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PARTIAL CUTTING IN MOUNTAINOUS OLD-GROWTH FORESTS IN COASTAL BRITISH COLUMBIA: HARVESTING PRODUCTIVITY AND COST, AND RESIDUAL STAND IMPACTS

D.M. Bennett

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Abstract

The Forest Engineering Research Institute of Canada (FERIC) and International Forest Products Limited developed and implemented a partial cutting trial at Chamiss Bay on the west coast of Vancouver Island in British Columbia. The 1995/96 study investigated the harvesting feasibility for partial cutting in old-growth stands on steep slopes. The productivity and cost results for engineering, tree marking, manual falling, and cable yarding provide important new information to help forest operators plan, budget, and implement partial cutting trials and operations.

Author

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Summary

The Forest Engineering Research Institute of Canada (FERIC) and International Forest Products Limited (Interfor) developed and implemented a partial cutting trial at Chamiss Bay on the west coast of Vancouver Island. The study was conducted to investigate the harvesting feasibility of partial cutting in old-growth stands on steep slopes. The study sites were located within the Very Wet Maritime subzone (Submontane variant) of the Coastal Western Hemlock biogeoclimatic zone (CWHvm1).

Harvesting, using manual falling and cable-yarding systems, was done in the summers of 1995 and 1996. Two partial cuts (referred to as retention units), two strip cuts, and one clearcut were included in the harvesting study. The retention units had high levels of tree retention, 65 and 70% by basal area, with uniform dispersal of the retained trees. Harvesting productivities and costs were derived from shift-level production reports. Post-harvest surveys were conducted to quantify residual stand damage and soil-disturbance levels in the retention units.

In the 65% retention unit, falling productivity was 31% lower and falling cost was 45% higher than in the clearcut. However, falling productivity was reduced by only 2% in the 70% retention unit, compared to the clearcut, mainly because of a marked difference in timber type between this unit and the clearcut.

Cable-yarding productivity, measured in volume of logs per productive machine hour, was 34 and 30% lower in the 65 and 70% retention units, respectively, than in the clearcut. Yarding costs, based on scheduled machine hours, were 46 and 32% higher in these same units. These are the relative differences in yarding productivity and cost for the Chamiss Bay trial where a clearcut in similar steep terrain, with no landings, was used for comparison.

Post-harvest surveys showed that 34 and 37% of the residual stems had at least one scar of any size, and 12 and 10% of the residual stems had at least one scar that was ≥900 cm^2, in the 65 and 70% retention units, respectively. Exposed mineral soil was observed on only 1.4 and 1.5% of the soil surface area in the 65 and 70% retention units, respectively.

The productivity and cost results for the retention units provide important new information to help forest operators plan, budget, and implement future partial-cutting trials and operations. The trial showed the potential to harvest timber on sensitive sites, with conventional equipment and crews, thus creating an opportunity to augment timber supplies.

Sommaire

L'Institut canadien de recherches en génie forestier (FERIC) et International Forest Products Limited (Interfor) ont préparé et mis en oeuvre un essai de coupe partielle à Chamiss Bay sur la côte ouest de l'île de Vancouver. L'étude avait pour but d'examiner la faisabilité de récolter par coupe partielle de vieux peuplements primitifs sur de fortes pentes. Les aires d'étude étaient situées dans la sous-zone maritime très humide (variante submontagnarde) de la zone biogéoclimatique de la pruche de l'Ouest côtière (CWHvm1).

La récolte a été effectuée par abattage manuel et téléphérage durant les étés 1995 et 1996. Les aires d'étude comprenaient deux coupes partielles (désignées comme unités de coupes avec réserves), deux coupes par bandes et une coupe rase. Dans les unités de coupe avec réserves, on conservait une proportion élevée des arbres, soit 65 et 70 % en surface terrière, avec dispersion uniforme. Les productivités et les coûts de récolte ont été dérivés des rapports de production par poste de travail. Des inventaires après coupe ont permis de quantifier les niveaux de dommages au peuplement résiduel et de perturbation du sol dans les unités avec réserves.

Dans l'unité avec 65 % de réserves, la productivité à l'abattage était de 31 % plus faible et le coût de l'abattage y était de 45 % plus élevé que dans la coupe rase. Cependant, la productivité à l'abattage était réduite de 2 % seulement dans l'unité avec 70 % de réserves, comparativement à la coupe rase, principalement à cause d'une différence marquée dans le type de peuplement entre ces deux unités.

La productivité du téléphérage, mesurée en volume de billes par heure-machine productive, était de 34 et de 30 % plus faible dans les unités avec 65 et 70 % de réserves, respectivement, que dans la coupe rase. Le coût du téléphérage, basé sur le nombre d'heures-machines prévues, était de 46 et de 32 % plus élevé dans ces mêmes unités. Ce sont les

différences relatives dans la productivité et le coût du téléphérage pour l'essai de Chamiss Bay où une coupe rase dans un terrain escarpé similaire, sans jetées, a été utilisée aux fins de comparaison.

Les inventaires après coupe ont montré que 34 et 37 % des tiges résiduelles avaient au moins une blessure de dimensions quelconques, et que 12 et 10 % des tiges résiduelles avaient au moins une blessure de 900 cm^2, dans les unités avec 65 et 70 % de réserves, respectivement. Une exposition du sol minéral a été observée sur seulement 1,4 et 1,5 % de la surface du sol dans les unités avec 65 et 70 % de réserves, respectivement.

Les résultats relatifs à la productivité et au coût dans les unités de coupe avec réserves représentent une nouvelle information importante susceptible d'aider dorénavant les opérateurs forestiers à planifier, à budgéter et à exécuter des essais et des opérations de coupe partielle. L'essai a démontré la possibilité de récolter des arbres sur des sites fragiles, avec de l'équipement traditionnel et des équipes manuelles, offrant ainsi l'occasion d'augmenter les approvisionnements de matière ligneuse.

INTRODUCTION

Several studies have examined cable yarding operations for commercial thinning and partial cutting prescriptions in second-growth forests (Kellogg et al. 1996; Kellogg et al. 1986; Tesch et al. 1986; Howard et al. 1996; Hedin 1994). Others have assessed the opportunity to apply alternative silvicultural systems to mature forests in coastal British Columbia (Nelson et al. 1990; Weetman et al. 1990; Moore 1991; Sanders and Wilford 1986). However, there are few well-documented operational trials of partial cut harvesting using cable systems in mountainous old-growth forests of coastal British Columbia. Therefore the harvesting feasibility—in terms of harvesting productivity and cost, and impacts on residual stands and soils—of such operations is not well understood.

In particular, no operational trials have been performed in the Very Wet Maritime subzone (Submontane variant) of the Coastal Western Hemlock biogeoclimatic zone (CWHvm1). This biogeoclimatic unit is very common along western Vancouver Island and the outer mainland coast of British Columbia, and forms a critical component of the timber supply in these regions.

This report describes the results of a cable harvesting trial involving the use of high-retention silvicultural systems on steep, environmentally sensitive slopes on the west coast of Vancouver Island. Harvesting operations were conducted between July 1995 and September 1996 at International Forest Products Limited's (Interfor) Chamiss Bay operation in Kyuquot Sound.

BACKGROUND

In early 1992, Interfor was asked by local citizens and the Kyuquot/Checleset First Nations to explore alternatives to clearcutting in the Kyuquot Sound area on the west coast of Vancouver Island. Traditional clearcutting and plantation silviculture are proven, well-established practices for regenerating the forested ecosystems within Kyuquot Sound. However, the need to reduce the visual impact of harvesting, maintain the stability of steep slopes, and preserve the quality of water on sensitive sites were the primary reasons for the request.

Subsequently, a steering committee composed of representatives of Interfor, the Forest Engineering Research Institute of Canada (FERIC), the University of British Columbia (UBC) Faculty of Forestry, a forest resources consultant,[1] the B.C. Ministry of Forests (BCMOF) Vancouver Region's Forest Sciences Section, and other coastal forest companies began a series of meetings to discuss the feasibility of an operational trial. A trial of alternative harvesting systems was proposed by the group, and Interfor's operating area at Chamiss Bay in Kyuquot Sound was chosen as the location (Figure 1). The committee recognized that implementing alternative silvicultural systems in old-growth stands on steep, sensitive coastal sites would be a challenge for harvest planners and practioners, especially if high levels of tree retention were required. However, an investigation into partial cutting under these conditions was needed because such sites are often permanently deferred from conventional clearcut harvesting (Sauder and Wellburn 1989). A successful demonstration of silvicultural systems that maintain high levels of tree retention might permit similar harvesting methods to be employed on previously deferred environmentally sensitive sites and thereby augment the coastal timber supply. More recently, the need for operational harvesting trials was recognized by the Clayoquot Sound Scientific Panel (CSP 1995).

The steering committee felt strongly that it was essential to involve forest workers from the outset to ensure that they gained direct experience with alternative harvesting practices. It was also important to determine whether

[1] Shelterwood Forest Management Ltd., Courtenay, B.C.

