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

by

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Abstract

The Forest Engineering Research Institute of Canada (FERIC) worked with International Forest Products Limited (INTERFOR) to plan and implement a partial cutting trial at Chamiss Bay on Vancouver Island's west coast. A 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 CWHvm1 biogeoclimatic unit.

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 unit falling cost was 45% higher than in the clearcut. However, falling productivity was reduced by only 1.6% 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 m^3 (volume of logs) per productive machine hour (m^3/PMH), was 34 and 30% lower in the 65 and 70% retention units, respectively, than in the clearcut. Unit yarding costs, based on scheduled machine hours (SMH), 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 33.5 and 37.3% of the residual stems had at least one scar of any size, and 11.7 and 9.7% of the residual stems 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.

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

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1. INTRODUCTION

In early 1992, International Forest Products Limited (INTERFOR) was asked by a local citizens group and the Kyuquot native band to examine alternatives to clearcutting in the Kyuquot Sound area on the west coast of Vancouver Island. An operational trial of alternative harvesting systems was proposed and INTERFOR's operating area at Chamiss Bay was chosen as the location.

A planning team with representatives from 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 Forest Sciences Section, and coastal forest companies was formed to initiate the trial. The planning team decided to adapt INTERFOR's local crews and equipment to carry out the trial because it was important to involve local workers from the outset and ensure that they gained direct experience with alternative harvesting practices.

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 issues that led to the partial cutting proposals at Chamiss Bay. Traditional clearcutting and plantation silviculture are proven, well-established practices for producing timber in the ecosystems within Kyuquot Sound. However, the Chamiss Bay planning team had to propose alternative cutting treatments and recommend a harvesting system for partial cutting in old-growth stands, on steep slopes, to address these issues.

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

An investigation into partial cutting in old-growth stands on steep slopes is needed because sensitive sites are often permanently deferred from conventional clearcut harvesting (Sauder and Wellburn 1989). Silvicultural systems that maintain high levels of tree retention could augment the timber supply because harvesting activities may be allowed on some previously-deferred sensitive areas. Many sensitive sites are found in the Submontane Very Wet Maritime Coastal Western Hemlock biogeoclimatic variant (CWHvm1). This biogeoclimatic unit is the most extensive in the Vancouver Forest Region (Green and Klinka 1994) and a critical component of the timber supply in Kyuquot Sound.

Foresters must consider several criteria when selecting an appropriate reproduction method for a particular stand and one criterion is harvesting feasibility (Klinka *et al.* 1994). However, harvesting feasibility for partial cutting systems in old-growth on steep slopes is not well understood. (Harvesting feasibility is discussed in terms of harvesting productivity and cost, and the physical impacts on the residual trees and soil). Without knowledge about harvesting feasibility it is difficult for foresters to consider partial cutting for the type of sensitive sites identified at Chamiss Bay.

There have been very few documented cases of partial cut harvesting, using cable systems, in mountainous old-growth forests in coastal British Columbia. Studies of operational trials are needed to identify appropriate engineering procedures for cable yarding layout and to establish a range of harvesting productivities and costs for partial cutting in old-growth on steep slopes. Further, the Clayoquot Sound Scientific Panel (CSP, 1995) has recently recommended that operational trials be undertaken to provide baseline information for partial cutting in coastal old-growth stands.

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A study was designed to investigate the feasibility of the harvesting operations in the Chamiss Bay trial. The specific objectives of the study were to:

1. Specify procedures for, and conduct the engineering and tree marking phases of the trial and document the costs for these phases.

2. Determine the harvesting productivity and cost for the partial cutting units in the trial.

3. Compare the harvesting productivities and costs for the partial cuts to a clearcut under similar terrain conditions.

4. Determine post-harvest levels of residual stand damage in the partially-cut units.

5. Determine the levels of soil disturbance associated with cable yarding in the partially-cut units.

Secondary objectives of the study were to:

1. Present information about the changes that partial cutting made to the landscape visual conditions at the trial sites.

2. Make preliminary observations about the windfirmness of the residual stands.

Although landscape visual conditions and stand windfirmness were not analyzed using formal study methods, some observations were made because these are important considerations for planning partial cuts in coastal B.C.'s steep terrain.

To meet the study objectives, the following framework was used to conduct the study and report the findings:

First, the literature was reviewed to learn about: 1) cable yarding systems and engineering procedures that could be adapted to the Chamiss Bay trial, 2) productivities and costs for falling and cable yarding in partial cuts in the Pacific Northwest, 3) methods for conducting harvesting production studies, 4) damage levels experienced in other partial cutting trials, and 5) the methods used to determine residual stand damage. Material was selected based on its relevance to the terrain and old-growth stands at Chamiss Bay.

Second, the chapter on study methods describes the trial sites and cutting treatments, the selected harvesting system, and the engineering and tree marking procedures used in the trial. The methods used to collect and analyze the data for determining harvesting productivity and cost, and the levels of residual stand damage and soil disturbance, are described. Comments about evaluating changes to landscape visual conditions are included in this chapter.

Third, the results and discussion chapter provides information about engineering and tree marking costs, falling and cable yarding productivity and cost, residual stand damage, and post-harvest soil surface conditions. Observations about landscape visual conditions and stand windfirmness complete this chapter. Finally, conclusions are presented.

2. LITERATURE REVIEW

2.1 Planning and Engineering for Partial Cutting

Information about engineering design and field layout in partial cuts is reviewed in this section to determine appropriate procedures for laying out the Chamiss Bay trial. To put reasonable bounds on this review, material was selected based on its relevance to partial cutting in old-growth stands on steep terrain. A large body of work has accumulated on second-growth and small wood harvest planning in the Pacific Northwest. This work was examined if it was pertinent to the terrain and stand conditions at Chamiss Bay.

Public and forest industry interest in alternatives to clearcutting in B.C. has spurred the compilation of several literature reviews in recent years. Nelson *et al.* (1990) concentrated on silvicultural systems and harvesting alternatives for old-growth forests in coastal B.C. They reviewed the traditional *high forest* silvicultural systems and their applicability to B.C.'s west coast. They felt that selection and shelterwood silvicultural systems are inappropriate for most steep coastal sites because there is high potential for windthrow. If these systems are attempted then a plan for salvaging windthrow should be in place. The dangerous nature of manual felling was another reason to avoid the shelterwood and selection methods in the opinion of the authors. If manual felling was deemed to be safe on a particular site then the preferred equipment options for timber extraction were skyline systems (implying large slackline tower yarders) and helicopters. Alternatives to clearcutting mean higher logging costs and more extensive road networks if cutting levels are to be maintained.

Howard *et al.* (1993) had the objective of proposing harvesting systems for alternative silvicultural systems in coastal B.C.'s second-growth forests. The recommended harvesting systems for regeneration and removal cuts in the context of shelterwood management are considered here. For sensitive sites the use of aerial systems, such as helicopter or balloon logging, was preferred provided that log values were high enough to offset the additional costs. Medium and large skyline yarders were also cited as an option. The authors felt that it was preferable to use long-reach systems with long lateral yarding capability because the volume per unit area harvested is relatively small in alternative cuts. It was suggested that these systems would permit wider spacing of yarding roads and minimize total logging costs.

