WOOD HARVESTING
Technical Note TN-199 July 1993

PARTIAL CUTTING IN A SECOND-GROWTH DOUGLAS-FIR STAND IN COASTAL BRITISH COLUMBIA: PRODUCTIVITY, COSTS, AND SOIL IMPACTS

D.M. Bennett, R.P.F.

Abstract

Fletcher Challenge Canada Limited (FCCL) conducted a partial-cutting trial in a second-growth Douglas-fir stand on Quadra Island, British Columbia from October 1991 to March 1992. The Forest Engineering Research Institute of Canada (FERIC) monitored the harvesting operation to determine the productivities, costs, and operational feasibility of using a ground-based, multiple-entry harvesting method in a second-growth Douglas-fir stand. FERIC also examined the condition of the residual stand, and the type and nature of soil disturbance and compaction created by harvesting.

Introduction

A partial-cutting trial was conducted in a second-growth Douglas-fir stand on Quadra Island, British Columbia (Figure 1), from October 1991 to March 1992, by Fletcher Challenge Canada Limited (FCCL). FCCL's objective was to provide a socially acceptable and economically viable harvesting alternative on public forest land in the vicinity of a rural community. Local citizens are keenly interested in the management of Quadra's forests and wish to examine alternatives to such conventional harvesting systems as the clearcutting and grapple yarding of large areas. The trial cutblock, located on Crown land within the company's Tree Farm Licence No. 47, lies in a visually sensitive area and contains significant non-timber values including recreation, food and plant gathering activities, and water quality for downstream fish populations.

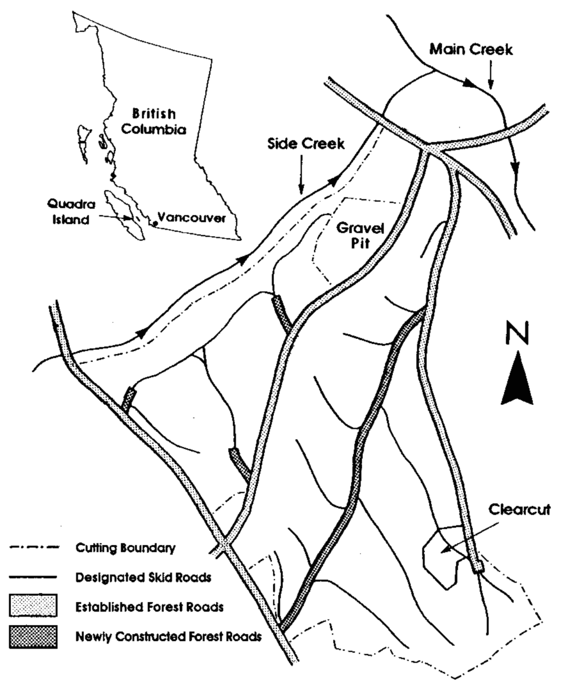

Figure 1. Study location, and block configuration.

FCCL developed a harvesting plan in consultation with an ad hoc citizens group, the Quadra Island Forest Resources Committee. Influenced by alternative management practices that have been implemented on some private land tracts in Oregon, FCCL foresters chose a

Keywords: Harvesting, Partial cutting, Productivity, Costs, Evaluation, Methodology.

Author: Doug Bennett is a Senior Researcher in the Harvest Engineering Group at FERIC's Western Division.

 ISSN 0381-7741

cutting method that involved an unconventional silviculture prescription. A local logging contractor, Skookum Logging and Towing was awarded the harvesting contract, after the Pre-Harvest Silviculture Prescription had received the required approval from the British Columbia Ministry of Forests (BCMOF).

The Forest Engineering Research Institute of Canada (FERIC) monitored the harvesting operation. The objective of FERIC's study was to determine the productivity, costs, and operational feasibility of implementing a ground-based, multiple-entry harvesting method in second-growth timber. Surveys were done to quantify the condition of the residual stand, and the type and nature of soil disturbance and compaction created by harvesting. Being beyond the scope of FERIC's project, the silvicultural implications of the cutting method were not evaluated.

Site and System Descriptions

Biogeoclimatic ecosystem classification places the cutblock area in the Western Very Dry Maritime Coastal Western Hemlock variant (CWHxm2) (Klinka et al 1991). Site index is 32 (m/50y) and the mean annual increment is approximately 12 m³/ha/y.[1] The trial unit's forest cover (Table 1) typifies the second-growth Douglas-fir (*Pseudotsuga menziesii*) stands on Quadra Island, most of which are reaching harvestable age and size. The stand regenerated naturally after a wildfire in 1925, followed by salvage harvesting in 1926-27. No stand-tending activities have been carried out. Elevation of the cutblock ranges from 60 to 150 m; and slopes are gentle, ranging from 10 to 30%.

Figure 1 shows the configuration of the study block. Main public roadways border and bisect the 33-ha block. An additional 0.9 km of haul roads and landing spurs were constructed to develop the area for harvesting and to segregate harvesting activities from the public roads.

The partial-cutting method implemented by FCCL entails the scheduling of harvesting entries at intervals of 5-7 years. The harvesting entries are not regeneration cuts. With each stand entry, approximately 12-15% of the stand volume is removed by cutting individual premarked trees distributed throughout the stand. Marked trees are selected from the stand's dominant and highest-value trees. A small area (<1 ha) within the cutblock was designated for clearcutting due to the presence of root rot (*Phellinus weirii*).