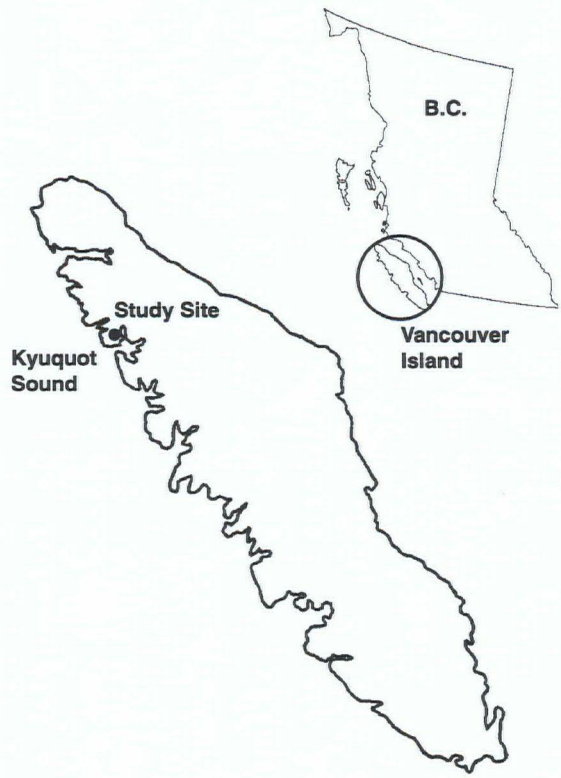


Figure 1. Location of the study sites.

conventional cable-yarding equipment currently used in coastal B.C. could be successfully applied to partial cutting in old-growth stands. If so, investment in new alternative yarding equipment could be minimized.

FERIC and Interfor worked together to plan and implement the trial, and designed a study to determine the feasibility of the harvesting operations. The study had the following objectives:

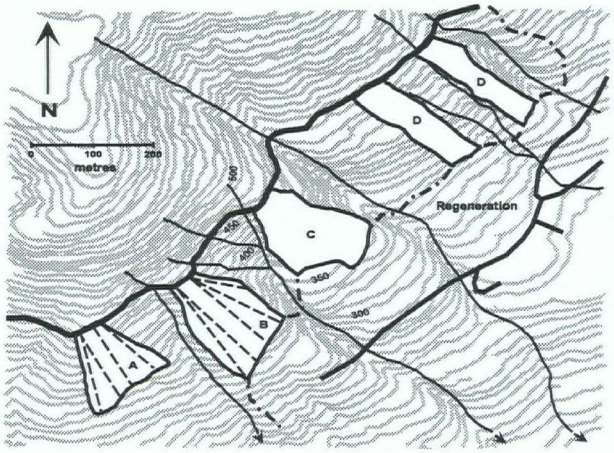
- Develop and implement procedures for the engineering and tree-marking phases, and document the methods and costs for these phases.
- Determine harvesting productivities and costs for the partial cutting units in the trial, and compare them to a clearcut in similar terrain and stand conditions.
- Determine the levels of residual stand damage and soil disturbance associated with harvesting in the partial cutting units.
- Provide preliminary comment on the short-term effects of the partial cutting methods on visual quality and windthrow.

STUDY METHODS

Study Sites

Two areas considered typical of the sites that were the focus of this trial were selected for harvesting. One area was a uniform sidehill interrupted by occasional gully complexes; this site was subdivided into four cutting units (A,B,C, and D) (Figure 2) with similar terrain conditions and aspects. Unit boundaries were located around stands of timber situated between the steep gullies; the sizes of the cutting units were dictated by gully spacings. The second site, consisting of one cutting unit (E), was located in a neighbouring valley (Figure 3). This cutting unit had the steepest terrain, with slopes on some portions exceeding 100%. The areas and average ground slopes for all cutting units are found in Table 1. Elevations ranged from 300–600 m above sea level, and ground slope varied from 55–100%.

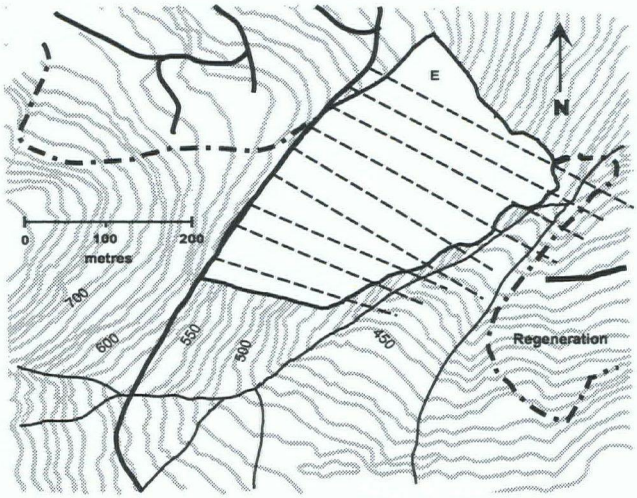
The stands represented old-growth forests on zonal sites within the CWHvm1 biogeoclimatic unit. The predominant tree species were western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*) with a minor component of western red cedar (*Thuja plicata*) (Table 1). The shrub layer was comprised mainly of huckleberry and blueberry (*Vaccinium spp.*).



Cutblock
A - 55% Retention
B - 70% Retention
C - Clearcut
D - Strip clearcuts

Yarding corridors
Roads

Figure 2. Layout of four of the five cutting treatments.



Cutblock E - 65% Retention

Yarding corridors
Roads

Figure 3. Layout of the 65% retention unit.

Like many areas on the west coast of Vancouver Island, the trial sites are subject to storm-force winds in winter. The high potential for windthrow influenced the choice of tree retention levels in the Chamiss Bay trial. A windthrow hazard assessment was conducted to provide baseline information about stand level characteristics (Mitchell 1993). Topographic exposure, rooting depth, and exposure to winds were used in conjunction with observed windthrow patterns to assess the relative windthrow risk in the cutting units.

Table 1. Stand Conditions by Cutting Unit

Cutting unit description	55% retention [a]	65% retention	70% retention	Strip cuts [b]	Clearcut
Area (ha)	1.7	5.1	2.4	2.8	2.3
Average ground slope (%)	65	81	61	58	62
Species composition					
Western hemlock (%)	55	71	65	56	72
Amabilis fir (%)	6	24	16	6	26
Western red cedar (%)	34	4	14	33	2
Other species (%)	5	1	5	5	0
Tree density (no./ha)	441	494	435	437	503
Basal area (m^2/ha)	62	76	84	64	75
Net volume (m^3/ha)	616	821	893	638	809

[a] This cutting unit is not included in the productivity and cost analysis.
[b] Two strip cuts, 1.4-ha each, were harvested.

Cutting Treatments

Five cutting treatments were selected for the trial, and one treatment was assigned to each cutting unit. High levels of tree retention were prescribed for three cutting units and two variations of clearcutting were prescribed for the other two units. The following basal area retention targets for live trees were set for the partial cutting units, hereafter referred to as "retention units":

- 55% retention.
- 65% retention.
- 70% retention.

The other treatments were:

- One small clearcut.
- Two strip cuts, each 50–60 m in width.

Four of the five cutting treatments (the 55 and 70% retention units, the small clearcut, and the strip cuts) were situated on one hillside (Figure 2), and the 65% retention treatment was assigned to the other site.

Although three retention units were harvested in the Chamiss Bay trial, only the 65 and 70% units were included in the harvesting study. The 55% retention unit was located in a poor timber type and had only a small volume harvested from it. This unit provided Interfor with an opportunity to gain additional operational experience with partial cutting, but it was not a suitable source of data for the harvesting study.

Harvesting Productivities and Costs

Engineering and tree marking. The cutting units were designed around existing roads. Standard forest engineering procedures were used to locate and traverse the external boundaries of the cutting units and were not included as part of this trial. Only the incremental time—i.e., the time spent on corridor layout and tree marking was used in the calculation of engineering and marking costs.

Falling, yarding, and loading. Productivities and costs for the falling and cable-yarding phases were determined for the 65 and 70% retention units, the strip cuts, and clearcut. Shift reports, detailing time and production, were completed daily by the falling and cable-yarding crews and collected for the shifts worked in each cutting unit—i.e., 100% of the shifts were sampled. These shift-level records formed the basis for the productivity and cost analyses.

The total volume yarded (m^3) from each cutting unit was tracked and scaled at the Chamiss Bay sortyard.

Hourly owning and operating costs were developed using FERIC's standard costing methodology for examples of typical cable-yarding and log-loading equipment used in the study and for an individual faller (Appendix I and II) and applied to the productivity measures to generate unit harvesting costs for each phase. Costs for log loading were summarized together with the yarding phase because operating conditions in the steep terrain required the yarder and log loader to work as a team.

Residual stand damage and soil surface conditions. Surveys were conducted to quantify the level of damage to residual trees and changes to soil surface conditions resulting from harvesting in the 65 and 70% retention units. The sampling scheme was based on the principles of cluster sampling (Cochran 1977), combined with systematic selection of the clusters. A randomly oriented grid with grid points spaced on a 35-m by 35-m pattern was superimposed over the site maps, providing 34 and 17 evenly distributed plot centers for the 65 and 70% retention units, respectively.

Each grid point served as the center of a circular fixed-area plot, with a radius of 11.28 m and area of 0.04 ha, to document residual stand damage. The species and diameter of all trees in each plot were recorded. For trees with scarred boles, the diameter, width, and length of individual scars; scarring severity; and location of each scar were recorded.

The grid points were also used as plot centers for assessing soil surface conditions. At each grid point two 17-m transects were established with their origins at the grid point. The first transect was run on a random bearing and the second transect was run on an offset bearing 90° clockwise from the first transect.