Severe harvesting-related mass wasting events occurred in the Queen Charlotte Islands during the 1970's. As a result, timber on slopes greater than 35° (70%) and half of the available timber on 25° to 35° slopes was deferred from harvesting (Sauder *et al.* 1987). Several studies were commissioned under the Fish/Forestry Interaction Program (FFIP) to analyze planning and yarding operations in the region's sensitive terrain. Three reports (Krag *et al.* 1986, Sauder and Wellburn 1987, 1989) produced recommendations to improve planning and engineering practices for cable harvesting in clearcuts on landslide-prone terrain. This material is useful for overall development planning and must be incorporated into projects like the one at Chamiss Bay. However, procedures for engineering and layout of partial cutting units were not addressed.

Planning costs of alternative group selection systems were treated in detail in a study reported by Edwards *et al.* (1992) and Kellogg *et al.* (1996). The project was carried out in second-growth Douglas-fir stands near the Oregon coast. Five treatments plus a clearcut were laid out and harvested using a 21 m tower yarder. All yarding was uphill. A MSP carriage with self-contained

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skidding line was used to yard up to 45 m laterally. Ground slope ranged from 0 to 73% with a weighted average of 31%. A total of one-third of each treatment unit area was logged. One-hectare strip cuts and 0.20-ha patches were spaced along parallel yarding roads. Wedge-shaped 1.0 ha cuts, 0.20-ha patches and 0.61-ha patches were located along yarding roads radiating from central landings.

Planning and layout costs were 263 and 283% higher for the strip and wedge cuts, respectively, compared to clearcuts. In the small patch units, increased planning costs ranged from 459 to 591% compared to clearcutting. This study stressed that thorough planning by competent personnel is critical to achieving acceptable harvesting costs. The prescriptions in this trial did not include any retention systems where residual trees were dispersed uniformly over unit areas.

Kellogg *et al.* (1991) reported on a related project in the same region. This study also showed increased planning costs over clearcut harvests. Layout for two-story and group selection cuts took 2 to 5 times longer due to more detailed skyline road layout. Requirements for harvesting in future stand entries were considered in the initial planning exercise. Potential tailholds and guyline anchors for these subsequent operations were identified and protected where possible.

Recent studies in coastal B.C. have presented models for optimizing skyline corridor width. McNeel and Young (1994) developed their model for large slackline yarders working in clearcuts in old-growth. (In this case, yarding road width on the external boundary of a circular setting was optimized. This is different than determining spacings for a parallel network of corridors in a partial cut.) Total yarding cycle time was minimized when yarding road width was 45 m.

However, the authors did not expect much effect on productivity if this width was varied by plus or minus 10 m.

Total yarding cost was minimized with respect to corridor spacing in a model by Howard *et al.* (1996). Operations in second-growth stands on gentle terrain (less than 10% ground slope) were the basis for this analysis. Observations from case studies, covering several corridor configurations and crew and equipment arrangements, were compared to predicted spacings from the model. Most optimal spacings for the case study scenarios were shown to be in the 50 to 55 metre range.

The models cannot be applied directly to the Chamiss Bay project because the sites and the yarding systems and conditions differ greatly. However they are valuable as a reference when examining other operations.

The importance of coordinating silvicultural objectives with harvesting capabilities was discussed in a paper by Mann and Tesch (1985). Experience in Oregon with shelterwood systems demonstrated this point. Planning decisions made early in the process have an impact on the success of subsequent overstory removal. A decision support system was proposed to help maintain the integrity of advanced regeneration during overstory removal. Although the examples in the paper are not directly applicable to the Chamiss Bay project, an important lesson can be learned: silviculturists and forest engineers must communicate and work together closely to successfully implement alternative silvicultural systems.

The operational aspects of overstory removal in shelterwood systems were documented by Tesch *et al.* (1986). A case study, in southwest Oregon, was conducted to examine the logging factors

that influence seedling survival during cable yarding. A small swing yarder, rigged in a running skyline configuration, was used to uphill yard the overstory timber. Yarding corridors radiated from a central landing. The results of their study suggested that logging plans should minimize corridor width and restrict the number of corridors radiating from one landing. Steep cross-slope yarding reduced log control, and resulted in wide corridors and more damaged seedlings. (Cross-slope gradient is the ground slope measured perpendicular to the yarding corridor).

A retrospective study of partial cutting operations was conducted by the USDA Forest Service (Fieber *et al*. 1982). The objective was to determine why excessive levels of residual stand damage had occurred on several timber sales in California. Large slackline tower yarders were used in overstory removal and diameter limit cuts during the 1970's. Yarding corridors radiated from machines positioned in central landings. The study recommended to: eliminate cross-slope yarding (if logs are not fully suspended), position the skyline so that logs are fully suspended as they enter the corridor during lateral yarding, position the skyline high above the ground to reduce corridor width, restrict setting size (and thus increase the number of rig-ups) to minimize the clearcut effect near the landing, and finally, carefully develop and adhere to logging plans. The study highlights the difficulties of applying large slackline machines to partial cuts. It is a useful analysis but many of the recommendations will not apply to the Chamiss Bay project if a swing yarder is selected for the trial.

Binkley and Starnes (1988) made basic recommendations for downhill yarding, in clearcuts and partial cuts, with a variety of skyline systems. For partial cutting systems they did not feel that partial, or "one-end" log suspension was advisable, because considerable damage to the residual stand would occur. Fully suspended turns were recommended. If partial suspension is necessary

then it should be limited to 35% slopes. Logs tend to overrun the carriage on steeper slopes which create hang-ups and residual stand damage.

Perhaps the most important point to consider is the safety of the yarder operator and landing crew when yarding downhill through a corridor. Because the machine is positioned at the corridor's base, it is in the direct path of any runaway logs and debris. Crew safety is compromised and the potential for machine damage is great. Downhill yarding in partial cuts may be an option if the yarder can be positioned well back from the base of the slope. If this is not possible then downhill yarding should be restricted to gentle slopes. Downhill yarding will not be considered for the Chamiss Bay trial because all candidate trial sites have steep slopes and high cutbanks along the roads.

The running skyline configuration used in conjunction with a slackpulling carriage is a flexible system suitable for clearcuts or partial cuts (Lysons and Twito, 1973). The mobility of a swing yarder and its ability to operate on road systems without a series of landings reduces excavation requirements in steep, sensitive terrain. Lysons and Twito (1973) believed that yarding logs partially-suspended, the usual method for swing yarders, results in minimal levels of soil disturbance. They felt that there was little to be gained in terms of soil disturbance by fully suspending turns of logs with the use of large tower yarders. An exception would be harvesting in the vicinity of riparian areas. (Note that modern swing yarders have the power and capability to fully-suspend logs when necessary, provided that adequate deflection exists along the yarding path).

Several makes and designs of yarding carriages are available and these are reviewed by Studier (1993). A simple mechanical slackpulling carriage (MSP), with skidding line attached to the mainline, can be used for yarding in partial cuts. These carriages are well matched to 3-drum swing yarders. The yarder powers the slackpulling function. The design is simple; there are no on-board engines for pulling slack or powering self-contained drums and no skyline clamps to control. This ensures easy operation and maintenance.

Doyle (1975) presented an overview of planning and layout procedures for running skyline systems. Special care must be taken to select suitable tailholds and guyline anchor stumps during the planning process.

Tailhold structures, along with suitable tie-back stumps or trees, have important implications for harvest system design in partial cuts. Tailhold stumps or backspar trees dictate one terminus of the skyline yarding corridor. After they are selected in the field, they must be accurately mapped. An exact bearing for the corridor can then be determined and field location of the corridor proceeds. Tailholds must be selected carefully because once the corridor has been felled there is no opportunity to re-orient the corridor toward an alternative anchor.

