.78	0.70
Lateral out (min)	0.60	0.69	0.53	0.49	0.27	0.34
Hook (min)	1.10	0.76	1.66	1.20	1.71	1.70
Lateral in (min)	0.69	0.81	0.74	0.61	0.40	0.57
Inhaul (min)	1.28	2.27	1.30	1.23	1.37	1.36
Total cycle (min)	5.15	6.85	5.80	4.92	5.16	5.32

Table 9. Production cost summary by treatment

Harvesting phase	Commercial thinning ($/$m^3$)	SW100 ($/$m^3$)	SW200 ($/$m^3$)	SW300 ($/$m^3$)
Planning	1.46	1.46	1.46	1.46
Road development	1.16	1.16	1.16	1.16
Falling & bucking	8.71	6.96	13.93	20.17
Loader forwarding	5.05	3.15	4.47	7.66
Yarding	33.17	n.a.[a]	22.41	22.21
Skidding/sorting	8.25	3.44	5.64	5.59
Loading/hauling	4.40	4.40	4.40	4.40
Ground man	0.00	1.69	0.00	0.00
Total	62.20	22.26	53.47	62.65

[a] Not available.

Table 10. Trees damaged by wind

Treatment	Trees blown down (no.)	Trees with broken tops (no.)	Trees leaning (no.)	Undamaged trees (no.)	Proportion of trees damaged (%)
Control	8	22	35	109	37
Commercial thinning	34	25	3	58	52
SW200	10	8	0	28	39
SW300	29	16	1	42	52
Total	81	71	39	237	45

occurrence was not monitored until the study area was hit by a severe storm in December 1997. The storm began with a heavy fall of wet snow that stuck in the tree crowns and was followed by high velocity out-flow winds from a northeasterly direction. Following the storm, extensive wind damage was observed on all treatment areas of the study block and in neighboring stands of second growth. The damage included stem breaks, and leaning and overturned trees (Figure 7), and was consistent with descriptions of catastrophic windthrow (Stathers et al. 1994).

Figure 7. Wind damage from December 1997 storm.

Although this windfall event was discouraging for those involved with the study, it did provide an opportunity to study the implications of thinning treatments on wind stability for these types of stands. A survey was conducted on four of the five treatment areas to quantify the wind damage. The ground-based commercial thinning area was not included in the survey as falling was incomplete. Table 10 illustrates the number of wind-damaged trees by treatment area. Although all treatments were dramatically affected by the wind, the block least affected was the untreated control with 37% of the surveyed trees being either snapped off or blown over. The wind damage on the control block reduced the residual volume per hectare by 31% (Table 11). The higher proportion of damage by number of trees rather than by volume suggests that the smaller trees were more susceptible to the wind than the large ones. This result was evident on all four of the treatments surveyed. Field observations also noted that the heaviest damage occurred to intermediate crown class trees with the

Table 11. Wind damage survey results

Treatment	Total trees damaged (no./ha)	Total volume damaged (m^3/ha)	Proportion of trees damaged (%)	Proportion of volume damaged (%)
Control	542	274	37	31
Commercial thinning	239	171	52	41
SW200	90	117	39	31
SW300	256	197	52	42

greatest slenderness ratio.[1] Intermediate crown class stems, whether well rooted or not, present the greatest risk for post-harvest wind damage from both overturning and snapping and should be a primary target for removal.

As crown, root, and bole characteristics for trees differ between species, there is a question of whether one species becomes more vulnerable to wind damage than the other species after stand density is reduced. In three of the four treatments surveyed, the proportion of hemlock trees damaged exceeded its pre-storm proportion in the stand, while the proportions of cedar, amabilis fir and spruce damage was less than pre-storm proportions. Initially, it would appear that hemlock may have a higher susceptibility to wind damage. However, when crown class distribution is considered, hemlock had the highest proportion of intermediate class stems and this probably contributed more to the disproportionate wind damage than any physiological difference between species.