The harvesting operation comprised handfalling and ground-based skidding. FCCL forestry and engineering staff carried out engineering, timber cruising, tree marking, and supervision. FCCL devised and located a skidding network consisting of 2.5 km of designated skid roads that are 4-m wide and spaced approximately 100 m apart (Figure 1). The skid roads are permanent access routes and will be used in successive stand entries. Skid roads were constructed concurrently with harvesting, with the blade of a small crawler-tractor. Trees were manually felled toward the skid roads in a herringbone pattern and manually bucked to preferred lengths.

Random, or dispersed, skidding between the skid roads was required to retrieve the logs. To minimize soil and residual tree damage, FCCL stipulated that the only machine permitted to travel off the designated skid roads was a crawler-tractor. The contractor used his discretion in determining the crawler-tractor's dispersed skidding routes (referred to as skid trails in this report) and was not permitted to use the crawler-tractor's blade to build the trails.

A two-person contract crew carried out the operation, with one person being assigned primarily to handfalling while one person operated the crawler-tractor. The contractor chose a new (1991 model) John Deere 450G crawler-tractor to be the primary skidding machine (Table 2). The 52-kW crawler-tractor was equipped with a six-way blade arrangement and winch with a logging

Table 1. Pre- and Post-Harvest Stand Descriptions [a]

	Species					
	Douglas-fir (%)	Western hemlock (%)	Net volume (m³/ha)	Merchantable trees (no./ha)	Net volume (m³/tree)	Average dbh (cm/tree)
Pre-harvest data	81	19	700	917	0.8	30
Harvest data	95	5	95	45	2.1	47
Residual stand data	78	22	605	872	0.7	29

[a] Data supplied by FCCL. Timber volumes removed from road right-of-ways are not included.

[1] S. Lackey, Regional Forester, North Island Region, FCCL, Campbell River, B.C.; personal communication, June 1992.

Table 2. John Deere 450G Crawler-Tractor: Specifications

Engine power	52 kW
Transmission	Power shift 4-speed
Standard track gauge	1.45 m
Blade width	2.29 m
Dozer control	Single lever, T-bar
Approx. weight (c/w winch)	7300 kg

arch. A 1979 John Deere 540 rubber-tired cable skidder was used intermittently to augment log forwarding on the designated skid roads. The occasional operation of the JD540 skidder was done by either person as circumstances allowed. Log hauling was sub-contracted to an owner-operated self-loading log truck.

Study Methods

Productivity and costs were evaluated by collecting shift-level and detailed-timing information. The shift-level time study was conducted using DSR Servis recorders mounted in the cabs of the crawler-tractor and skidder. The contractor supplemented the recorder-produced charts with daily shift reports that described falling and skidding activities and log production. FERIC also conducted detailed timing of skidding-cycle elements over ten operating shifts using a hand-held computer. Costs for this report were developed by FERIC using standard procedures and no attempt was made to simulate site-specific contract bid prices.

A 100-m x 100-m grid was superimposed over the cutblock to establish 33 grid points, uniformly distributed over the cutblock, to sample damage to the residual stand, as well as soil disturbance and soil compaction. To determine the level of harvesting damage incurred by the residual stand, a fixed-radius 0.01-ha plot was established at each of the 33 grid points. Percentage of crown loss was estimated and the number and surface area of individual scars to tree boles were measured for each damaged tree found within a plot. Damage to tree root systems was not assessed.

Soil disturbance was surveyed following harvesting to determine the proportion of cutblock area taken up by haul roads and landings, skid roads, and the dispersed skid trails. The version of the BCMOF soil-disturbance survey procedures (Curran and Thompson 1991) current when this study took place was used to estimate dispersed skidding disturbance. At each of the 33 grid points, one 30-m transect was established on a random bearing, with its origin at the grid point. The type of surface material, depth of impressions (or deposits) in mineral soil, and whether the observation point fell on a machine track or between tracks were recorded at 2-m intervals along each transect.

Areas occupied by haul roads, landings, and skid roads were estimated by traversing and cross-sectioning these structures.

Total soil bulk densities (including coarse fragments) were measured following harvesting with a Campbell Pacific model MC-1DR moisture/density gauge. Two soil layers, extending 10 cm and 20 cm from the surface, were measured. Three categories of soil disturbance and an undisturbed control were selected for soil bulk density sampling. The dispersed skid trails created by the crawler-tractor constituted two categories of disturbance: light-use trails, subjected to one or two passes of the crawler-tractor; and heavy-use trails, subjected to 3 to 6 (and occasionally more) passes. Designated skid roads, which were subjected to numerous passes by the crawler-tractor and the rubber-tired skidder, constituted the third category of disturbance.

To sample the light-use and heavy-use skid trails, the 33 grid points used for the soil disturbance measurements were again used. In the immediate vicinity of each gridpoint an example of a light-use and heavy-use skid trail was identified and sampled with the density gauge.

To sample the designated skid roads, 37 cross-sections were established at intervals of 80 m, beginning at the 40-m station on each skid road. Even coverage of the harvest area was attained because the designated skid roads were evenly distributed throughout the cutblock. At each cross-section, total bulk density was measured at two points with the density gauge: in the skid-road track and in the undisturbed soil adjacent to the skid road. Sampling of the machine tracks alternated between the left and right sides of the skid roads.

The resulting data was subjected to one-way analysis of variance (ANOVA) to determine variation in mean total bulk density of light-use and heavy-use skid trails, designated skid roads, and undisturbed soils, by depth class. Duncan's multiple range test, at the 0.10 level of significance, was applied to distinguish the significantly different means for each soil layer.