Practical planning measures and harvesting techniques for minimizing the visual impact of harvesting operations are found in two sources. Daigle (1996) listed planning and harvesting techniques for reducing the visual impact of cable yarding corridors in partially cut stands. The USDA Forest Service (1978) presented treatment concepts for Sitka spruce - western hemlock forests that could be applied to the Chamiss Bay sites. Techniques, documented in the USDA manual, for controlling corridor width are also appropriate for the Chamiss Bay trial.

The harvesting implications of variable-retention silvicultural systems were discussed in the recent planning and practices report by the Clayoquot Sound Scientific Panel (CSP 1995). The findings and recommendations for harvesting systems relate well to the Chamiss Bay trial because the terrain and vegetation are similar in Clayoquot and Kyuquot Sounds. Findings pointed to the utility of yarding cranes equipped with MSP carriages for high-retention systems. Narrow yarding corridors oriented in a parallel fashion across a slope were recommended.

More recently, Rutherford (1996) gave a detailed explanation of the engineering procedures used in his study of optimal spacing of skyline corridors for commercial thinning in second-growth stands in coastal B.C. In this study, optimal corridor spacings were determined for a swing yarder working in wide and narrow corridors with different crew complements, and for a stationary yarder working in narrow and wide corridors. Optimal spacings were 46.7 m for the stationary yarder in both corridor widths. For the swing yarder, optimal spacings ranged from 49.8 to 58.8 m.

It is likely that the engineering principles applied by Rutherford, and others (Kellogg *et al.* 1996, Kellogg *et al.* 1991, Edwards *et al.* 1992, and Tesch *et al.*, 1986), in second-growth thinning operations can be applied to the Chamiss Bay trial, that is, a system of yarding corridors spanning the distance between a haul road and suitable backspar trees. However, many elements of the harvesting system will have to be specified for the conditions at the Chamiss Bay sites. For example, corridor spacings in the 50 to 60 m range may be too wide for the initial partial cutting trial at Chamiss Bay because the terrain is much steeper and the timber larger compared to the gentle slopes and second-growth stands used for most commercial thinning studies. Also, it will

not be possible to directionally fall large old-growth timber toward the yarding corridors in a herringbone arrangement as is often done in thinning operations.

2.2 Harvesting Production Studies

A review of relevant production studies provides perspective for the productivities and costs and that will be compiled from the Chamiss Bay trial. Also, estimates of productivity and cost are needed to help budget resources for the harvesting study and the harvesting operations. This review concentrates mainly on productivity information because the time lag between studies and different currencies makes direct cost comparisons difficult. The falling and yarding phases are the focus.

2.2.1 Falling Phase

A recent study by McNeel (1994) compared manual felling operations in partial cuts and clearcuts. The study sites were in B.C.'s northern interior. Conditions differed greatly from the Chamiss Bay sites because tree size was smaller and ground-based skidding was possible. The partial cutting prescription called for the removal of 65% of stand basal area and at least 50% of the white spruce component. Interestingly, the study showed similar falling productivities in the clearcut and partially cut units. However, productivity was predicted to drop substantially if cutting prescriptions require a greater percentage of small diameter stems to be harvested.

No literature was found that documents falling productivity for partial cuts in large old-growth timber on steep sites. Two studies done in coastal old-growth stands concentrated on reducing breakage in conventional clearcut operations. Guimier (1980) examined directional falling techniques to improve value recovery of large old-growth cedar trees in coastal B.C. A study by

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Hunt and Henley (1981), in coastal Oregon, found advantages to directional falling of old-growth Douglas-fir trees. The extra costs of the directional felling techniques employed were more than offset by gains in the value of the timber.

The studies by Hunt and Henley (1981) and Guimier (1980) focused on tree jacks and line-pulling techniques for directional felling. Guimier found that these operations cost 2 to 3 times more than conventional falling. Clearly these methods are meant for special situations, that is, high value timber that is close to a road and at risk of being broken if felled across or down the slope. They are not practical for use in partial cutting on a regular basis. Some directional felling can be achieved with the use of wedges and special felling techniques.

Three FERIC studies investigated the effect of tree size, species and terrain on handfalling productivity and costs. A study by Peterson (1987) tracked the performance of one faller at three sites on the east coast of Vancouver Island. Conventional clearcut operations in old-growth stands were observed. For different sites, average falling productivity ranged from 110 to 130 trees per shift and 116 to 225 m^3/shift.

2.2.2 Yarding Phase

Many studies of skyline yarding productivity in alternative silvicultural systems have been conducted in the Pacific Northwest. Various methods of describing site and stand characteristics have been used which makes comparisons between studies difficult.

Running skyline and slackline yarding configurations were used in larch-fir stands on 45 to 60% slopes in Montana (Gibson 1975; Gardner 1980). These studies determined the influence of varying levels of wood utilization on skyline system productivity and identified variables

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influencing rates of production for harvesting under clearcut, shelterwood, and group selection silvicultural prescriptions. Substantial differences in landing conditions and stand characteristics precluded comparisons of harvesting costs for the different silvicultural systems. The greatest yarding productivity at 26.9 m^3/hr was obtained in group selection units using a Skagit GT-3 swing yarder rigged in a running skyline configuration. Yarding was downhill. The lowest productivity (10.0 m^3/hr) was observed during uphill yarding with a running skyline in a shelterwood cut. Yarding distance, lateral yarding distance, and number of logs per turn were the primary variables affecting production.

Peters (1973) presented a method of estimating yarding production for a partial cutting operation in Oregon. Trees in the overstory were removed, using a prototype running skyline yarder, on slopes ranging from 40 to 80%. Production equations were produced for the prototype yarder to demonstrate the method.

Dykstra (1976) reported on extensive time studies of running skyline, balloon and heavy-lift helicopter operations in Oregon. Running skyline and helicopter systems were used in clearcuts and partial cutting units. The balloon system was only used in clearcuts. The partial cuts were done under shelterwood management systems implemented in old-growth Douglas-fir stands. Interestingly, the design of all the cutting units was driven by the need to reduce the visual impact of harvesting on the landscape. This is not unlike the impetus for the Chamiss Bay trial, more than 20 years later.

Regression models for yarding cycle time elements were produced for each yarding system. For the running skyline system, Dykstra found productive yarding time to be a function of yarding

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distance, lateral yarding distance, turn volume, chordslope and number of logs per turn. He also compared the results for the running skyline in partial cuts to a similar study for the system in a clearcut, one year earlier. He concluded that direct yarding costs were about 67% higher in the partially cut units than in the clearcuts.

More recently, extensive multi-disciplinary projects have been initiated in old-growth forests in coastal British Columbia. Alternatives to clearcutting for harvesting potentially unstable slopes in the Queen Charlotte Islands are being investigated (Krag and Clark 1995). A Sikorsky S64E helicopter was used to remove timber from single tree and partial cuts at two sites in Rennell Sound in 1992. These sites were excluded from conventional clearcut cable harvesting because of high landslide hazard.

Small patch cuts, green tree retention, and shelterwood systems were investigated in old-growth montane forests on Vancouver Island in a study called the Montane Alternative Silvicultural Systems project (MASS) (Beese 1995). The main objective was to analyze and improve the poor regeneration performance often experienced in high elevation clearcuts. Other objectives were to minimize negative impacts on wildlife habitat, biological diversity, and visual aesthetics. A ground-based harvesting system, excavator forwarding, was applied to all treatment units in 1993. Crew involvement at the planning stage and close on-site supervision were key elements in the project's implementation.