Cluster sampling, using clusters of equal sizes, was applied to record soil conditions. The lengths occupied by each class of soil surface condition, along each transect, were recorded and then summed for both transects at each grid point. The proportion of total transect length (based on the combined 34-m length of both transects) was calculated for each class of soil surface condition at each grid point.

DESCRIPTION OF OPERATIONS

Engineering

Prior to beginning the layout phase, the following harvest design specifications were developed to guide engineering activities:

- All cutting units were designed for uphill yarding.
- Yarding corridors were to be 4 m wide and spaced approximately 30 m apart.
- Parallel yarding corridors, oriented perpendicular to the contours, were preferred.
- Partial suspension of logs was required during lateral yarding and uphill yarding along the corridors.
- The yarder's running lines were to be confined within the yarding corridor at an elevation of 10–15 m above the ground.
- Backspar trees were to be used wherever possible to achieve desired line clearances and partial suspension.

Field layout was performed in a series of steps. First, cutting unit boundaries were located, surveyed, and mapped at a scale of 1:2000. Second, potential backspar trees or tailhold stumps, and suitable tieback trees or stumps, were located; next, preferred yarder positions on the road were identified. These points were then connected in a closed traverse and mapped. Third, a centerline for each yarding corridor was located to match the preferred yarder position on the road with the selected backspar tree or stump that most closely met cable-deflection requirements and the desired spacing between corridors. Finally, deflection lines were surveyed and load path analyses were conducted for each corridor. Required rigging heights for the backspar trees were determined from these analyses.

The longest slope yarding distance and longest distance to a tailhold were 320 and 380 m, respectively. These distances were required for some yarding corridors in the 65% retention unit.

Input from Interfor's woods foreman, the falling contractor, and the Worker's Compensation Board of British Columbia (WCB) was obtained in the field and incorporated into the design and engineering of cutting treatments and the tree-marking criteria.

Tree Marking

Five goals were specified for the post-harvest condition of the stands:

1. Maintain a continuous forest cover, and evaluate the need to plant any gaps, such as yarding corridors, after harvesting.
2. Retain a high proportion of relatively uniformly distributed residual trees to prevent windthrow.
3. Retain approximately the same proportion of tree species and diameter classes in the residual stands as in the natural untreated stands.
4. Retain some of the forest structures, such as large trees and downed wood, for biological diversity.
5. Give priority to removing trees with hemlock dwarf mistletoe (*Arceuthobium tsugense*) or other diseases to improve forest health.

These goals guided tree-marking in the retention units. Tree retention and removal targets were expressed in terms of live tree basal area (m^2/ha). Total basal area in each retention unit was reduced by marking trees for cutting in all diameter classes such that the proportion of trees in each diameter class after harvesting was similar to that class's proportion in the original stand—i.e., trees were marked across the stand profile so that a similar diameter distribution was retained.

Wherever possible, trees that appeared vigorous and well-formed were left to continue to grow. Trees given priority for cutting were:

- All snags, to comply with WCB safety regulations.
- Western hemlock infected with hemlock dwarf mistletoe, and all species displaying conk or other pathological indicators.
- Trees displaying poor form, and those thought to be dying.
- Trees judged to be susceptible to windthrow, based on criteria in Stathers et al. (1994).

Inter-tree distance, crown width, and canopy closure were also considered during marking, but rigid criteria were not practical given the irregular structure of the old-growth stands. A tree spacing of 5 m was occasionally used as a general rule when marking in dense clumps of trees.

Falling feasibility, taking into account the adjacent residual trees and surrounding terrain, was a crucial factor in marking. Usually several trees were evaluated simultaneously because cutting one tree often meant that others had to be taken to prevent hang-ups and brushing of residuals during falling.

Species, diameter-at-breast-height (dbh), and pathological indicators were recorded for all marked live trees in each retention unit to control the marking process. Also, species, dbh, and estimated height were recorded for all snags. Tree data were entered into a datalogger in the field as tree marking progressed, and were downloaded and analyzed at the end of the day to ensure that the basal area retention targets were being met.

Marking was done with a three-person team: two people measured diameters and marked the selected trees with paint, and one person entered data in the data logger. Forest engineering and forestry personnel collaborated in the tree-marking phase. Occasionally the operation's woods foreman and lead contract faller assisted the markers, thus providing a good opportunity to review the practical aspects of tree selection methodology.

Trees were marked to cut in the following sequence: (1) two adjacent 4-m-wide yarding corridors were delineated by marking all trees within 2 m either side of the corridor centerline; and (2) the segment of the stand in between the two corridors was then marked. Because corridor centerlines had been previously plotted, individual areas for these stand segments were easily calculated on the 1:2000 scale maps. The areas were used to compute unit basal area as each segment of the stand was marked.

In the early stages of marking, ribbon was used to flag the selected trees and data were analyzed as each stand segment was completed. Tree marking with paint did not begin until markers were confident that the basal area targets for a cutting unit could be met. The retention units were under-marked by 3 to 5% of basal area to allow for additional tree removals during the falling phase for safety reasons, and to recover any stems damaged during falling or yarding.

Although all snags within the cutting units were felled for safety reasons, abundant snags remained in the "leave" areas and forested gullies adjacent to the trial's small cutting units. These snags, and the high numbers of trees within the retention units themselves, meant that much of the natural forest's structural diversity was retained in the vicinity of the retention units.

Falling and Bucking

One contractor[2] was responsible for manual falling and bucking in all units. Except in the 65% retention unit, only one faller could work in each cutting unit because of their small sizes. However, the cutting units (except the 65% retention unit) were on a common hillside and close enough to each other that fallers could monitor one another as they worked in neighbouring units, thereby satisfying WCB requirements.

The fallers used a chainsaw, an axe, and wedges to fall and buck trees in the retention units. Practices were the same as for conventional falling in clearcuts. Fallers worked up the slope progressing back and forth over a section of the stand, using the tree's natural lean to fall each tree across the slope, and trees were wedged over when necessary (Figure 4). The limbs were removed and the stems were bucked to Interfor's preferred lengths.

[2] Shiels Falling and Consulting Ltd., Nanaimo, B.C.

Figure 4. Faller wedging a tree in the 65% retention unit.

All trees within the yarding corridors were felled concurrently with the rest of the marked trees in the stand. Corridor trees were felled in the same manner as other marked trees, across the slope, and bucked where they rested. Directional felling of timber toward yarding corridors in a herringbone pattern was not attempted because of the large tree sizes and steep slopes. The fallers were directed to use their discretion and substitute marked trees with similar unmarked trees if they felt uncomfortable about a falling situation.

Yarding and Loading

Interfor's crews used company-owned equipment for the yarding and loading phases. A Cypress 7280B swing yarder (Figure 5) rigged in a running skyline configuration harvested the three retention units and the clearcut. A Johnson mechanical slackpulling (MSP) carriage was used to provide the necessary lateral yarding capability (Figure 6). The yarder worked on single-lane roads in the retention units and clearcut, and swung logs onto the road surface for unhooking.

The swing yarder, weighing 72 700 kg, is typical of the large yarders that are used extensively on the B.C. coast for harvesting clearcuts in old-growth timber. The winch for the 7280B model is comprised of two side-by-side main drums (connected by a geared counter-rotating assembly), and a haulback drum. It is mechanically interlocked in both directions and, in this case, was retrofitted with water-cooled regenerative clutches.

A system of yarding corridors was used in the retention units. Logs were pulled laterally into each skyline corridor and then yarded up the corridor to roadside. For each yarding corridor, the designated backspar tree was rigged at the height needed to achieve the required deflection in the running lines and ground clearance.

Figure 5. Cypress 7280B swing yarder.

Figure 6. MSP (dropline) carriage used with the swing yarder.

The four longest corridors in the 65% retention unit (see Figure 3) were rigged to stumps in a cutover across a gully, which provided the required deflection and running line clearance for yarding. Backspar trees were also used in the clearcut. The clearcut provided a good comparison to the retention units, in terms of yarding operations, because the swing yarder was again equipped with the MSP carriage, and the terrain and landing conditions were similar.

A Madill 171 tower yarder, rigged in a slackline configuration and equipped with an MSP carriage, was used to harvest the two strip clearcuts. The deflection lines run during the engineering phase had shown that timber in the lower portions of each strip

could not be yarded by high-lead or running skyline systems. Good deflection was assured in each strip cut by anchoring the skyline on a ridge located 600 m slope distance below the yarder. The tower yarder worked on large landings above each strip cut making it easy to land logs and unhook chokers in front of the machine.

The droplines used with the two MSP carriages were 45 m long and 22 mm in diameter, while chokers were 7.5 m long and 19 mm in diameter.

Hydraulic log loaders were paired with the swing yarder and tower yarder in all the cutting units.

The yarding crew complement for the retention units was slightly different than for the strip cuts and clearcut. A rigging slinger[3] and one chokersetter hooked chokers in the retention units, while two chokersetters worked with the rigging slinger in the strip cuts and clearcut. Most of the time two chokers were attached to the dropline in the retention units; three chokers were used in the strip cuts and clearcut.

In the retention units, the hooktender, swing yarder operator, and rigging slinger communicated with hand-held radios. The rigging slinger directed the yarder operator where to stop the carriage for log hookup; the rigging crew then pulled the dropline and chokers laterally to the logs. After the chokers were set and the crew was at a safe distance from the yarding lines, the rigging slinger directed the operator to yard the logs laterally into the corridor.