Finally, soil texture was determined through gradation analysis of five representative soil samples collected in the cutblock.

Results and Discussion

Time Distribution

Shift-level time distributions are presented in Figures 2 and 3 for the JD450G crawler-tractor and the JD540 rubber-tired skidder, respectively. Productive machine

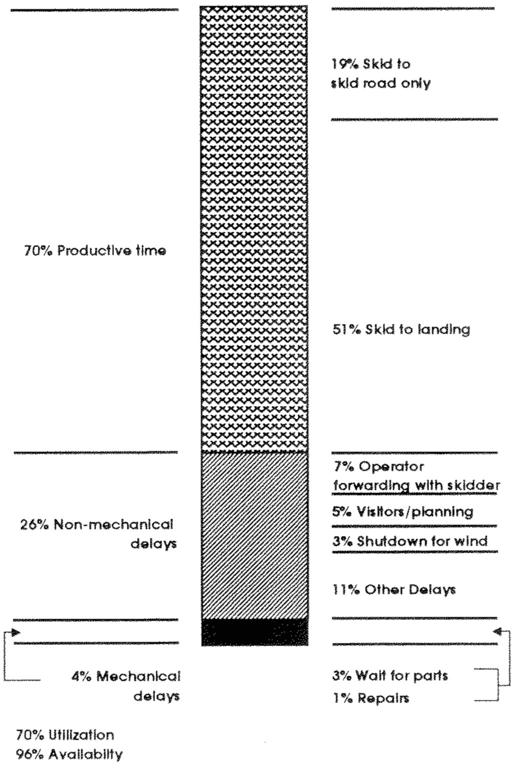

Figure 2. Time distribution for 50 shifts with the JD450G crawler-tractor.

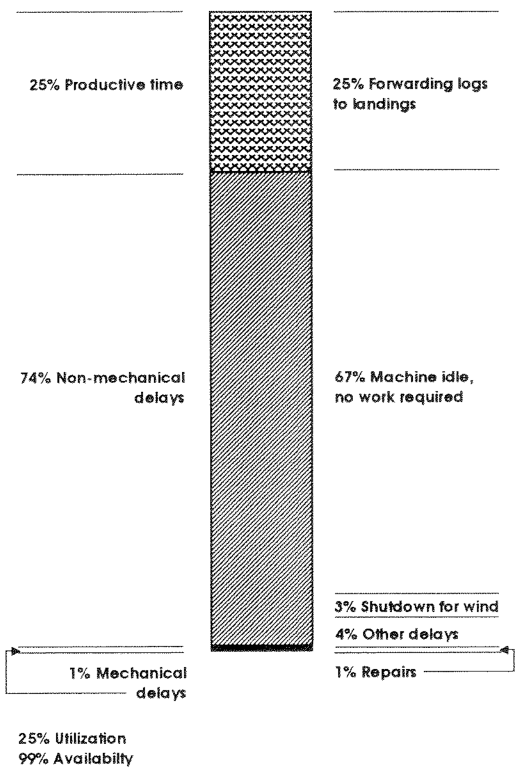

Figure 3. Time distribution for 50 shifts with the JD540 rubber-tired skidder.

times were influenced by the crew arrangement because the crawler-tractor operator and the faller shared the duty of operating the skidder.

Fifty-one percent of the crawler-tractor's time was spent gathering a turn of logs within the stand, travelling to a designated skid road, and then forwarding along the skid road directly to a landing. An additional 19% of total time involved only dispersed skidding from the stump to the designated skid road, where the logs were then unhooked (Figure 4). The latter practice was preferred by the operator when forwarding distances along the skid road exceeded 150 m. In this situation the operator felt it was quicker to use the rubber-tired skidder to forward the logs to the landing area (Figure 5). The crawler-tractor operator would skid two to three turns to the skid road and then use the skidder to forward the accumulated bunch to the landing.

Machine availability for the crawler-tractor was very high. Only 1% of total time was classed as downtime for repairs (Figure 2).

Figure 4. Skidding logs to a designated skid road.

Figure 5. Forwarding on a designated skid road.

A significant proportion of the operator's time was taken up by discussions with visitors; the experimental nature of the trial attracted a considerable amount of outside interest.

The rubber-tired skidder was used to forward logs along the skid roads for 25% of the shift-level study period. The contractor's objective at the outset of the project was to boost his overall productivity by using this machine to forward logs over the longer skid road distances rather than to maximize the skidder's productive machine time. The large proportion of idle time for the skidder was acceptable to the contractor because the machine was old and had relatively low ownership costs.

Seventy-seven of the crawler-tractor's skidding cycles underwent detailed timing to better describe its activities when it was engaged in skidding from the stump to the landing. Table 3 summarizes average times for the skidding cycle elements and describes the skidding conditions during timing. The combined elements of machine positioning, hook-up, and log winching accounted for 37% of total cycle time. This significant proportion of time reflects the intricacies of retrieving individual trees throughout a partially cut stand. FERIC's observations suggest that the efficiency of this retrieval phase is influenced by the layout of the designated skid roads, orientation of marked trees relative to the skid roads, and the quality of directional felling.

Productivity and Costs

Productivities for individual machines and for the total skidding system are summarized in Table 4. Productive machine hours (PMH) refers to the time a machine was engaged in the skidding function and excludes mechanical and non-mechanical delays. During the shift-level study, the productivity of the skidding system was 48 m^3/shift. The total volume harvested during the trial was augmented by timber recovered from haul road right-of-ways. This additional timber volume is not included in the productivity figures shown in Table 4.