Preliminary costs were presented for falling, yarding and "other" phases based on shift-level reporting of time and production. Other costs included training, supervision and administration. Total cost increases compared to conventional-size clearcuts were 24, 25 and 40% for the green

tree, patch cut and shelterwood treatments, respectively. Beese recognized that the harvesting feasibility and cost results are not applicable to areas of steeper terrain that require different yarding systems. This includes the Chamiss Bay trial sites. He also suggested that, for future operations in shelterwood units, trees should continue to be pre-marked for felling rather than evolving to a faller's selection method. The already difficult falling task would be further complicated if the faller must balance all the tree-marking criteria in such complex old-growth stands.

In 1993, FERIC conducted shift-level and detailed-timing studies of a shelterwood harvest in second-growth Douglas-fir (Hedin 1994). The harvest unit was part of the BCMOF's Roberts Creek Study Forest located near Vancouver, B.C. *Partial retention* was the stipulated visual quality objective for the unit. A low residual tree retention silviculture prescription was implemented. A total of 57 trees/ha and basal area of 31 m^2/ha were left on the site. The yarding equipment used was a Cypress 6280 swing yarder rigged in a running skyline configuration. A rudimentary dropline carriage was made by removing the grapple legs from a yarding grapple and using the closing line as a skidding line.

Falling productivity was 150 m^3/shift and yarding productivity was 205 m^3/shift. Hedin noted that falling was the most critical phase because the placement of stems directly affects yarding productivity and residual tree damage.

Another BCMOF/FERIC cooperative study in southwestern B.C. was conducted at Fletcher Challenge Canada Limited's operations (Hedin and Delong 1993). Again, the sites were quite different from Vancouver Island's west coast. The project centred on the Coast-Interior transition

zone and both cable and ground-based yarding systems were monitored. Clearcut, seed-tree and shelterwood systems were setup to test regeneration performance on dry Douglas-fir ecosystems. Equipment used in the cable yarding units included a small tower yarder (Skylead C-40) and a MSP carriage with radio-controlled skyline clamp. Several layout and operational factors confounded some of the productivity measurements in this study. The authors did not find significant differences in cable yarding productivity between the silvicultural treatment units.

In the study reported by Edwards *et al*. (1992) and Kellogg *et al* (1996) skyline yarding productivities and costs were presented for the various group selection configurations, in addition to the planning results already discussed. Felling costs increased from 0.4 to 2.6% because more wedging was required to direct the selected stems. Final yarding costs ranged from 3.4 to 26.0% higher than clearcut operations. A combination of shift-level (daily production reports) and detailed-timing study methods were used in this harvesting study.

Another approach was taken by Keegan and Fiedler (1995) to determine the impacts of "New Forestry" prescriptions on stand-level harvest costs. They wanted to generate information more quickly than embarking on a lengthy series of production studies. They devised a detailed interview process and contacted operators in western Montana. Operators were asked to estimate their costs, by harvesting phase, for a variety of silviculture prescriptions in four major stand types. The operator's average harvest costs in 1991 were used as the basis for comparison. The firms interviewed accounted for 85% of the timber harvested in this region.

Estimates were made for both tractor and cable yarding-type sites. On cable ground, the highest cost increases were estimated for partial cuts in "second-growth Ponderosa pine/Douglas-fir" and

"mixed conifer" stand types compared to average uphill skyline yarding costs. A "commercial thin/shelterwood" prescription in lodgepole pine resulted in a one-third increase in logging costs over average conventional harvesting costs. About two-thirds of the increased costs were attributed to the yarding phase with most of the remainder being attributed to falling. Estimated cost increases for the other prescriptions ranged from 0 to 14%.

Keegan and Fiedler recognized that the potential for increased harvesting costs must be weighed carefully when planning alternative prescriptions. However they noted that, since 1991, there was a dramatic increase in stumpage prices on National Forest timber sales due to high market prices. Given these increases they concluded that the forest industry could absorb the level of additional harvest costs found in their study of partial cutting systems.

Productivity information for Cypress 7280B swing yarders working in clearcuts is available in Peterson (1988) and Peterson *et al.* (1991). Results from two and seven case studies were compiled in the 1988 and 1991 reports, respectively. All case studies were done on the east coast of Vancouver Island, where the terrain permitted use of an excavator as a mobile backspar. A running skyline system with yarding grapple was used for all the operations. Shift-level production reporting and detailed-timing studies were the study methods used by Peterson.

Peterson (1988) reported average productivities of 261 and 673 m^3/8-hr shift for second-growth and old-growth cutting units, respectively. The high productivity in the old-growth unit was due in part to the large average piece size; 2.37 m^3/piece yarded, compared to 0.89 m^3/piece in the second-growth unit. Modified bucking practices were employed in the old-growth unit and much of the timber was yarded tree-length.

Average productivities found in Peterson *et al.* (1991) are very high by any standards. For the seven case studies, the range was 540 to 1496 m^3/8-hr shift. Perhaps these results can be explained, in part, by the following factors: average piece size was high, ranging from 2.2 to 4.1 m^3/piece; average yarding distance was low, ranging from 51 to 123 m; and slopes were gentle, average slope ranged from 5 to 15% for five out of the seven sites monitored.

Peterson's studies provide information about swing yarders, equipped with grapples, working under very favourable conditions. They are not suitable as sources of baseline conventional productivities for comparison with the planned partial cuts at Chamiss Bay. In Peterson's studies, logs were decked in front of the yarders and mobile backspars were used for tailholds; two factors that increase swing yarder productivity. The steep terrain at the Chamiss Bay sites will not permit decking of wood at roadside or the use of mobile backspars.

2.3 Residual Stand Damage

Minimizing residual stand damage during the partial cutting operations in the large old-growth timber and steep terrain at Chamiss Bay will be a demanding task. Some scarring of residual trees will be inevitable but the extent and severity of damage cannot be predicted because there is no experience with this type of harvesting in coastal B.C. Studies of residual stand damage in second-growth thinning operations are reviewed here so that damage results for the Chamiss Bay trial can viewed in the context of other studies. Another reason to examine this literature is to determine appropriate methods of sampling for residual damage. Also, any information about what constitutes damage, in terms of a minimum scar surface area per tree, will be used to structure the presentation of the Chamiss Bay results.

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Residual stand damage estimates are an indirect measure of the care exercised by the crew during the harvesting operation. They can also alert planners as to the feasibility of the harvesting system they have designed for a steep slope partial cutting unit. However for the type of old-growth stands at Chamiss Bay, there is little information about acceptable threshold levels for scarring in terms of the size of individual scars and the proportion of residual trees affected.

In his literature review on tree wounding Nevill (in press) found that: "Most wounds larger than 9 dm^2 (1 ft^2) become infected regardless of tree species. After wound size, width and depth of injury are the most important characteristics in determining severity of decay." Nevill noted that true firs and hemlocks are more susceptible to scarring than species such as Douglas-fir. Also, wound location is important because the "...incidence and extent of decay increases with increasing proximity to the soil."

Nevill (in press) summarized the results of several studies that showed relatively high proportions of residual tree damage following harvesting (that is, greater than 40%). These studies covered second-growth conifer or eastern hardwood stands and a variety of harvesting systems. On the issue of wound size, Nevill cited several studies that showed: "Wound size is one of the most important characteristics related to the amount of decay. Generally, 60 to 85% of wounds larger than 9 dm^2 on western hemlock, true firs or spruce are decayed: roughly double that of smaller wounds."