The ability of swing yarders to operate within the width of a single-lane road is important when cable yarding on steep slopes because road widths must be kept to a minimum and opportunities to build landings are limited in this type of terrain. A swing yarder can move easily along such roads between parallel yarding corridors, and rig-up involves setting only two guylines. The running skyline configuration used for these yarders, combined with an MSP carriage, is a flexible system suitable for clearcuts or partial cuts (Lysons and Twito 1973; Mann 1977). Also, log handling is facilitated in steep terrain if the yarder can swing and land logs on the road for unhooking or pass them to an accompanying log loader as the logs reach roadside. These factors led to the choice of a swing yarder for the retention units in the Chamiss Bay trial.

The region's WCB Occupational Safety Officer[4] visited the sites on several occasions prior to and during engineering, falling, and cable yarding operations. Additional safe work procedures were developed for the trial, including guidelines for the maximum wind speed under which the yarding crews could safely work in the partially cut stands.

RESULTS AND DISCUSSION

Engineering

Nine and five yarding corridors were laid out to harvest the 65 and 70% retention units, respectively (see Figures 2 and 3). The time and costs for corridor layout in the 65 and 70% retention units are shown in Table 2. Incremental engineering activities included in corridor layout are: locating and mapping backspars, tailholds, tie-backs, and yarder positions; locating and flagging corridor centerlines; running deflection lines; and conducting load path analyses for each corridor. Person-hours represent the combined time for all members of the engineering crew. One-third of the total hours spent on corridor layout was charged at $56.25/h while two-thirds were charged at $31.25/h. This apportionment represents a crew of one field engineer/forester and two assistants. Costs were $2.57/m^3 and $2.66/m^3 for the 65 and 70% retention units, respectively.

An accurate cutting unit base map is imperative for yarding corridor layout. Roads, cutting boundaries, backspar locations, and yarder positions must be carefully surveyed. Because the corridors were narrow (4 m) and distances to the tailhold extended up to 380 m, the flagged line connecting the yarder's positions with the backspars had to be perfectly straight to ensure that after falling, the yarder's lines would run without obstruction to the backspar. If bearings are not accurate, several attempts may be needed to connect corridor end points. The mapping scale of 1:2000 was found to be appropriate for this purpose. Key points could be plotted accurately, which in turn enabled correct bearings to be calculated for yarding corridor centerlines.

The 4-m wide corridors used in this trial worked well. The narrow corridors were specified to reduce the visual impact of harvesting and to prevent wind from penetrating the stand. Figure 7 shows a corridor in the 65% retention unit, viewed after falling but prior to yarding. The tailhold stump in the foreground was one of four located on a slope across the creek from the cutting unit. Figure 8 shows a post-harvest view looking up the slope from within the corridor.

[3] A "rigging slinger" supervises the chokersetters, chooses the logs for hookup, and participates in choker setting.

[4] John Galuska, Occupational Safety Officer, Worker's Compensation Board of British Columbia, Courtenay, B.C.

Table 2. Field Work Required for Retention Units

	65% retention			70% retention		
	person-h	$/m³	$/ha	person-h	$/m³	$/ha
Corridor layout	117	2.57	908	60	2.66	990
Tree marking	91	2.00	706	32	1.42	528
Total	208	4.57	1 614	92	4.08	1 517

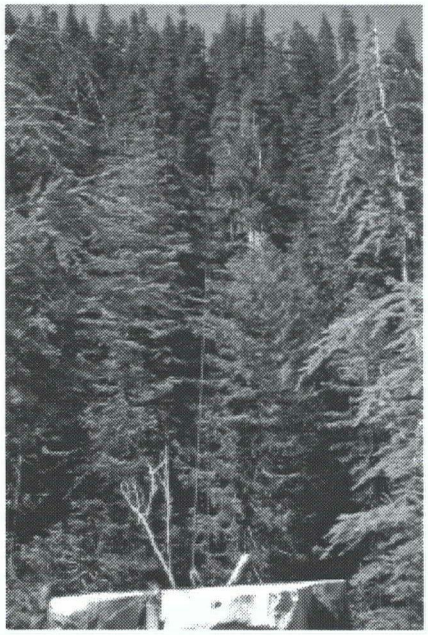


Figure 7. Yarding corridor in the 65% retention unit immediately prior to yarding—tailhold stump in foreground.

Figure 8. Yarding corridor in the 65% retention unit after yarding was completed—ground level view, looking up the slope.

A relatively close corridor spacing of 30 m was chosen because the steep terrain and large trees raised a concern that logs would tend to roll downhill during lateral yarding and hang up behind residual trees. In most cases this spacing was achieved. In practice, a rigid specification for corridor spacing cannot be maintained on sites like those at Chamiss Bay. In a few cases the distance was increased up to 40 m when rock bluffs interfered with the desired corridor location or the preferred backspar trees were widely spaced.

The trial showed that the target height above ground of 10–15 m for the running lines was correct. This provided enough clearance between the ground and the running lines to yard logs laterally and move them into the corridor without damaging the trees bordering the corridor. Too much clearance would allow the lines to lift out of the corridor and damage tree tops. During lateral yarding, the running lines would often lightly contact some trees bordering the corridor. Logs turned easily from their lateral cross-slope position into the corridor when the specified height of the running lines was maintained. Adhering to the engineering specifications for running line height is important when yarding in retention units.

Parallel corridors, oriented perpendicular to the contours, were preferred to provide control of logs and to reduce hang-ups during yarding. A parallel corridor configuration was laid out on the 65% retention unit but ridges and gullies, and the orientation of the haul road and unit boundaries, dictated corridors in a fan-shape—i.e., several corridors radiating from one yarder position—in the other retention units. The number of fan-shaped corridors emanating from one landing was kept to two or three to minimize the amount of cross-slope yarding within the corridors. In fact, corridors in the fan-shaped configuration still ran roughly perpendicular to the contour because landings were positioned on ridges. Such positions enabled the yarder to bring logs directly uphill on either side of a ridge.

Downhill yarding was not considered for the Chamiss Bay trial because of the steep slopes and high cutbanks along the roads. The safety of the yarder operator and landing crew may be jeopardized when yarding downhill through a steep corridor if the yarder is positioned at the

corridor's base, in the path of potential runaway logs and debris. Downhill yarding in partial cuts may be an option if the harvesting system is designed appropriately, for example, the yarder is positioned beyond the base of the slope, or yarding is restricted to gentle slopes.

Tree Marking

The marking procedures developed for the Chamiss Bay trial worked well operationally. On-site input from the falling contractor and the woods foreman was especially useful because by the time engineering and tree marking were completed, these individuals were assured that the harvest plan was workable and they were determined to make it succeed. Evidence of the success of the marking scheme is that the fallers substituted very few marked trees with alternate unmarked trees.

Table 3. Post-Harvest Stand Descriptions for Retention Units

	65% retention	70% retention
Species composition		
Western hemlock (%)	71	69
Amabilis fir (%)	22	17
Western red cedar (%)	6	12
Other species (%)	1	2
Tree density (no./ha)	381	302
Basal area (m^2/ha)	49	57
Net volume (m^3/ha)	518	632

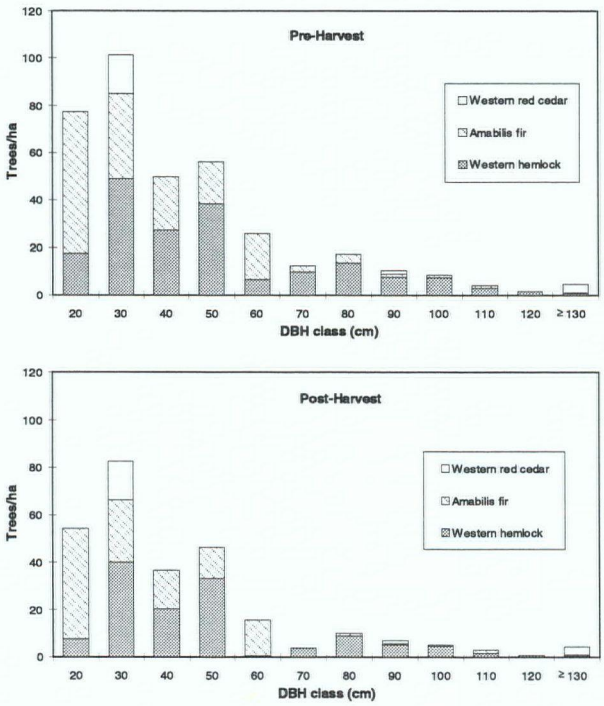


Figure 9. Pre- and post-harvest diameter distributions for the 65% retention unit.