The total number of logs forwarded by the rubber-tired skidder exceeds the number skidded by the crawler-tractor to the edge of the skid roads. The skidder's additional production was derived from felled timber within reach of the skid roads.

Falling was done concurrently with skidding and usually did not advance further than one-half to one day ahead of the crawler-tractor. Because the faller could easily keep ahead of skidding, he would occasionally help set chokers or forward logs with the rubber-tired skidder.

Costs for the three phases of the harvesting system are summarized in Table 5. The unit costs were calculated using the all-found machine and falling hourly rates developed in Appendix I. Forwarding with the rubber-

Table 3. Detailed-Timing Results: JD450G Crawler-Tractor (77 Cycles)

	Mean (min)	Standard deviation (min)	Portion of total cycle time (%)
Skidding cycle elements			
Travel empty	2.30	1.27	11
Position	1.06	1.54	5
Hook	5.16	3.91	24
Winch	1.56	1.74	8
Travel loaded	3.26	1.83	15
Unhook	1.88	1.94	9
Deck	1.57	1.49	7
Delays within cycle	4.39	7.77	21
Total cycle time	21.18	10.78	100

	Mean	Minimun	Maximum
Skidding conditions			
Distance travelled in stand (m)	20	0	120
Distance travelled on skid roads (m)	90	10	190
Logs/turn (no.)	3	1	6
Volume/turn (m^3)	2.6	0.8	4.9

Table 4. Summary of Skidding System Productivity for the Shift-Level Study (50 Shifts)

	JD450G crawler-tractor		JD540 rubber-tired skidder	Total system
	Skidding to skid roads only	Skidding to landings	Forwarding logs to landings	Production to landings
No. of turns	281	662	335	997
No. of logs	698	1773	1143	2916
Logs/PMH (no.)	10	9	12	n.a.
Logs/shift (no.)	14	35	23	58
m^3/PMH	8	8	10	n.a.
m^3/shift	11	29	19	48

tired skidder occurred intermittently, so the total time for this activity was pro-rated over all shifts. Average shift length was calculated for each phase based on the shift-level study data; this was the average time accumulated per shift by the two-person crew in a particular phase. Note that the productivity and shift length information reflects the use of a two-person crew to conduct a three-phase operation.

During the shift-level study, the combined unit cost for falling and skidding was \$15.40/m^3. FERIC estimates that conventional harvesting costs were exceeded by approximately 20-30%. In this case, the prime conventional harvesting alternative would have been clearcut falling and grapple yarding.

The calculated falling and bucking cost of \$5.48/m^3 is estimated by FERIC to be 25-35% greater than falling costs for conventional clearcuts in the same area. The higher unit falling cost is indicative of the extra care and time required for successful falling and bucking in a partial-cutting situation. The falling cost would have been even higher if the faller had been unable to work in other phases, which allowed some of the faller's time to be charged to the other phases.

Residual Stand Condition

The levels of damage to tree crowns and scarring in a residual stand is an indication of the quality of harvesting operations. FERIC surveyed post-harvesting damage in thirty-three 0.01-ha plots to quantify the stand damage resulting from the cutting method. Table 6 summarizes reductions in live crown mass as a result of falling, and Table 7 summarizes tree scarring caused by falling and skidding.

As both tables show, the extent of damage to the residual stand was minimal. An average of 30 trees/ha show significant crown damage and 27 trees/ha show scarring. This represents 3% of the residual stems in each case. A tree was significantly damaged if loss of

Table 5. Cost Summary: Harvesting System

	Avg. shift length[a] (h)	Costs \$/shift	Costs \$/m^3
Primary skidding function (JD450G)	7.0	362	7.54
Pro-rated forwarding (JD540)	2.5	114	2.38
Falling and bucking	5.6	263	5.48
Total system cost		739	15.40

[a] Average time accumulated by the two-person crew on each phase.

Table 6. Damaged Residuals: Crown Loss [a]

Species	Residuals with crown loss: Total (no./ha)	Average diameter (cm)	Crown loss/ residual (%)
Douglas-fir	27	39	17
Western hemlock	3	19	15
Total	30	37	17

[a] For trees 10 cm dbh. Trees were tabulated if crown loss exceeded 10%.

Table 7. Damaged Residuals: Scarring [a]

Species	Residuals with scarring: Total (no./ha)	Average diameter (cm)	Scarred area/ residual (cm^2)
Douglas-fir	12	34	1078
Western hemlock	15	17	603
Total	27	25	814

[a] For trees 10 cm dbh. Trees were tabulated if cumulative scar area exceeded 450 cm^2.

crown mass exceeded 10%, or if cumulative scarred area per tree exceeded 450 cm^2. These threshold levels for residual damage were adopted from the section of the BCMOF *Silviculture Manual* on commercial thinning operations (BCMOF 1983).

The severity of crown damage and scarring was also minimal. Of the damaged residuals, the percent of live crown mass lost was 17% and the average area scarred was 814 cm^2. Of all scarring occurring in the stand, 27% was attributed to falling and 73% to skidding.

The low levels of crown and stem damage demonstrate the commitment of FCCL and the contractor to falling and skidding with care. During an initial period of adjustment the contractor refined techniques for directional falling, and for manoeuvering and winching with the crawler-tractor, to facilitate log removal. Also, to prevent scarring, sections of corrugated polyethylene culvert pipe were split longitudinally and sometimes placed around the key rub trees that bordered skidding routes (Figure 6).