Kellogg *et al.* (1986) determined skyline yarding costs and stand damage levels for three thinning treatments in second-growth Western hemlock-Sitka spruce stands in Oregon. The treatments were: low thinning with "narrow" and "wide" residual tree spacing, and a form of strip thinning

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using a herringbone design. Twelve percent of the residual trees were scarred in the strip treatment, and 47 and 61% of the residual trees were damaged in the narrow and wide treatments, respectively. They also identified five yarding variables that influenced stand damage and recommended practices to minimize damage.

Howard (1995) developed separate regression models for the proportion of residual trees damaged as functions of distance to the corridor, distance to the landing, and diameter-at-breast-height (DBH), based on observations at two commercial thinning sites in second-growth stands in coastal B.C. High overall damage levels, 28.3 and 38.9% of the residual trees, were found at the two sites. Howard recommended increasing corridor spacing to reduce harvesting damage.

Stand damage studies were conducted on two cable thinning operations in 33-yr-old Douglas-fir stands as part of an integrated research project in the Oregon coastal mountains during 1992 (Pilkerton et al. 1996). Three thinning treatments with residual stockings of 74, 148, and 247 trees/ha were analyzed. Objectives of the study included characterizing and comparing damage levels between treatments. Another objective was to evaluate four different methods of sampling residual stand damage. These were: 1) systematic circular plots, 2) systematic line transects, 3) blocks along the skyline roads, and 4) random circular plots.

Pilkerton et al. (1996) found that, depending on the thinning treatment, 8 to 13% of residual trees were scarred at one operation and 18 to 39% of residual trees were scarred at the other operation. The authors thought that the type of carriage in the latter operation was harder to position accurately on the skyline, thus increasing the propensity for damage, and that the crew was perhaps less diligent in minimizing damage compared to the former operation. Only trees with a

cumulative scar area of 450 cm^2 were reported as damaged. This threshold level, and other levels including 900 cm^2, are documented in the B.C. Ministry of Forests Silviculture Manual (BCMOF 1983). These levels correspond to a graduated scale of penalty payments for scarring damage in commercial thinning operations.

In their evaluation of sampling methods, Pilkerton *et al.* (1996) found that systematic circular plots, that is, cluster sampling, "appears to be the most efficient in establishing, traversing, and implementing a stand damage survey while providing an acceptable estimate of residual damage."

Bennett (1993) also reported damaged levels, using the BCMOF criteria, in a study of a ground-based partial cutting operation in a second-growth stand in coastal B.C. In this study, a system of systematically located circular fixed-area plots, that is, cluster sampling, was used to sample residual stand damage.

McNeel *et al.* (1996) discussed the findings from a survey of commercial thinning practices in western Washington state. Government and industry forest land managers thought that damage to 5% of the residual stand was acceptable when using either cable or ground-based systems. However, there was no clear indication about what constitutes damage to a residual tree in terms of a threshold level for scar surface area.

2.4 Other Partial Cutting Studies

Others have struggled with the problem of proposing alternative silvicultural systems in old-growth stands on the B.C. coast. Traditional silvicultural systems, such as selection and shelterwood systems, have evolved over centuries under European conditions and they are not

directly applicable to coastal old-growth forests in B.C., but they may have limited application in mature second-growth (Weetman and Vyse 1990). Because our knowledge of stand dynamics is limited, it is difficult to predict the long-term impacts of alternative systems on the soil, vegetation and wildlife.

Silvicultural alternatives for unstable sites in the Queen Charlotte islands were discussed in Sanders and Wilford (1986). Biological, management and physical constraints to the application of traditional silvicultural systems were identified. However, it was suggested that selected features of these systems could be incorporated into the management of unstable sites or protection forests. Clear objectives, skilled foresters and a long-term management commitment are essential if stands are to be manipulated in this way.

Also in the Queen Charlotte Islands, Moore (1991) reviewed the results of partial cutting operations on sensitive floodplains. Many of the issues he dealt with parallel those of the Chamiss Bay trial. Potential for windthrow in the residual stand, possible residual tree damage during harvesting, and the silvicultural implications of the treatments were some of the concerns. Moore concluded that the project was a success but he recognized that the acceptance of slower growth rates may be necessary if other forest management objectives are to be met.

A study for B.C.'s Prince Rupert Forest Region produced recommendations that merit review in the context of the Chamiss Bay trial. Weetman *et al.* (1990) assessed opportunities for alternative silvicultural systems in three of the region's biogeoclimatic zones. Lessons were learned from past partial cutting experience and the suggestions in the report are widely applicable. For example:

- Concentrate on smaller-scale, well-planned trials of alternative silvicultural systems before considering large-scale implementation.

- Test "biologically-sensible" silvicultural prescriptions and follow through with long-term stand monitoring. Prescriptions must be thoroughly prepared by qualified staff.

- Tailor prescriptions to local forest management objectives and site-specific ecological conditions. Application of "blanket" textbook silvicultural systems was discouraged.

Finally, Alexander (1972) presented guidelines for initial partial cutting in old-growth spruce-fir stands in Colorado and southern Wyoming. Partial cutting practices were presented for different stand conditions depending on their susceptibility to windthrow. The objective of the alternative practices was to maintain a continuous high forest cover and create conditions that preserve the forest landscape, and minimize the impact on water yields and wildlife habitat. Although the sites and stands are different than Chamiss Bay, the paper provides useful background information for planning and marking trees for partial cutting in old-growth stands.

2.5 Summary

Much of the material covered in the literature review is useful background information for designing an operational partial cutting trial. However, there are gaps in knowledge about the harvesting feasibility of partial cutting on sites like those at Chamiss Bay. The steep slopes, large old-growth timber and high levels of tree retention will require site-specific forest engineering solutions.

Issues of yarding corridor width, spacing and orientation were addressed by several sources. Opinions vary about the optimum configuration for these key elements in yarding system design. The steep terrain and large timber at Chamiss Bay mean that corridors should be more closely spaced than the 50 to 60 m spacings used in some second-growth operations on gentle slopes. Orienting corridors perpendicular to the contours is advisable but terrain features such as ridges and limited yarder positions on roads could make some radial, or fan-shaped, corridors necessary. The issue of maintaining forest landscape visual quality after harvesting, and concerns about windthrow on the west coast sites, mean that the corridors for the Chamiss Bay trial should be kept as narrow as possible. Also, narrow corridors are important if the goal is to have the residual trees uniformly dispersed in the partial cutting units.

There was very little information about falling techniques and productivity that could be applied to the Chamiss Bay sites. Concerns about the operational feasibility of partial cutting systems often stem from the falling phase. Unsafe working conditions for fallers, high potential for damage to residual trees, and unacceptably low productivity are often cited as reasons to discount alternative cutting practices on steep slopes. Yet, there have been few studies that examine the falling phase in detail. Limits for falling timber in partial cutting systems, in terms of stand characteristics and slope gradient, have not been defined in the literature.

Most of the numerous cable yarding production studies showed lower productivities and higher unit costs in partial cuts compared to clearcuts. A substantial proportion of the work came from Oregon where shelterwood systems have been established in dry Douglas-fir ecosystems. The literature confirmed the conventional wisdom: reductions in cable yarding productivity should be expected in partial cuts. Therefore, lower yarding productivity should be anticipated for the

partial cuts in the Chamiss Bay trial but the magnitude of the decline is difficult to predict. Also, impacts on productivity over a gradient of residual tree retention levels are not known. In many studies, shift-level time and production reporting was conducted in conjunction with detailed-timing of cable yarding cycle elements to provide harvesting productivity and cost information.