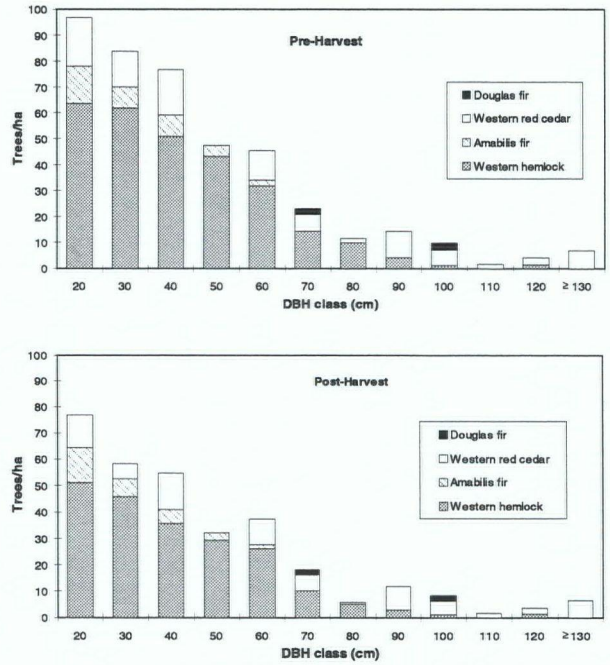


Figure 10. Pre- and post-harvest diameter distributions for the 70% retention unit.

Table 3 shows the post-harvest stand descriptions, and Figures 9 and 10 show the pre- and post-harvest diameter distributions for the 65 and 70% retention units, respectively. The retained trees were dispersed as uniformly as possible in each unit, although the pattern of retention was variable because the spatial distribution of trees in the untreated stands was irregular with numerous gaps.

Tree marking costs were \$2.00/m^3 (\$706/ha) and \$1.42/m^3 (\$528/ha) for the 65 and 70% retention units, respectively (Table 2). The higher cost in the 65% retention unit is attributed to two factors. First, this unit had the longest yarding distances and the steepest, most rugged terrain, so a greater proportion of hiking time was required to complete the marking. Second, the tree-marking procedures were first used and refined in this unit, so the experience gained here reduced the marking time required for the 70% retention unit.

Tree marking in old-growth is complex and unfamiliar to most foresters on the B.C. coast. It is difficult to balance all the tree marking criteria because a forester must weigh many objectives simultaneously and make tradeoffs during the process. The marking system must be coordinated with the natural lean of the trees to make

the falling operation safe and to minimize damage to the residual stand. Perhaps most importantly, markers must try to visualize the sequence and direction in which each tree will be felled. This means being able to gauge a tree's lean even when it is not obvious, something that is often difficult to do in such forests. The marker is not likely to have this skill and input from an experienced faller is invaluable at this stage. When marking has been done correctly, fallers should be able to fall trees, successively, into natural gaps in the stand, and into the openings created when snags and other marked trees have been felled. In the end, the fallers must have the option to exchange marked trees with similar unmarked trees for safety reasons.

The trial's planners marked each tree for cutting, with input from the fallers, because the novel silviculture prescriptions, developed for the structurally complex old-growth stands, were untried. Tree marking forces planners to thoroughly review and implement their harvesting proposals on the ground. For several reasons, this is a prudent step when planning partial cuts in challenging stand and terrain conditions. First, it ensures that planners deal with the practical aspects of tree selection and falling. Second, the marking process promotes a better understanding of long-term stand management goals. And finally, when advice from operations personnel is drawn into the process, the possibility of an unworkable harvest plan being forced on an operation should be eliminated. An acceptable alternative, for subsequent operations in similar stands, is to have experienced fallers select the trees as they carry out their falling and bucking activities.

Falling and Bucking

Table 4 presents four productivity measures for falling and bucking by cutting unit. Compared to the trial's small clearcut, falling productivities were 31% lower in the 65% retention unit, 2% lower in the 70% retention unit, and 18% lower in the strip cuts. The 65% retention unit and the clearcut provide the best comparison of the relative difference in falling productivity under the trial conditions (i.e., 31% lower falling productivity for the retention unit compared to the clearcut) because species composition and volumes per ha were very similar in these units. The falling productivity in the 70% retention unit (27.5 m^3/h or 178.8 m^3/shift) was relatively high, only 1.6% lower than the falling productivity in the clearcut. This was attributed mainly to the tall, uniform timber and the high net volume per hectare in the 70% retention unit (Table 1).

The substantial difference in productivity between the two retention units probably resulted from a combination of factors. First, the terrain was steeper and yarding distances were longer in the 65% retention unit and therefore the proportion of faller's time needed to pack equipment into the unit, and to hike in and out of the work area each day, was greater. Second, although average dbh of the marked stems was greater in the 65% retention unit, the trees appeared to be shorter and more limby compared to the tall, uniform timber and the higher volume per ha in 70% retention unit.

The lower falling productivity in the strip cuts compared to the clearcut reflects in part the fact that when a working area is confined to a 50- to 60-m-wide strip, the faller must spend more time directing trees into the strip along each side boundary. Timber type was another factor. Even though the clearcut and strip cuts were in close proximity on the same hillside, the strip cuts were in a relatively low-volume cedar-hemlock stand and the clearcut was in a higher volume hemlock-amabilis fir stand.

The costs per cubic metre for falling and bucking are shown in Table 5. Even for the retention units, these are quite low compared to most conventional falling operations in coastal B.C. because allowances for crew transportation, overhead, and profit were not included in the calculation of hourly falling cost, and falling

Table 4. Average Falling and Bucking Productivity by Cutting Unit

Productivity	65% retention	70% retention	Strip cuts	Clearcut
Pieces [a]				
no./shift [b]	63.8	112.4	95.7	109.8
no./h	9.8	17.3	14.7	16.9
Volume				
m^3/shift	125.1	178.8	149.3	181.7
m^3/h	19.2	27.5	23.0	28.0

[a] A "piece" is a manufactured log, ready for yarding.
[b] A faller's shift length is 6.5 h.

Table 5. Average Falling and Bucking Cost by Cutting Unit [a]

Activity	65% retention	70% retention	Strip cuts	Clearcut
Falling and bucking ($/m^3)	3.82	2.67	3.20	2.63

[a] These costs are quite low compared to most conventional falling operations in coastal B.C. because allowances for crew transportation, overhead, and profit were not included in the calculation of hourly falling cost, and falling productivities in the trial units were quite high. The cost results should therefore be used primarily to examine the relative differences in falling costs between the trial units themselves.

productivities in the trial units were quite high. The results should therefore be used primarily for examining the relative differences in falling costs between the trial units themselves. Compared to the trial's small clearcut, falling costs were 45% higher in the 65% retention unit, 2% higher in the 70% retention, and 22% higher in the strip cuts.

Also, because Interfor's preferred log lengths were maintained in all cutting units, there were no negative impacts on log value associated with the retention units.

Partial cutting prescriptions add to the complexities of falling old-growth timber, and the fallers' paramount concern was maintaining safe work practices. All snags were felled concurrently with marked green trees. (There were 35 and 55 snags/ha in the 65 and 70% retention units, respectively.) Potential problems such as hang-ups, brushing of standing timber during falling, and limbs hanging up in the residual canopy were infrequent. Falling and bucking operations were completed without any safety incidents. The fact that high productivities were also achieved in all cutting units is evidence of the skill and hard work that the falling contractor brought to bear on this project.

Yarding and Loading

Table 6 summarizes cable-yarding production. Scheduled machine hours (SMH) represent the time spent on all activities during the study period including delays (with the exception of long-term mechanical delays), and includes productive yarding time plus mechanical and non-mechanical delays. Productive machine hours (PMH) includes only actual productive yarding time and the time required to change yarding roads or corridors.

Figure 11 shows the distribution of total SMH for cable yarding in each cutting unit. The *yarding logs* component accounted for 78% of the total SMH in the 65% retention unit, 83% in the 70% retention, 70% in the strip cuts, and 77% in the clearcut. In the strip cuts, the time available for yarding logs was lower because 13% of SMH was taken up with *other delays* (failures of guyline stumps and a skyline anchor stump).

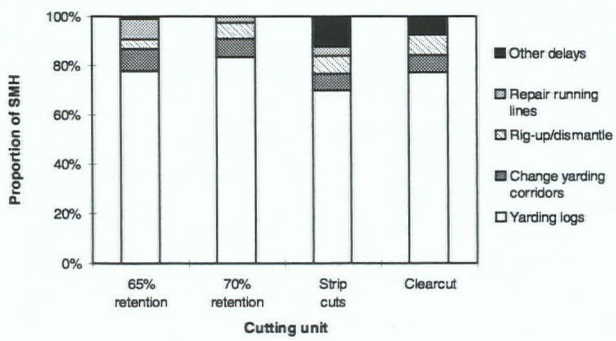


Figure 11. Time distribution for cable yarding operations.

Table 6. Average Cable Yarding Production: Summary

Production	65% retention	70% retention	Strip cuts	Clearcut
Total time				
PMH [a]	109.7	51.0	99.5	82.8
SMH [b]	125.4	56.0	128.8	98.5
Yarding production				
Volume (m^3)	1 799	894	1 791	2 069
Volume (m^3/piece)	1.1	0.8	0.9	0.8
Pieces (no./cycle)	2.3	2.4	2.6	2.7

[a] PMH = productive machine hours.
[b] SMH = scheduled machine hours.

Yarding road changes accounted for 9% of SMH in the 65% retention unit, 8% in 70% retention, 7% in strip cuts, and 7% in the clearcut. For the retention units, each yarding corridor required a yarding road change; in the strip cuts, two skyline yarding road changes were required in each strip. The retention units required more road changes per unit volume of timber logged, but the average time per road change was longest in the strip cuts because the skyline anchor and the tower yarder were both repositioned.