The decay-free second-growth Douglas-fir and hemlock trees, and the gentle terrain, were conducive to successful directional felling (Figure 7). The faller noted that the incidence of felled trees hanging up in standing timber, or being deflected from their intended path, was low because, unlike in thinning operations, the largest trees were being removed.

Soil Disturbance

The soil disturbance surveys estimated that 18.2% of the cutblock area was occupied by haul roads, landings, designated skid roads, and skid trails (Table 8). Haul roads, landings, and the designated skid roads (which are permanent access structures within the cutblock and will be used for future harvest entries and stand management activities) occupied 6.5% of the cutblock. Unbladed dispersed skid trails accounted for 11.7% of cutblock area.

Figure 6. Protecting rub trees with culvert pipe.

Figure 7. Falling a dominant Douglas-fir tree.

Table 8. Soil Disturbance Survey Results

Disturbance category	Portion of harvest area affected (%)
Haul roads and landings	2.7
Skid roads	3.8
Skid trails (light- and heavy-use)	11.7
Other disturbance	11.4
Undisturbed	70.4
Total	100.0

The category "other disturbance", which accounts for 11.4% of the site, includes scuffing of the soil surface and exposure of mineral soil resulting from activities other than machine contact with the soil. This disturbance usually resulted when logs were winched toward the crawler-tractor, leaving a drag track. This type of disturbance appeared to FERIC to be insignificant in terms of affecting the physical properties of the soil.

Note that these observations record only the cause of soil disturbance in the cutblock and are not intended to imply that a particular source or type of disturbance is detrimental. However, it is generally accepted that the permanent access network represents a loss of growing site.

On the trial area, the gentle, benchy terrain and the absence of cuts and fills reduced the total area occupied by designated skid roads. Sample measurements indicated that designated skid roads averaged 3.1 m in width (standard deviation = 0.42 m), well below the 4-m maximum prescribed.

The *Pre-Harvest Silviculture Prescription, Procedures and Guidelines for the Vancouver Forest Region*

(BCMOF 1991) recognizes dispersed skidding as an option for harvesting on this site because its overall sensitivity to degradation (i.e. loss of productivity) was low. Several factors contributed to the cutblock's low sensitivity to degradation: gentle, benchy terrain with slopes of 10-30%; moderately dry soil moisture regime and well-drained site; and coarse soil texture, i.e. gravelly sandy loam with high coarse fragment content (50-70%).

However, other characteristics tended to increase the site's sensitivity: thin humus layers—the mean thickness of the LFH layer was only 5.3 cm (standard deviation = 2.5 cm), and impermeable soil parent material layer at the 70-90 cm depth.

The presence of a fish-bearing stream, 200 to 300 m downslope from the cutblock, was an additional consideration in developing the harvesting plan for the cutblock.

Soil Compaction

Table 9 presents results of total soil bulk density sampling, including statistical analyses. Significant increases in bulk density, relative to undisturbed soils, were found for the three skidding-related disturbance categories in both the 0-10 and 0-20 cm soil layers. As the table also shows, mean total soil bulk density increased as the frequency of machine travel over the soil increased. However, except for a significant increase between light-use skid trails and skid roads in the 0-10 cm soil layer, travel-related effects were not strong enough to be statistically significant.

Both light-use and heavy-use skid trails have significantly higher bulk densities than undisturbed soils, but are not significantly different themselves. This result supports the widely held view that much of the increase in bulk density occurs during the first few passes of a machine over the soil (Froehlich et al 1980). The light-use trails exhibited the least amount of mineral soil exposure; often the only evidence of machine travel was a track impression in the moss cover. Heavy-use trails resulted when terrain and obstacles sometimes forced the crawler-tractor to concentrate its travel on certain routes (Figure 8).

In the 0-10 cm soil layer, significant differences in bulk density were more readily detected, suggesting that the impact of machine travel is more pronounced in this layer. Again, this is consistent with many other studies (Burger et al 1985; Froehlich et al 1980; McNeel and Ballard 1991).

In most soils, natural bulk density and soil strength increases with depth, which accounts for the higher mean bulk densities measured in the 0-20 cm layer. Table 10 shows that the percent increase in bulk density was slightly greater in the 0-20 cm layer. This may be attributable to larger proportions of fine-fraction soil particles (<2 mm in diameter), and higher moisture contents, i.e. below the 0-10 cm layer.

Froehlich and McNabb (1983) and Carr et al (1991) reviewed several studies that show decreases in seedling and residual tree growth are related to increases in soil bulk density. The critical level at which an increase in soil bulk density reduces tree growth varies with soil conditions and tree species. A standard applied on U.S. National Forest lands in the Pacific Northwest by the Forest Service of the U.S. Department of Agriculture defines the threshold level for detrimental compaction to be a 15% increase in bulk density for soils other than volcanic ash/pumice soils (Meurisse 1987).

Results from the literature suggest that observed soil compaction levels for the light-use and heavy-use skid trails (Table 10) are moderate and probably not of significant consequence to overall site productivity. The designated skid roads do exhibit detrimental compaction levels, but these are part of the cutblock's permanent access network and have been previously deducted from the available growing site.