Studies of residual stand damage have primarily been done in second-growth commercial thinning operations. Levels of damage have varied greatly in past studies and no consensus has been reached on what constitutes an acceptable level of damage in a partially cut stand. This is understandable because a level of tolerance for scarring depends on many factors including stand age, species composition, and long-term stand management goals. Methods of reporting residual stand damage, and the variables used in analyses, differed considerably between studies. Cluster sampling was shown to be an efficient and practical method for obtaining estimates of residual stand damage in partial cutting units.

Others have examined silvicultural alternatives for coastal forests in B.C., and much is known about partial cutting and thinning in second-growth stands, but there is little information about some ecosystems that are important to B.C.'s coastal timber supply. Absent from the literature are studies of partial cutting on steep slopes in mature stands of the CWHvm1 biogeoclimatic variant. Limited knowledge about stand dynamics and a widespread perception that partial cutting is economically prohibitive are two factors that have perhaps held back attempts to implement alternative silvicultural systems on these sites. Also, many people anticipate that worker safety would be compromised and this has undoubtedly led to a reluctance to test alternative prescriptions.

Swing yarders, designed for the running skyline cable configuration, are used extensively in coastal B.C. They have been applied to many types of partial cutting operations but their adaptability to partial cuts with high levels of tree retention, in old-growth on steep slopes, needs to be explored. Successful adaptation of this equipment would extend its range of use and create more employment for forest workers because access to deferred timber may be gained with partial cutting systems. And, by adapting this equipment the industry can avoid large investments in new yarding machines to address sensitive site harvesting needs.

An operational trial of partial cutting systems in old-growth forests on steep slopes is timely. Land use planning initiatives and forest practices regulations have created special management areas that preclude clearcutting. Many such sites are in the CWHvm1 biogeoclimatic unit, the most extensive in the Vancouver Forest Region, and a critical component of the coastal timber supply. Studies of partial cutting systems on these sites are needed.

3. STUDY METHODS

A harvesting study was designed to address the specific objectives stated in the introduction. The first six sections of this chapter describe the methods used to address these specific objectives. First, the cutting treatments, cutting unit arrangement, and pre- and post-harvest stand structures are described. Second, the falling and cable yarding phases of the harvesting system, the focus of this study, are described. Third, the engineering procedures, and tree marking criteria and procedures, are presented and the method for calculating engineering and tree marking costs is described. Fourth, the methods for determining falling and cable yarding productivity and cost data are outlined. Fifth, the methods and analysis used to determine residual stand damage are presented. And finally, the methods and analysis used to determine post-harvest soil surface conditions are presented.

Secondary objectives of the study were to present information about the changes that partial cutting made to the landscape visual conditions at the trial sites, and to make preliminary observations about the windfirmness of the residual stands. These objectives were addressed informally using visual observations. The seventh and final section in study methods contains a description of the type of photographic records made at the study sites for evaluating changes in landscape visual conditions.

3.1 Study Sites

The trial sites, located on public land, are in the Kyuquot Timber Supply Block of the Strathcona

Timber Supply Area. Cutting authority was established under Forest Licence A19232. The

licensee is International Forest Products Limited (INTERFOR) and their operation is centred at

Chamiss Bay in Kyuquot Sound on the west coast of Vancouver Island (Figure 1).
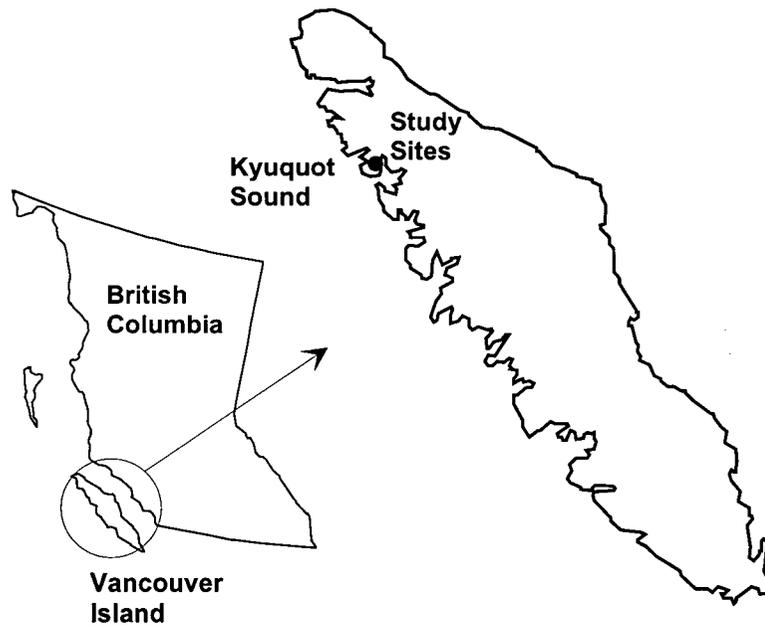
Figure 1. Location of study sites.

On Vancouver Island's exposed west coast, the potential for windthrow is high in stands altered

by cutting. Like many areas on the west coast the trial sites are subject to storm force winds in

winter and the potential for windthrow influenced the choice of tree retention levels in the partial

cuts. A windthrow hazard assessment was conducted on the sites to provide baseline information

about stand level characteristics. Assessments of topographic exposure, rooting depth and

previous tree exposure to winds were used in conjunction with observed windthrow patterns to assess the relative windthrow risk in the cutting units (Mitchell 1993). Mitchell made recommendations for boundary placement, timber removal levels, and tree selection criteria.

3.1.1 Cutting Treatments

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

- 55% retention.

- 65% retention.

- 70% retention.

The other treatments were:

- One small clearcut.

- Two strip cuts, each 50 to 60 m in width.

3.1.2 Cutting Unit Arrangement and Descriptions

Four of the five cutting treatments, the 55 and 70% retention units, the small clearcut, and the strip cuts, were situated on one hillside; terrain conditions and aspect were the same (Figure 2). Unit boundaries were located around stands of timber situated between steep gully complexes; the sizes of the cutting units were dictated by gully spacings.
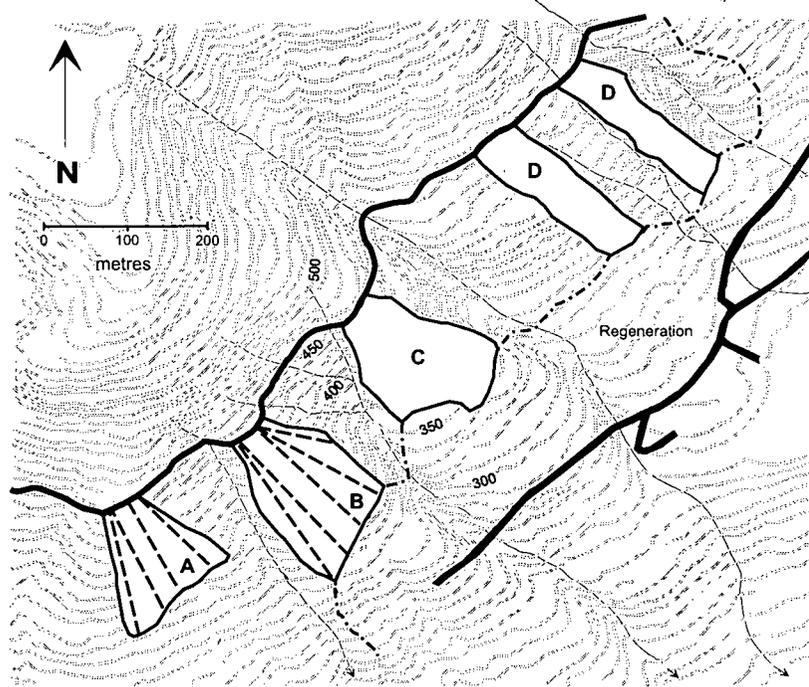
A - 55% retention unit
B - 70% retention unit
C - Clearcut
D - Strip clearcuts