Rig-up/dismantle, the time required for the initial setup and subsequent dismantling of the cable yarder in each cutting unit, accounted for 4% of SMH in the 65% retention unit, 6% in 70% retention, 7% in the strip cuts, and 8% in the clearcut. There was one occurrence in each retention unit and the clearcut, and two occurrences in the strip cuts, i.e., one for each strip.

The major category within mechanical delays was *repair running lines*, which included downtime associated with broken wire rope and subsequent splicing of the yarder's operating lines. The largest proportion of SMH for line repairs, at 8%, was recorded in the 65% retention unit. On several occasions the haulback[5] line broke at the point where it was secured to the drum. This occurred only at the start of the project, in the first and the longest corridors yarded, and the problem was eventually rectified.

Table 7 shows productivity results for the cable-yarding phase by cutting unit. On the basis of m^3/PMH (excluding mechanical and non-mechanical delays), yarding productivities relative to the trial's clearcut were 34% lower in the 65% retention unit, 30% lower in the 70% retention, and 28% lower in the strip cuts.

On the basis of SMH, yarding productivity ranged from a low of 13.9 m^3/SMH in the strip cuts to a high of 21.0 m^3/SMH in the small clearcut. The 65 and 70% retention units had yarding productivities of 14.3 and 16.0 m^3/SMH, respectively. The lower production per SMH in the strip cuts compared to the retention units was due to the guyline and skyline anchor stump failures that occurred in the strips.

Table 8 presents costs for the yarding and loading operations, calculated by dividing hourly costs by m^3/SMH. Total costs for the yarding phase were \$26.86/m^3 for the 65% retention unit, \$24.12 for the 70% retention, \$24.00 for the strip cuts and \$18.34 for the clearcut. Compared to the clearcut, therefore, yarding costs were 46% higher in the 65% retention unit, 32% higher in the 70% retention, and 31% higher in the strip cuts.

The costs for log loading depended on the productivity of the yarding machines because the yarders and log loaders have to work side-by-side in the steep terrain. Total loading costs were therefore \$11.77/m^3 for the 65% retention unit, \$10.57 for the 70% retention, \$12.12 for the strip cuts and \$8.03 for the clearcut.

The study sites provided an opportunity to compare yarding productivity and costs in the retention units and the clearcut for the same yarding system, under similar terrain and landing conditions. However, the reader is reminded that this study was conducted in difficult terrain. Thus the yarding phase cost for the

[5] The "haulback" is the yarder's line that is used to outhaul the carriage, butt rigging, or grapple.

Table 7. Average Cable Yarding Productivity by Cutting Unit

Productivity [a, b]	65% retention	70% retention	Strip cuts	Clearcut
Cycles				
no./PMH	6.8	7.5	7.1	7.7
no./SMH	6.1	6.8	5.5	6.7
Pieces				
no./PMH	15.6	18.2	18.0	21.6
no./SMH	13.7	16.6	14.2	19.0
Volume				
m^3/PMH	16.4	17.5	18.0	25.0
m^3/SMH	14.3	16.0	13.9	21.0

[a] PMH = productive machine hours.
[b] SMH = scheduled machine hours.

Table 8. Average Yarding and Loading Cost by Cutting Unit

	65% retention	70% retention	Strip cuts	Clearcut
Yarding				
Equipment ($/m^3)	15.78	14.17	10.60	10.77
Labour ($/m^3)	11.08	9.95	13.40	7.57
Subtotal ($/m^3)	26.86	24.12	24.00	18.34
Loading				
Equipment ($/m^3)	6.95	6.24	7.16	4.74
Labour [a] ($/m^3)	4.82	4.33	4.96	3.29
Subtotal ($/m^3)	11.77	10.57	12.12	8.03
Total ($/m^3)	38.63	34.69	36.12	26.37

[a] Includes cost of full-time landing bucker.

clearcut in this trial is higher than the average yarding phase cost for most coastal forest operations.

The supervisory personnel and harvesting crews responded positively to the new challenge of yarding in the retention units. Initially, two chokersetters accompanied the rigging slinger, and up to four chokers were used in the 65% retention unit. This was the first retention unit to be yarded and crews were anxious to show traditional productivity levels under the new system. However, this arrangement was quickly abandoned when damage to residual trees occurred. A more controlled approach was then adopted using a rigging slinger and one chokersetter with two chokers, and steady production was achieved.

Also, some pre-setting of chokers[6] was initially attempted, again to maximize production. However, this practice too was quickly abandoned because, in the steep terrain, there was the risk of logs running away from the yarder or loader working on the road above. After setting the chokers, the crew would walk well beyond one side of the corridor, ensuring that they were not below the yarder or loader, and remain there until the carriage returned for the next cycle of log hookup. Yarding and loading operations were completed without any safety incidents.

Rigging the yarding corridors and positioning the MSP carriage during each yarding cycle required additional skill and concentration on the part of the rigging crew in order to remove the logs without damaging the residual trees. The rigging slinger has a key role in this type of yarding operation. This worker must anticipate the path that the logs will take as they begin to move from their position on the slope. Patience is required to position the carriage accurately for lateral yarding, and time must be taken to reposition the carriage if a log does not follow the anticipated path. The yarder's interlock mechanism facilitated positive carriage control and positioning.

Residual Stand Damage

Tables 9 and 10 summarize residual stand damage levels for the 65 and 70% retention units, respectively, in terms of *trees/ha* and *proportion of residual stems (%)* with scarring of tree boles. Damage from the falling and yarding phases is combined in the tables. Two levels of damage are shown: (1) all scarred trees regardless of scar size; (2) scarred trees having individual scars of 900 cm^2 or greater. (When scars exceed this threshold size, 60 to 85% of scars on western hemlock and true firs usually become infected by disease (Nevill, in press).)

The proportion of trees with scars of any size was similar for the two retention units. In the 65% retention unit, 88 trees/ha (34% of residual trees) were scarred and damage was evenly distributed over western hemlock and amabilis fir. In the 70% retention unit, 147 trees/ha (37%) were scarred and damage was concentrated on the western hemlock. With approximately one-third of the trees in each unit exhibiting at least one scar of any size, there is room for some improvement in damage levels as crews gain more experience with partial cutting.

The proportion of residual trees with scars ≥900 cm^2 was similar for the two retention units (31 trees/ha and 12% in the 65% retention unit, and 38 trees/ha and 10% in the 70% retention unit). This is considered a good result given the steep slopes and large timber of these units.

[6] The practice of "pre-setting" chokers requires two sets of chokers for the yarding operation; while logs are being yarded to the landing with one set, the crew works to hookup logs for the next yarding cycle with the second set.

Table 9. Damage to Residual Trees in the 65% Retention Unit[a]

Damage	Western hemlock	Amabilis fir	Total
Residual trees			
With scars of any size (no./ha)	43 (5)	45 (4)	88 (7)
With scars ≥ 900 cm^2 (no./ha)	18 (3)	13 (2)	31 (3)
Proportion of residual trees			
With scars of any size (%)	16.5 (2.0)	17.0 (1.8)	33.5 (3.0)
With scars ≥ 900 cm^2 (%)	7.0 (1.1)	4.7 (1.0)	11.7 (1.6)

[a] Means for the variables of interest are presented; standard errors are shown in parentheses.

Table 10. Damage to Residual Trees in the 70% Retention Unit[a]

Damage	Western hemlock	Amabilis fir	Western red cedar	Other species	Total
Residual trees					
With scars of any size (no./ha)	103 (16)	12 (5)	31 (8)	1 (1)	147 (17)
With scars ≥ 900 cm^2 (no./ha)	25 (5)	4 (3)	7 (4)	1 (1)	38 (6)
Proportion of residual trees					
With scars of any size (%)	26.1 (4.3)	3.0 (1.4)	7.8 (2.1)	0.4 (0.3)	37.3 (4.8)
With scars ≥ 900 cm^2 (%)	6.3 (1.5)	1.1 (0.7)	1.9 (0.9)	0.4 (0.3)	9.7 (1.7)

[a] Means for the variables of interest are presented; standard errors are shown in parentheses.

During the yarding operations it was observed that the incidence of scarring increased when the yarder's running lines were too low. This was apparent in two corridors in the 70% retention unit when the haulback block was not hung at the optimal height in the backspar tree. Low running lines made maneuvering logs into the corridor more difficult, resulting in more damage to residuals.

On rare occasions, severely damaged corridor trees were felled and yarded to roadside after cable yarding operations had been completed on a particular corridor.

Soil Surface Conditions

Table 11 summarizes soil surface conditions following harvesting for the 65% and 70% retention units. Three classes of soil surface condition were identified: (1) *forest floor displacement (exposed mineral soil)*, (2) *mixed organic material and mineral soil*, and (3) *undisturbed soil*. The *undisturbed* category dominated both units and accounted for 89.8 and 95.9% of the soil surface area in the 65 and 70% retention units, respectively. *Mixed organic material and mineral soil* (scuffing and mixing of soil surface layers where partially suspended logs were dragged over the soil) accounted for 8.8 and 2.6% of surface area in the 65 and 70% retention units, respectively. *Exposed mineral soil* was observed on only 1.4 and 1.5% of the surface area in these same units.

Soil disturbance was observed only within the yarding corridors, and there, only in discontinuous patches. Yarding did not create linear gouges or channels in the yarding corridors. Because logs were partially suspended, the trailing ends of the logs often bounced and touched the ground at intermittent points as they were yarded uphill along a corridor. In fact, full suspension of logs was achieved along many segments of the corridors and the soil surface was not disturbed in these areas.