*Table 9. Mean Total Soil Bulk Density, by Disturbance Class (Standard Deviation Shown in Brackets)**

Soil layer	Undisturbed soil (g/cm^3)	Skid trails: Light use (g/cm^3)	Skid trails: Heavy use (g/cm^3)	Skid roads (g/cm^3)
Depth from surface				
0-10 cm	1.18 [a]	1.28 [b]	1.31 [b,c]	1.35 [c]
	(0.16)	(0.17)	(0.19)	(0.20)
0-20 cm	1.23 [a]	1.35 [b]	1.37 [b]	1.42 [b]
	(0.18)	(0.18)	(0.21)	(0.17)

* Means in the same row with the same superscript are not significantly different. ($p \leq 0.10$, Duncan's multiple-range test).

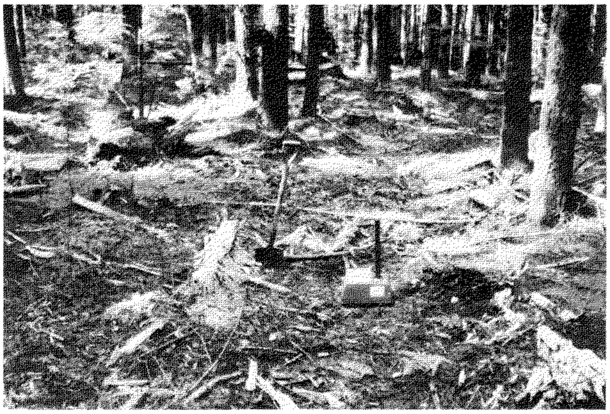

Figure 8. Density gauge on heavy-use skid trail.

Table 10. Percent Change in Total Soil Bulk Density, Relative to Undisturbed Soils

Soil layer	Skid trails		Skid roads
	Light use (%)	Heavy use (%)	(%)
Depth from surface			
0-10 cm	+8	+11	+15
0-20 cm	+10	+12	+16

Froehlich and McNabb (1983) point to several studies that show the rate of recovery for compacted forest soils in the Pacific Northwest's mild climate is slow and may take several decades. The 5-7 year stand-entry interval proposed for the study cutblock may be sufficient to allow surface soil bulk density to return to natural levels on the dispersed skid trails, but this is not yet known. However, the literature suggests that compaction in the 0-20 cm layer will persist to some degree until the next stand entry.

FERIC cautions that compaction is only one of several degradation processes that may affect a soil's productivity. The importance of compaction relative to other processes such as puddling, displacement, surface erosion, and mass wasting varies with soil type, terrain and climate, and must be assessed at each site. Lewis et al (1991) and Froehlich and McNabb (1984), among others, are useful references for information about the impact of harvesting on soil properties.

Other Observations

The project demanded careful selection of harvesting equipment to minimize damage to the soil and residual trees. The JD450G crawler-tractor proved to be an effective machine for this operation. The contractor noted that the 6-way angle blade, with a single T-bar controlling all blade functions, was beneficial for manoeuvering in confined spaces. The attributes of the blade arrangement, coupled with the machine's narrow track gauge, facilitated travel between the large number of residual stems.

The machine complement and skidding system were well-matched to the small-scale short-term trial. The contractor acknowledged that he was financially restricted to using an older cable skidder for the intermittent forwarding function. If the harvesting method was applied on a steady basis it would be feasible to acquire a later-model rubber-tired skidder, equipped with a swing grapple, to work in conjunction with two or three small crawler-tractors over a harvest area.

Old-growth stumps and the residual standing timber restricted the crawler-tractor's ability to reach some bucked logs. The contractor would often pull the machine's mainline and then winch the log into a favourable position (Figure 9). For large turns and situations involving difficult manoeuvering, the contractor found that a progressive sequence of winching was an effective way to extract the logs without compromising skidding productivity. The crawler-tractor would repeatedly travel forward with the mainline slack, and then winch the turn to the machine. This practice appeared to reduce soil impacts because the ground-pressure peaks, created when the crawler-tractor manoeuvers with a heavy turn, were reduced. (Pressure peaks are concentrated beneath the rear portion of the machine's track (Burger et al 1985; Lysne and Burditt 1983)).

Safety issues relating to the partial-cutting operation were reviewed on-site by the contractor, FCCL, and the Workers' Compensation Board of British Columbia. Of primary concern were the maintenance of safe working distances from snags, and their systematic removal when necessary. The study cutblock contained occasional large old-growth snags and abundant smaller snags (10-20 cm in diameter) resulting from natural mortality in the second-growth stand. The contractor anticipates that subsequent stand entries will be less difficult because many snags were removed during this harvest and dense patches within the stand were thinned.

A substantial volume (412 pieces) of pole- and piling-grade timber was recovered although this practice clearly required extra time and effort by the contractor. Seventy-five percent of the total timber harvested in the cutblock was graded as Douglas-fir J-grade or better.

The time required for engineering, tree marking, and supervision of the partial-cutting method is significantly greater than that for a conventional operation. Thor-

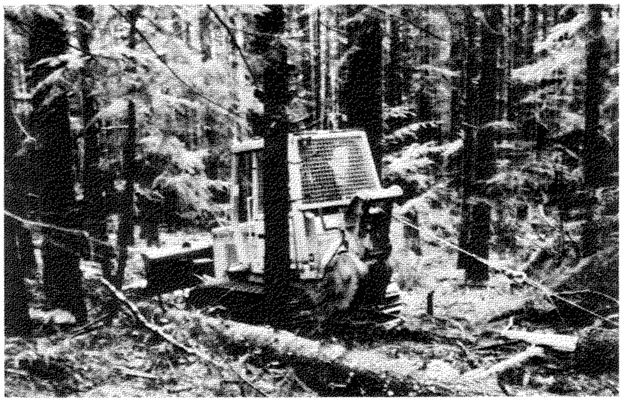

Figure 9. JD450G crawler-tractor winching logs.

ough planning and follow-up supervision are two of the most important factors in achieving a successful operation. This trial highlighted the importance of marking trees for cutting, with reference to the field-located network of designated skid roads. The contractor noted that skidding productivity can be improved when extraction routes are considered during the tree-marking process.