Another observation made during the wind damage survey was the vulnerability of multiple stems growing from a single root system. Falling instructions required that all stems on a single root system either be left standing or be felled, rather than retaining a single stem on the common root system and risking both wind damage and fungal entry through the cut stumps. The increased wind exposure following thinning acted on the combined crowns of the multiple stems to develop more overturning moment than the root systems could resist, and most of the multi-stem clumps blew over. Tree selection criteria should target multi-stem cluster for removal in hemlock thinning.

Site disturbance

Table 12 presents the results of the site disturbance surveys. The SW300 and commercial thinning treatments have the highest proportion of disturbed area resulting primarily from rehabilitated skid trails. The skid trails were established during the windfall recovery process and deactivated by the hydraulic log loader after the windfall was removed.

When in-block disturbance proportions are extrapolated to estimate area disturbed and then combined with area occupied by roads and landings, the total disturbed area is 4.9 ha, or 10.2% of the block. This level of disturbance seems excessive for treatments that were predominantly cable harvested. However, 6% occurred on treatment units that were initially cable harvested and then re-entered with ground-based equipment to recover windfall. It was during the blowdown cleanup that most of the site disturbance occurred.

[1] Slenderness ratio is a unitless quotient of tree height over dbh (e.g., 33 m ht/0.29 m dbh = 114 slenderness ratio). Slenderness ratio is commonly used in Europe to rank potential windthrow risk of thinned stands. A slenderness ratio greather than 100 in Norway Spruce is considered at high risk to wind damage.

Table 12. Site disturbance: summary of results

Treatment	Area (ha)	Undisturbed (%)	Light disturbance (%)	Disturbed (%)	Area disturbed (ha)
Commercial thinning - cleanup	3.6	80.0	8.6	11.4	0.41
Commercial thinning	8.1	81.0	2.6	16.4	1.33
SW100	9.6	81.4	15.6	3.0	0.29
SW200	7.5	65.4	30.0	4.6	0.35
SW300	7.1	65.7	17.4	16.9	1.20
Control	6.2	100.0	0	0	0
Buffer zones	4.5	100.0	0	0	0
Road and landings	1.3	0	0	100.0	1.30
Total area	47.9				4.87

The SW100 block, the only block completely harvested with ground-based equipment, has the lowest proportion of site disturbance. This occurred because the block was manually felled and most of the logs were forwarded to roadside with a hydraulic log loader. This created light disturbance to the organic layer but almost no mineral soil exposure, gouging or rutting. Also, harvesting occurred at the end of a dry summer.

Tree wounding

An objective of this study was to compare residual tree wounding levels between different treatment prescriptions and operational techniques. Unfortunately, three unexpected occurrences increased the wound severity on the treatment units and confounded the data to a point that the intended comparisons are inappropriate. The post-harvest residual stand damage survey identified that 71% of surveyed trees were wounded and that 30% of the wounded trees were severely or mortally damaged. This level of damage was very high due to the following reasons: harvesting of two treatments occurred during sap flow; the feller-processor's work pattern exposed residual trees to excessive wounding; damage occurred during the windstorm; and multiple entries occurred on three treatments to salvage windthrow.

Conclusions

A total volume of 18 525 m^3 was harvested and hauled from four treatment areas over a two-year period. Costs ranged from a low of \$22.26/m^3 for the loader-forwarding of a uniform shelterwood with 100 residual trees/ha to a high of \$62.65/m^3 for the cable yarding of a uniform shelterwood unit with 300 residual trees/ha.

Two of the treatment blocks were manually felled and two were mechanically felled. Manual falling was the more successful practice in this trial because the fallers were experienced and were able to clearly view the work site and stand. As a result, they were able to make better residual tree selections compared to the feller-processor operator who had restricted visibility and limited experience. Many of the shortcomings observed in this trial could be overcome with more appropriate machine selection, better work planning and a more experienced operator. However, mechanical falling does have advantages not quantified by this study, such as lower accident risk for the operator compared to manual falling, the ability to work longer hours in a shift, and the potential to recover more usable fibre from a harvest block.