Overall, the impact of the harvesting operations on the soil appears to be minor. It is not likely that post-harvest soil surface conditions have increased the risks for mass wasting or surface erosion. The levels of forest floor displacement are well below the limits specified for sensitive sites in B.C.'s Forest Practices Code Soil Conservation Guidebook (BCMOF 1995a).

Other Observations

Changes to landscape visual conditions. To assess whether high-retention partial cutting with cable

Table 11. Post-Harvest Soil Surface Conditions in the 65% and 70% Retention Units

Soil conditions	Proportion of cutting unit area affected [a]			
	65% retention unit (%)		70% retention unit (%)	
Forest floor displacement (exposed mineral soil)	1.4	(0.6)	1.5	(1.0)
Mixed organic material and mineral soil	8.8	(2.1)	2.6	(1.3)
Undisturbed soil	89.8	(2.2)	95.9	(1.5)

[a] Means for the variables of interest are presented; standard errors are shown in parentheses.

systems has the potential to meet stringent Visual Quality Objectives (VQO) in visually sensitive areas, photographs were taken of the cutting units and surrounding landscape before and after harvesting, from aircraft, along forest roads within the operation, and from an inlet to the east of the operation. (Refer to B.C.'s Forest Practices Code Visual Impact Assessment Guidebook (BCMOF 1995b) for VQO definitions.)

Figures 12 and 13 show the trial units from an aerial viewpoint. Note that aerial views accentuate alterations to the landscape, and that conventional visual impact assessments are usually done from a terrestrial viewpoint. It is difficult to detect any harvesting activity in the retention units in these photographs. The yarding corridors were visible from the air immediately after yarding was completed, but only in direct overhead light conditions. The corridors were not visible at oblique lighting angles due to dense shadows. One year later, during another flight over the sites, the ground cover in these same corridors had blended into the landscape, making the corridors more difficult to discern.

The narrow corridors in the retention units and the high levels of tree retention undoubtedly contributed to the minimal visual impact of the operations. The crowns of many trees adjacent to the 4-m-wide corridors overhung portions of the corridors, thus shielding them from view. Further, the irregular structure of typical coastal old-growth stands gives a "ragged" appearance compared to a uniform second-growth stand, which

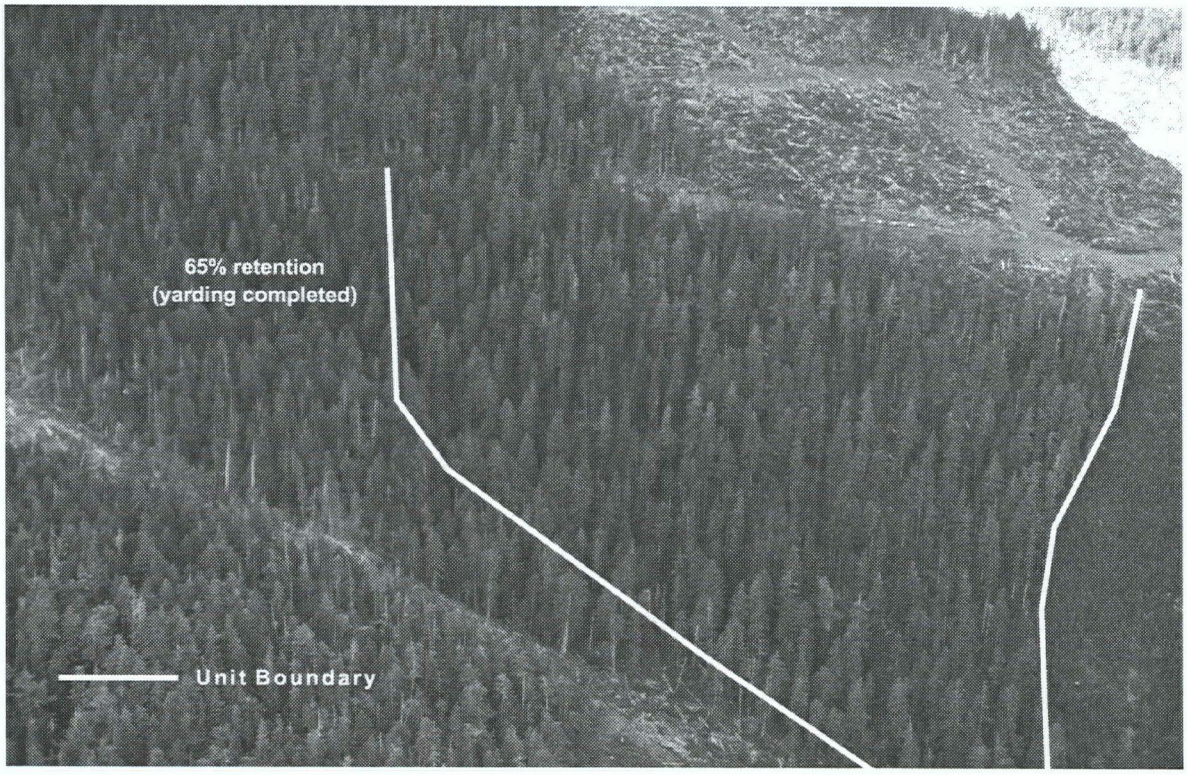


Figure 12. 65% retention unit following harvest.

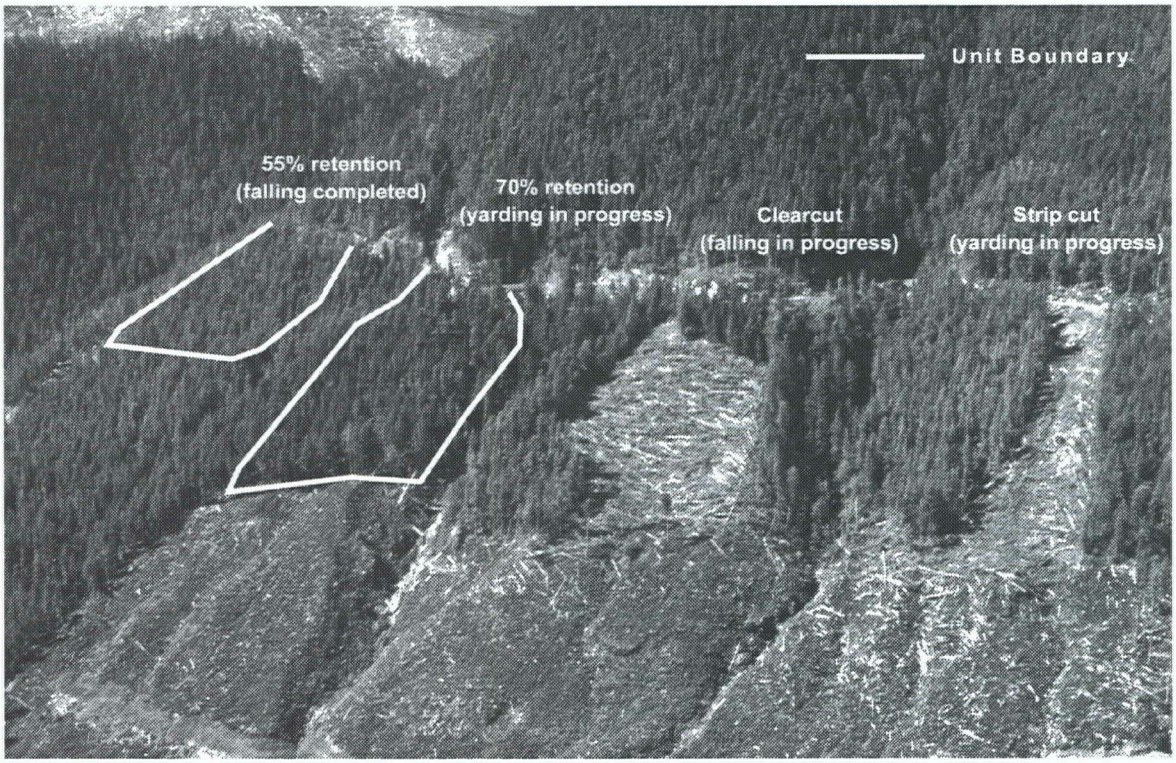


Figure 13. 55 and 70% retention units during harvest (oblique angle).

further helps lessen the negative visual effects of harvesting operations (USDA Forest Service 1978).

These results provide needed information about the visual impact of high-retention partial cutting in old-growth on steep slopes within the CWHvm1 biogeoclimatic unit. Whether a cutting treatment will meet a particular VQO is open to interpretation. However, it would appear that the retention units in the trial met a Partial Retention VQO—i.e., activities are visible but remain subordinate—when viewed from aircraft. If a terrestrial viewpoint was used, these units may satisfy a Retention VQO—i.e., activities are not visually evident.

Windfirmness of the residual stands. Like many areas on the west coast of Vancouver Island, the Kyuquot Sound region is subject to frequent storm-force winds in winter months. Particularly severe storms hit the area during the winter of 1995/96 and caused many windthrow and mass wasting events in the region's natural forests. However, no windthrow occurred in the retention cutting units at Chamiss Bay, suggesting that the windthrow management strategies adopted for these units may be appropriate and effective, at least in the short term, for several reasons. First, the high retention levels chosen for the trial and the relatively uniform distribution of the retained trees maintained sufficient crown cover to prevent wind from penetrating the residual stands. Second, trees that were considered most susceptible to windthrow—i.e., trees with defects and trees that appeared to be rooted on unstable substrates—were removed in the harvest. Finally, the retained trees represented the full natural stand profile and included both dominants and emergents. Mitchell (1993) noted that although the issue of leave tree selection is contentious, several studies have suggested that retaining both dominants and emergents improves the windfirmness of residual stands.