– – – – – – Yarding corridors

Figure 2. Layout of four of the five cutting treatments.
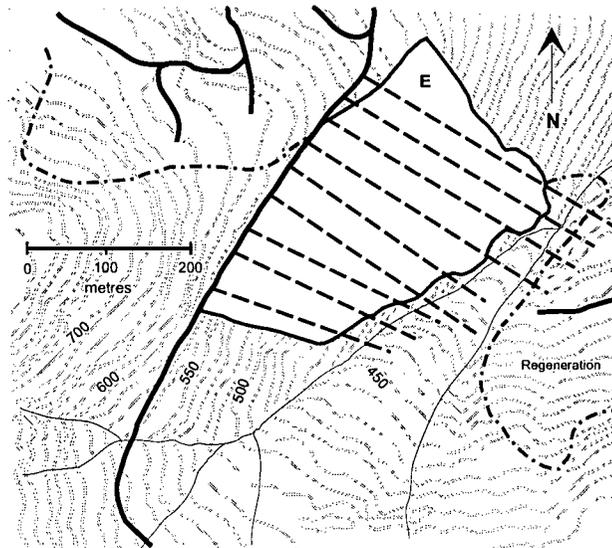
E - 65% retention unit

– – – – – – Yarding corridors

Figure 3. Layout of the 65% retention unit.

The 65% retention unit was located in a neighbouring valley (Figure 3). This cutting unit had the steepest terrain, with ground slope on some portions of the unit exceeding 100%. The northeast edge of the 65% retention unit borders on a clearcut and was windfirm. An untreated buffer was left on this edge to shield the modified stand from direct entry by wind.

The areas and average ground slopes for all cutting units are found in Table 1. Cutting unit elevations ranged from 300-600 m above sea level and ground slope varied from 55 to 100%. Terrain stability, assessed under B.C.'s system for terrain stability assessment[2], was categorized as class II and III with some class IV along the gullies.

Table 1. Area and average ground slope by cutting unit.

	55% Retention	65% Retention	70% Retention	Strip Cuts	Clearcut
Cutting unit area (ha)	1.7	5.1	2.4	2.8 [a]	2.3
Average ground slope (%)	65	81	61	58	62

[a] Two strip cuts, 1.4 ha ea., were harvested.

The availability of timber for conventional harvesting was limited, not to mention the availability of timber for an experimental harvesting project. This restricted the size and location of potential trial sites. Special approval to amend the five year development plan was granted by the BCMOF

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[2] See the Forest Practices Code of B.C. *Mapping and Assessing Terrain Stability Guidebook, April 1995*, for an overview of terrain stability classification and suggested references on this topic.

and trial sites were drawn from "leave" areas adjacent to some of INTERFOR's conventional cutting units.

Three retention units were harvested in the Chamiss Bay operational trial but only the 65 and 70% units are included in the harvesting study. The 55% retention unit was very small, located in a poor timber type, and only had a small volume harvested. This unit provided an opportunity to gain additional operational experience with partial cutting, but was not a suitable source of data for the harvesting study. Descriptive information about stand structure and engineering procedures for the 55% retention unit are included for reader interest, but study results focus on the 65 and 70% retention units, the strip cuts, and the clearcut.

3.1.3 Pre- and Post-Harvest Stand Structure

The stands at the trial sites represented mature 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*). The shrub layer was comprised mainly of huckleberry and blueberry (*Vaccinium spp.*). Pre- and post-harvest stand descriptions for the cutting units are shown in Table 2 and Table 3, respectively.

The graphs on pages 36 to 38 show the pre- and post-harvest diameter distributions for all the retention units (Figure 4 to Figure 9). The pre-harvest condition was derived from INTERFOR's operational-level timber cruise. Summaries of the trees that were marked, to attain the post-harvest diameter distributions in each retention unit, are contained in Appendix A. The retained trees were uniformly dispersed in each unit. "Uniform dispersal" loosely describes the pattern of

retention because the spatial distribution of stems in the natural, untreated stands was irregular with numerous gaps.

Table 2. Pre-harvest stand descriptions for cutting units.

	55% Retention	65% Retention	70% Retention	Strip Cuts	Clearcut
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 spp.	5	1	5	5	0
Stems/ha	441	494	435	437	503
Basal area/ha (m^2/ha)	62	76	84	64	75
Net volume/ha (m^3/ha)	616	821	893	638	809

Table 3. Post-harvest stand descriptions for retention cutting units.