FERIC observed that the water table often rose to the soil surface during heavy rains. Sometimes overland water flow and surface erosion on skid roads occurred. During heavy rains, the operation was shifted to alternative drier areas within the cutblock or suspended temporarily, and cross-ditches were installed on the skid roads.

The partial-cutting prescription employed in the project does not represent a true silvicultural system, nor is it a recognized element of a conventional system. It is not an attempt to convert the stand to true uneven-aged management on a site that is suited to even-aged management of shade-intolerant Douglas-fir, and minor components of grand fir (*Abies grandis*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*).

FCCL foresters have yet to determine the number of harvest entries—and the resulting limits to residual stocking—that can be made before the stand must be regenerated with ecologically preferred species. It is likely that a series of small patchcuts will be created and re-stocking accomplished by a combination of natural regeneration and planting starting with the second or third harvest entry.

FCCL has addressed the silvicultural implications of the cutting method and defined the management objectives for the study site in a detailed Pre-harvest Silviculture Prescription. Application of the method by other operators on other sites requires thorough silvicultural planning to ensure that forest health, quality, and productivity is maintained over the long-term.

Conclusions

FCCL undertook a trial of an alternative partial-cutting method in a second-growth Douglas-fir stand on Quadra Island, British Columbia in 1991-92. Harvesting productivities and costs, residual stand condition, and soil impacts were evaluated by FERIC.

The trial demonstrated that the chosen machine complement, and the design of the skidding system, can be applied effectively to light partial cutting in a Coastal second-growth stand. The light weight, the narrow track gauge, and the manoeuvrability of the small crawler-tractor were essential to the success of the dispersed skidding operation. Proficiency in the falling phase is critical to the success of partial-cutting methods. Accurate directional felling is needed to place the timber in lead for efficient skidding while preventing damage to residual stems. The study results showed scarring to the residual stand, from skidding and falling, to be minimal.

The combined unit cost for falling and skidding was estimated to be 20-30% higher than conventional harvesting. However, FERIC believes the operation was cost effective because the overall cost of logs delivered to market was acceptable, and the quality and value of the harvested timber were high. Also, non-monetary factors, such as local concern about harvesting practices and the visually sensitive location of the study site, were successfully addressed through this small-scale operation. The successful integration of these non-monetary factors into the plan merits consideration when weighing the trial's incremental harvesting cost against conventional alternatives.

Perhaps the most important element contributing to the operational success of the trial was the positive attitude displayed by the contractor and FCCL supervisory personnel. The contractor was committed to proving the operational feasibility of a difficult and novel partial-cutting method while minimizing negative impacts to the soil and residual stand. Supervision was extensive. This enabled plans to be fine-tuned in response to changing field conditions. Also, public involvement during both the planning and execution of the trial was fostered.

The study showed that all levels of machine activity over the cutblock significantly increased soil bulk density on travelled areas. FERIC believes that the extent and severity of soil compaction on this site resulting from the crawler-tractor's dispersed skidding activity are not detrimental to overall site productivity. However, because the impacts of soil compaction are cumulative, ground-based activities must be carefully planned and monitored over several stand entries to ensure compaction does not reach detrimental levels. This need is especially acute for the cutting method initiated at the study site because multiple stand entries, spaced at relatively short intervals, are proposed.

Although the study did not show significant differences between soil bulk densities of the light-use and heavy-use skid trails, FERIC believes that FCCL's goal to minimize the amount of concentrated traffic by the crawler-tractor was prudent. The heavy-use skid trails (i.e. those that incur 3-6 crawler-tractor passes) represent an intermediate stage of machine impact that could progress to detrimental levels during an operation, and in effect become skid roads, if machine operators and supervisors are not vigilant.

This study focused on the operational aspects of the cutting method, but FERIC recognizes that forest operations cannot be assessed in isolation from the silvicultural goals of the prescribed treatments. The reader is reminded that the suitability of the cutting method varies from site to site, and depends on the local climate, terrain, and type of soil and vegetation.

References

British Columbia Ministry of Forests. 1991 (updated periodically). *Pre-Harvest Silviculture Prescription Procedures and Guidelines for the Vancouver Forest Region.* Victoria. Vancouver Circular VR-554. 63 pp.

British Columbia Ministry of Forests. (Updated periodically). "Appendix 9-10B, Commercial Thinning, Summary of Standards, Schedule B (F.S. 763B)" in *Silviculture Manual, Volume 2.* Victoria.

Burger, J.A.; Perumpral, J.V.; Kreh, R.E.; Torbet, J.L.; Minaei, S. "Impact of Tracked and Rubber-Tired Tractors on a Forest Soil," pp. 369-373 in *1985 - Transactions of the ASAE* . St. Joseph, MI. ASAE paper No. 83-1621.

Carr, W.W.; Mitchell, W.R.; Watt, W.J. 1991. *Basic Soil Interpretations for Forest Development Planning: Surface Soil Erosion and Soil Compaction.* Victoria, British Columbia Ministry of Forests. Land Management Report No. 63. 17 pp.

Curran, M.; Thompson, S. 1991. *Measuring Soil Disturbance Following Timber Harvesting. Victoria,* British Columbia Ministry of Forests. Land Management Handbook, Field Guide Insert 5. 25 pp.