Although manual falling productivities were lower than those for mechanical falling, manual falling costs were also lower because of high capital and operating costs for mechanical falling. Contrary to the trend of harvest mechanization, manual falling at the Port McNeill trials was the most cost-competitive practice. While both technological and operational advances in the mechanical falling of partial cuts are happening, a substantial productivity margin between mechanical and manual falling is needed before mechanical falling is competitive in this type of operation.

Both the standing skyline cable system and ground-based loader-forwarding system were effective for the site, stand, and weather conditions in this trial. However, the capital and operating costs of the cable system used at Port McNeill was much greater than those of the hydraulic log loader, making the loader-forwarder a more appropriate choice where conditions allow. In this study, yarding productivity varied inversely with the residual densities of the treatment.

A post-storm windthrow survey identified that 45% of the trees sampled over the entire study block were damaged. The highest proportion of wind damage occurred on the SW300 treatment (52% of residual trees) and the lowest proportion on the untreated control (37%). Two falling practices observed on the SW300 block contributed to higher levels of windthrow vulnerability: the retention of intermediate crown class trees, and the retention of tree clusters on single root systems.

In second-growth western hemlock stands, intermediate crown-class trees and tree clusters should be targeted for removal during partial cutting.

The overall site disturbance level for the study block was 10.2% of total block area. The SW100 area had the lowest site disturbance and was only entered once by the loader-forwarder. The SW300 area had the highest site disturbance and had four machine entries.

The post-harvest residual stand damage survey identified a high level of damage to the surveyed trees. This was due to two treatments being harvested during sap flow; the feller-processor's work pattern exposing residual trees to excessive wounding; damage occurring during the windstorm; and multiple entries occurring on three treatments to salvage windthrow.

Implementation

Falling

- If mechanical falling is to be considered in partial cutting, planners should specify machines with felling heads capable of directional control and placement of severed stems. This feature will minimize damage to residual trees while processing and allow processed bunches to be properly aligned for subsequent extraction.

Log extraction

- Use loader forwarding rather than cable harvesting whenever terrain, residual density, and soil conditions permit.

Harvesting impacts

- Road right-of-ways in commercial thinning areas should be only as wide as necessary for equipment access. This will reduce site disturbance levels and improve the harvest yield at final entry.
- When closely spaced tree clumps are encountered in a stand being partially cut, the entire tree clump should be felled due to the high susceptibility of these clumps to windthrow when exposed.
- Curtail falling and extraction activities in partial cuts during the sap flow period (April to July) to reduce the incidence and severity of residual tree wounding.

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Acknowledgements

The author is grateful for the cooperation of the Port McNeill Division of Weyerhaeuser Company Limited and its logging contractors. Special appreciation is expressed to Doug and Glen Sawden of Millstone Contracting Ltd.; Bill Waugh, Jack Lavis, and Jeff Ternan of Weyerhaeuser; and Ingrid Hedin, Michelle Dunham, Ray Krag and Mihai Pavel of FERIC for their assistance, advice and patience over the extended duration of this project. The funding assistance provided by Forest Renewal BC is also gratefully acknowledged.