It must be stressed that these observations are only preliminary. More time must elapse before the long-term windfirmness of these retention treatments can be evaluated.

Planning and implementing partial cutting. Partial cutting is best planned in conjunction with clearcut operations in the same vicinity to make supervision and coordination of equipment between areas more efficient. In some areas, it may be possible to incorporate partial cuts into development plans without adding to road-development costs. This is because large areas of developed timber have already accumulated in coastal regions but are currently deferred from harvesting for environmental and other reasons. Also, forest operators are adding to the bank of deferred timber because they are building new roads through long sections of sensitive terrain to gain access to areas suitable for clearcutting. These sensitive areas are candidates for partial cutting.

The trial showed the potential to operate on such sites with conventional equipment and crews, thus creating an opportunity to augment timber supplies.

Also important are the intangible benefits that can flow from a high-retention partial cutting trial. For example, planners and operations personnel gain the skills and confidence needed to address other less difficult harvesting situations. They can apply the techniques to areas that need low or moderate levels of tree retention, where the trees are either dispersed or in clumps, and to riparian zones with special prescriptions. Also, silviculturists can now think about alternative silviculture prescriptions on sites where partial cutting was considered operationally unworkable. However, there is still much to learn about stand and regeneration responses to these cutting methods on the type of sites described in this trial. Treated stands need to be monitored over the long-term to generate the stand dynamics information that will strengthen future prescriptions.

CONCLUSIONS

This study investigated the harvesting feasibility of partial cutting in old-growth stands on the steep sensitive slopes of coastal British Columbia where clearcutting is restricted for environmental and/or visual quality reasons. The trial demonstrated that British Columbia forest workers have the skills needed to successfully implement high-retention partial-cutting systems in challenging terrain and timber conditions, and that industry-standard swing yarders are very effective in such operations. The productivity and cost results for the retention units provide important new information to help forest operators plan, budget, and implement future partial cutting trials and operations.

Implementing high-retention partial cutting under these conditions requires close cooperation between foresters, forest engineers, harvesting supervisors, and loggers. All groups must contribute and coordinate their efforts if the stand management objectives are to be met. Safe work procedures must be reviewed and, when necessary, new procedures developed to suit the working conditions of the operation. Cooperation was achieved in the trial, and the fallers and yarding crews adapted well and worked hard to make the project a success.

In the 65% retention unit, falling productivity was 31% lower, and cable yarding productivity (expressed in m^3/PMH) was 34% lower than in the clearcut. Falling costs therefore increased by 45% relative to the clearcut, while yarding costs (based on SMH) increased by 46%. In the 70% retention unit, however, falling productivity was reduced by only 2% compared to the clearcut, mainly because of a marked difference in timber type between this unit and the trial's clearcut. Cable yarding productivity in this unit was 30% lower than in the clearcut, and yarding costs (based on SMH) were 32% higher. It must be stressed that these are the relative differences in falling and yarding productivity and cost for the Chamiss Bay trial in which a clearcut in similar steep terrain, with no landings, was used for comparison. The steep slopes and narrow roads meant that the yarder could not deck logs along the roads, so a log loader had to work beside the yarder in all the cutting units. The cable-yarding phase cost for the clearcut in this trial is higher than the average cable-yarding phase cost for most coastal forest operations.

Post-harvest surveys showed that 34 and 37% of the residual trees had at least one scar of any size, and 12 and 10% of the residual trees had at least one scar that was 900 cm^2 or greater in the 65 and 70% retention units, respectively. Exposed mineral soil was observed on only 1.4 and 1.5% of the soil surface area in the 65 and 70% retention units, respectively.

A strategy for falling timber in high-retention systems must be carefully prepared. In this trial the fallers were included from the beginning in the planning and tree-marking processes. When operations commenced they were familiar with the objectives of the trial. They felt assured that a workable plan was in place and were determined to follow the marking scheme productively and safely.

The trial showed that a modern interlock swing yarder equipped with a mechanical slackpulling (MSP) carriage is well-suited to uphill yarding in partial cuts on steep slopes. This type of machine can be moved between yarding corridors and rigged-up quickly, and its ability to swing and land logs on the road is essential. The MSP carriage is needed to provide a lateral yarding capability.

Although the benefits of swing yarders and running skyline systems have been proven for over two decades, traditionally these systems have been narrowly applied in B.C. where they are usually configured for grapple yarding. As this trial shows, these yarding cranes are technologically advanced machines capable of addressing a wide range of harvesting challenges on sensitive sites. Fitting swing yarders with MSP carriages, using them over extended yarding distances, and applying them to partial cutting prescriptions is an alternative for harvesting sensitive sites. By adapting existing yarding cranes to such applications, the B.C. forest industry can avoid large investments in new yarding equipment to address sensitive site harvesting needs.

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Appendix I

Hourly Equipment Costs for Cable-Yarding Systems

Yarding and Loading [a]	Swing yarder 80 000 kg class	Tower yarder 50 000 kg class	Log loader 50 000 kg class
OWNERSHIP COSTS			
Purchase price (P) $			
Machine	1 350 000	825 000	600 000
Mechanical slack-pulling carriage	9 000	9 000	--
Depreciation period (D) y	7	7	7
Scheduled hours per year (h) h	1 600	1 600	1 600
Salvage value as % of P (s) %	30	30	30
Interest rate (Int) %	10.0	10.0	10.0
Insurance rate (Ins) %	2.5	2.5	2.5
Salvage value (S)=(P•s/100) $	407 700	250 200	180 000
Average investment (AVI)=((P+S)/2) $	883 350	542 100	390 000
Loss in resale value ((P-S)/D•h) $/h	84.94	52.13	37.50
Interest = ((Int•AVI)/h) $/h	55.21	33.88	24.38
Insurance = ((Ins•AVI)/h) $/h	13.80	8.47	6.09
Total ownership costs (OW) $/h	153.95	94.48	67.97
OPERATING AND REPAIR COSTS			
Fuel consumption (F) L/h	50	40	40
Fuel cost (fc) $/L	0.40	0.40	0.40
Lube and oil cost as % fuel cost (fp) %	10	10	10
Pro-rated annual wire rope cost (wc) $			
Skyline		900	
Mainline [b]	1 200	800	
Haulback	15 800	6 100	
Other lines, chokers, etc.	3 500	3 900	
Annual cost of supplies and rigging materials (SR) $	10 000	10 000	2 500
Annual repair and maintenance cost [c] (Rp) $	50 000	35 000	20 000
Wages (W) $/h			
Machine operator	24.04	23.41	22.77
including machine servicing allowance [d]	26.71	26.01	25.29
Hooktender	24.04	24.04	
Rigging slinger	21.74	21.74	
Chaser	20.61	20.61	
Chokersetters [e]	20.41	40.82	
Landing bucker			24.04
Wage benefit loading (WBL) %	40	40	40
Fuel cost (F•fc) $/h	20.00	16.00	16.00
Lube and oil cost ((fp/100)•(F•fc)) $/h	2.00	1.60	1.60
Wire rope cost (wc/h) $/h	12.81	7.31	
Supplies and rigging materials cost (SR/h) $/h	6.25	6.25	1.56
Repair and maintenance cost (Rp/h) $/h	31.25	21.88	12.50
Labour cost (W•(1+WBL/100)) $/h	158.91	186.50	69.07
Total operating and repair costs (OP) $/h	231.22	239.54	100.73
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	385.17	334.02	168.70

[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 transportation, supervision, profit, and office overhead. IWA rates effective June 15/96 have been used.

[b] Double mainlines on the swing yarder.

[c] Annual costs for repairs and maintenance are estimated by FERIC, with input from Interfor.

[d] The machine servicing allowance for operators is 2/3 of 1 hour at the overtime rate. It is prorated over an average shift length of 9 hours for this analysis.

[e] One chokersetter was used on the swing yarder; two chokersetters were used on the tower yarder.

Appendix II

Hourly Falling and Bucking Cost

Falling and Bucking [a]

Wages for one faller (W) $/shift	284.44
Wage benefit loading (WBL) %	40
Cost of saw, gas and oil, and supplies (Sw) $/shift	80.00
Shift length (Sl) h	6.5
Labour cost = ((W•(1+WBL/100))/sl)	61.26
Saw, gas and oil, and supplies (Sw/Sl) $/h	12.31
Total falling and bucking cost per faller $/h	73.57

[a] These figures are based on FERIC's standard costing methodology, and do not include such costs as crew transportation, supervision, profit, and office overhead. The IWA rate effective June 15/96 has been used.

The Forest Engineering Research Institute of Canada (FERIC) is a private non-profit research and development organization aimed at improving Canada's forest operations related to the harvesting and transportation of wood, and the growing of trees, within a framework of sustainable development.

FERIC is funded through a growing partnership made up of over 50 leading forest companies, the Government of Canada, and the provinces. Our mission is to provide these members with the knowledge and technology to conduct cost-competitive, quality operations that respect the forest environment.

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