Froehlich, H.A.; McNabb, D.H. "Minimizing Soil Compaction in Pacific Northwest Forests," pp. 159-191 in *Forest Soils and Treatment Impacts (1984), Proceedings of the Sixth North American Forest Soils Conference.* Earl L. Stone (ed.). Knoxville, University of Tennessee.

Froehlich, H.A.; Azevedo, J.; Cafferata, P.; Lysne, D. 1980. *Predicting Soil Compaction on Forested Land.* Montana, U.S. Dept. of Agriculture, Forest Service, Equipment Development Center. Report No. 7100-Engineering. 120 pp.

Klinka, K.; Pojar, J.; Medinger, D.V. 1991. "Revision of Biogeoclimatic Units of Coastal British Columbia" in *Northwest Science* 65:32-47.

Lewis, T.; Timber Harvesting Subcommittee. 1991. *Developing Timber Harvesting Prescriptions to Minimize Site Degradation.* Victoria, British Columbia Ministry of Forests. Land Management Report No. 62. 64 pp.

Lysne, D.H.; Burditt, A.L. "Theoretical Ground Pressure Distributions of Log Skidders," pp. 1327-1331 in *1983-Transactions of the ASAE.* St. Joseph, MI.

McNeel, J.F.; Ballard, T.M. "Analysis of Site Impacts from Thinning with a Harvester-Forwarder System," pp. 23-29 in *Journal of Forest Engineering.* Vol.4., No.1., 1992.

Meurisse, R.T. "Soil Productivity Protection and Improvement: Objectives, Policy, and Standards in the Pacific Northwest Region of the Forest Service," pp. 63-76 in *Proceedings of the Alaska Forest Soil Productivity Workshop.* U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-219. 120 pp. 1987.

Acknowledgements

The author would like to thank Steve Lackey of Fletcher Challenge Canada Limited's North Island Region for his cooperation during the study, and Keith and Arne Liseth of Skookum Logging and Towing for providing essential information and sharing their knowledge throughout the project.

The author is also indebted to Ray Krag of FERIC's Western Division for his advice in planning the study and analyzing the data, and for reviewing the draft report; and to Don Thibodeau, Marv Clark, and Shaun Berryman, and Jonathan Flintoft of FERIC Western Division for assisting with data collection.

Disclaimer

Appendix I

Harvesting System Cost Analysis

Item	JD450G Crawler tractor	JD540[b] Skidder (used)
SKIDDING AND FORWARDING COSTS[a]		
Ownership costs		
Total purchase price (P) $	81000	20000
Expected life (Y) yr	5	n/a
Expected life (H) h	7000	n/a
Scheduled hours per year (h)=(H/Y) h	1400	1000
Salvage value as % of P (s) %	30	100
Interest rate (Int) %	12.0	12.0
Insurance rate (Ins) %	2.0	2.0
Salvage value (S)=(P•s/100) $	24300	20000
Average investment (AVI)=((P+S)/2) $	52650	20000
Loss in resale value ((P-S)/H) $/h	8.10	0.00
Interest ((Int•AVI)/h) $/h	4.51	2.40
Insurance ((Ins•AVI)/h) $/h	0.75	0.40
Total ownership costs (OW) $/h	13.37	2.80
Operating costs		
Wire rope cost[c] (wc) $	2150	1150
Fuel consumption (F) L/h	10.0	15.0
Fuel cost (fc) $/L	0.36	0.36
Lube and oil cost as % of fuel cost (fp) %	10	10
Annual tire consumption (t) no.	-	1
Tire replacement cost (tc) $	-	1200
Track and undercarriage replacement cost (Tc) $	16500	-
Track and undercarriage life (Th) h	5000	-
Annual repair and maintenance costs (Rp) $	6000	10000
Operator wages (W) $/h	18.62	18.62
Wage benefit loading (WBL) %	35	35
Wire rope cost (wc/H) $/h	1.54	1.15
Fuel cost (F•fc) $/h	3.60	5.40
Lube and oil cost ((fp/100)•(F•fc)) $/h	0.36	0.54
Tire cost ((t•tc)/h) $/h	0.00	1.20
Track and undercarriage cost (Tc/Th) $/h	3.30	0.00
Repair and maintenance cost[d] (Rp/h) $/h	4.29	10.00
Wages and benefits (W•(1+WBL/100)) $/h	25.14	25.14
Total operating costs (OP) $/h	38.22	43.43
Total ownership and operating costs (OW+OP) $/h	51.58	46.23
FALLING AND BUCKING COSTS		
Wages (Wf) $/h	31.76	
Wage benefit loading (WBL) %	35	
Saw, gas and oil cost (Sc) $/shift	24.00	
Average shift length (sl) h	6.0	
Labour cost (Wf•(1+WBL/100)) $/h	42.88	
Saw, gas and oil cost (Sc/sl) $/h	4.00	
Total falling and bucking cost $/h	46.88	

[a] These figures are based on FERIC's standard costing methodology for determining machine ownership and operating costs, and do not include such costs as crew and machine transportation, supervision, profit, and office overhead.
[b] In this study the JD540 was an auxiliary machine, fully depreciated and used to forward logs on an intermittent basis.
[c] Annual wire rope costs are based on 5 mainlines and 40 chokers for the JD450G, and 3 mainlines and 20 chokers for the JD540. Mainlines cost $150, and chokers $35 each.
[d] Annual costs for repairs and maintenance were estimated by FERIC.