Appendix I

Cost analysis[a]

	150-kW Timbco 415 feller/processor (new)	200-kW Diamond D210 swing yarder (new)	Maki II carriage (new)	85-kW Ranger 667 grapple skidder (used)	65-kW Link-Belt hydraulic loader (used)	260-kW Kenworth W900 self-load log truck (used)
OWNERSHIP COSTS						
Total purchase price (P) $	565 000	540 000	60 000	40 000	70 000	95 000
Expected life (Y) y	7	12	7	5	4	5
Expected life (H) h	9 200	16 000	9 200	6 000	5 000	7 000
Scheduled hours per year (h)=(H/Y) h	1 314	1 333	1 314	1 200	1 250	1 400
Salvage value as % of P (s) %	20	30	25	20	20	20
Interest rate (Int) %	11.0	11.0	11.0	11.0	11.0	11.0
Insurance rate (Ins) %	2.5	2.0	2.0	2.0	2.0	2.0
Salvage value (S)=(s•P/100) $	113 000	162 000	15 000	8 000	14 000	19 000
Average investment (AVI)=((P+s)/2) $	339 000	351 000	37 500	24 000	42 000	57 000
Loss in resale value ((P-S)/H) $/h	49.13	23.63	4.89	5.33	11.20	10.86
Interest=(Int•AVI/h) $/h	28.38	28.96	3.14	2.20	3.70	4.48
Insurance=(Ins•AVI/h) $/h	6.45	5.27	0.57	0.40	0.67	0.81
Total ownership costs (OW) $/h	83.96	57.86	8.60	7.93	15.57	16.15
OPERATING COSTS						
Wire rope (wc) $	0	14 000	0	500	0	0
Wire rope life (wh) h	0	900	0	1 000	0	0
Rigging & radio (rc) $	0	11 000	0	0	0	0
Rigging & radio life (rh) h	0	6 000	0	0	0	0
Fuel consumption (F) L/h	32.0	29.0	1.5	20.0	20.0	36.0
Fuel (fc) $/L	0.42	0.42	0.42	0.42	0.42	0.42
Lube & oil as % of fuel (fp) %	15	15	15	15	15	15
Annual tire consumption (t) no.	0	0	0	1	0	12
Tire replacement (tc) $	0	0	0	1 200	0	420
Track & undercarriage replacement (Tc) $	35 000	0	0	0	28 000	0
Track & undercarriage life (Th) h	3 500	0	0	0	3 800	0
Annual operating supplies (Oc) $	2 500	1 000	100	1 200	1 200	1 200
Annual repair & maintenance (Rp) $	45 000	35 000	2 500	15 000	24 000	26 000
Shift length (sl) h	8	8	8	8	8	8
Wages $/h						
Operator	25.00	22.77	0.00	21.74	21.74	25.00
Hooktender	0.00	24.04	0.00	0.00	0.00	0.00
Chokersetter	0.00	20.41	0.00	0.00	0.00	0.00
Chaser	0.00	20.61	0.00	0.00	0.00	0.00
Total wages (W) $/h	25.00	87.83	0.00	21.74	21.74	25.00
Wage benefit loading (WBL) %	38	38	0	38	38	38
Wire rope (wc/wh) $/h	0.00	15.56	0.00	0.50	0.00	0.00
Rigging & radio (rc/rh) $/h	0.00	1.83	0.00	0.00	0.00	0.00
Fuel (F•fc) $/h	13.44	12.18	0.63	8.40	8.40	15.12
Lube & oil ((fp/100)•(F•fc)) $/h	2.02	1.83	0.09	1.26	1.26	2.27
Tires (t•tc/h) $/h	0.00	0.00	0.00	1.00	0.00	3.60
Track & undercarriage (Tc/Th) $/h	10.00	0.00	0.00	0.00	7.37	0.00
Operating supplies (Oc/h) $/h	1.90	0.75	0.08	1.00	0.96	0.86
Repair and maintenance (Rp/h) $/h	34.25	26.26	1.90	12.50	19.20	18.57
Wages and benefits (W•(1+WBL/100)) $/h	34.50	121.21	0.00	30.00	30.00	34.50
Total operating costs (OP) $/h	96.11	179.61	2.70	54.66	67.19	74.92
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	180.07	237.47	11.30	62.59	82.76	91.07

[a] Performed in 1997, and based on FERIC's costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit and overhead, and are not the actual costs incurred for the contractor or the company studied.