	55% Retention	65% Retention	70% Retention
Species composition (%)			
Western hemlock	69	71	69
Amabilis fir	6	22	17
Western red cedar	18	6	12
other spp.	8	1	2
Stems/ha	299	381	302
Basal area/ha (m^2/ha)	33	49	57
Net volume/ha (m^3/ha)	390	518	632
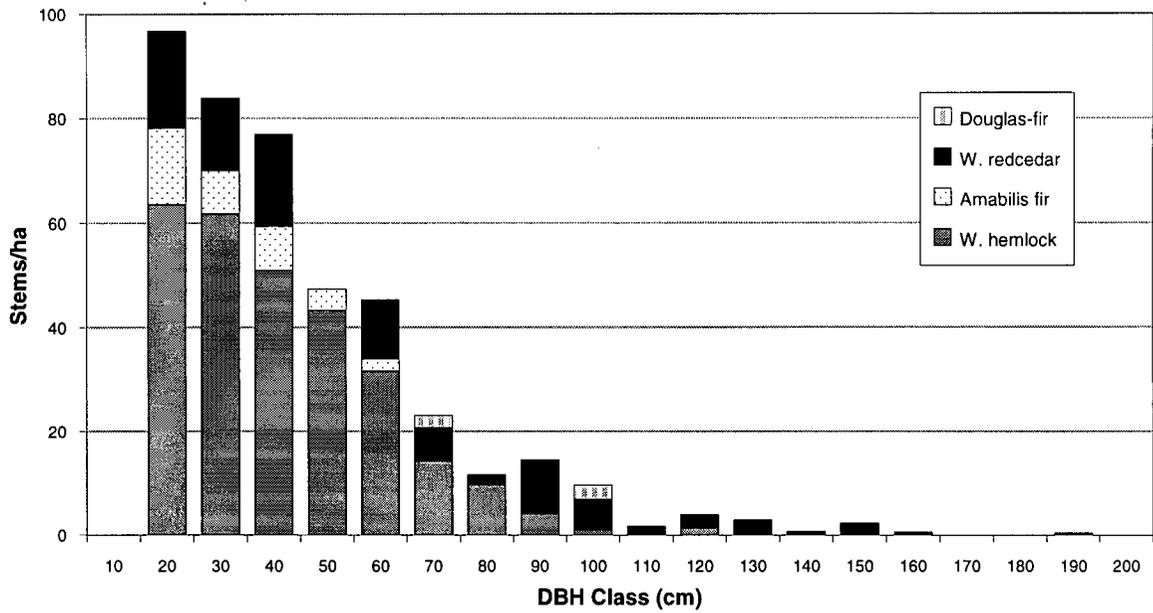
Figure 4. Pre-harvest diameter distribution for 55% retention unit.
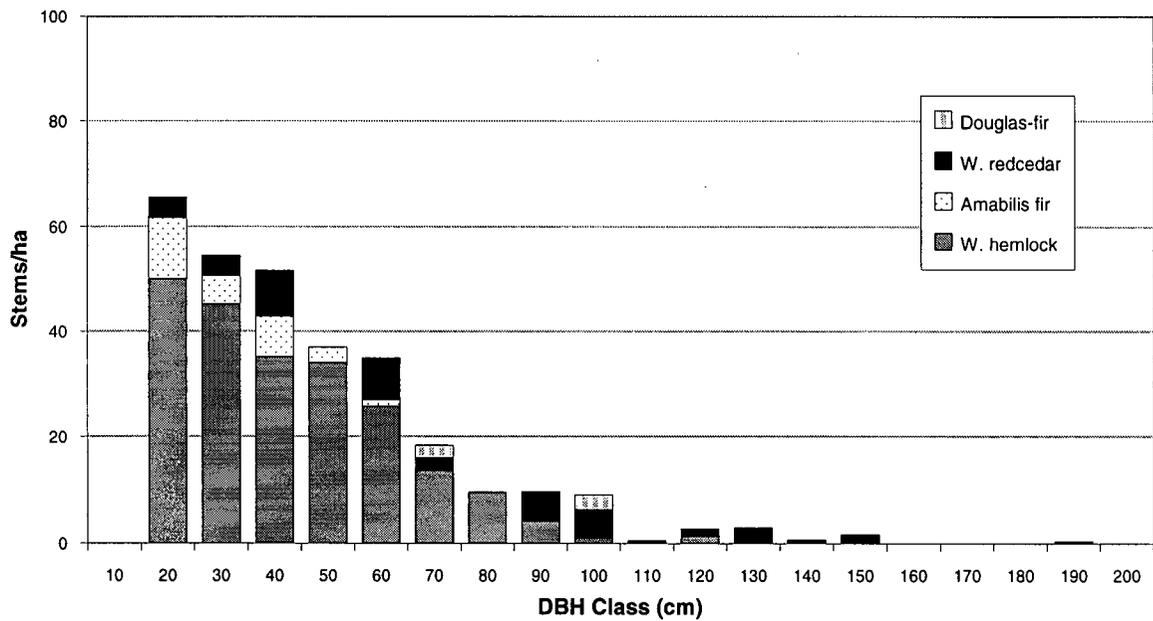
Figure 5. Post-harvest diameter distribution for 55% retention unit.

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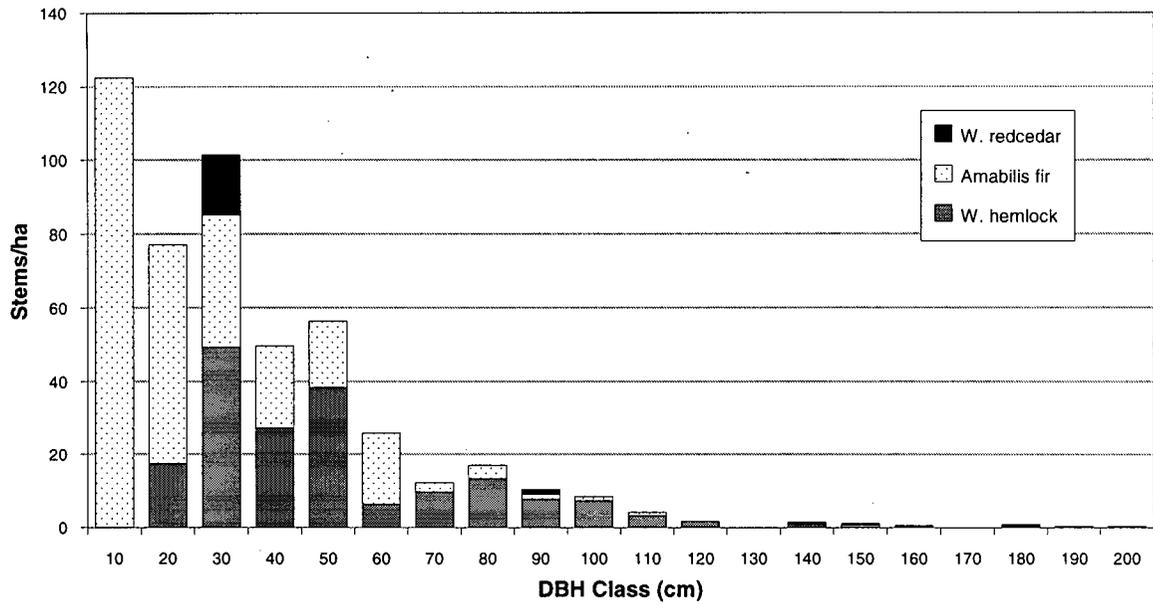
Figure 6. Pre-harvest diameter distribution for 65% retention unit.
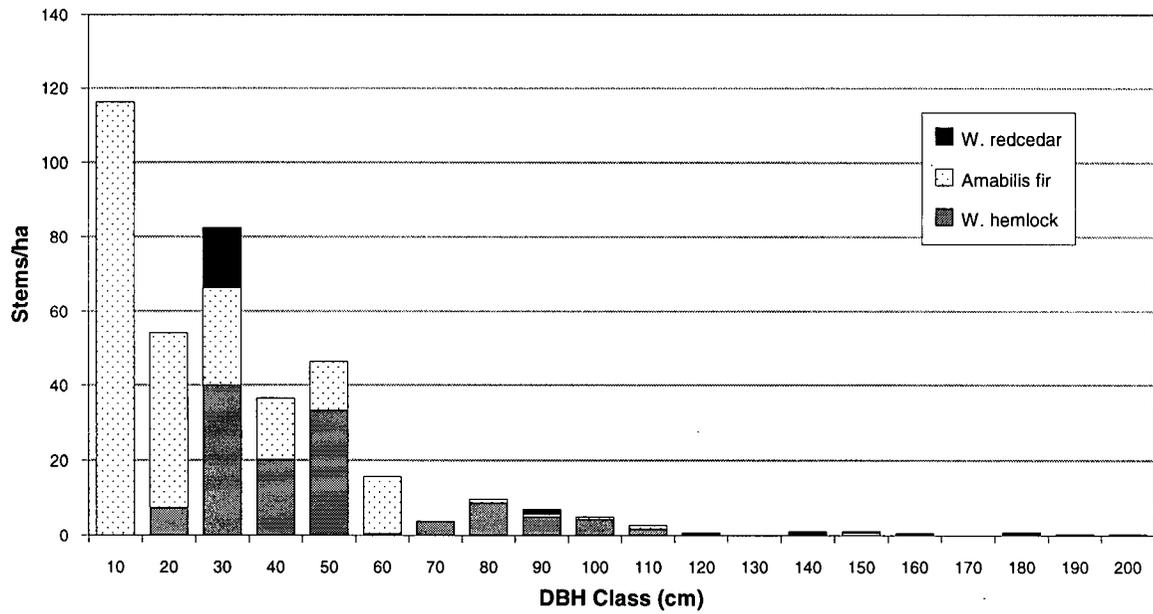
Figure 7. Post-harvest diameter distribution for 65% retention unit.

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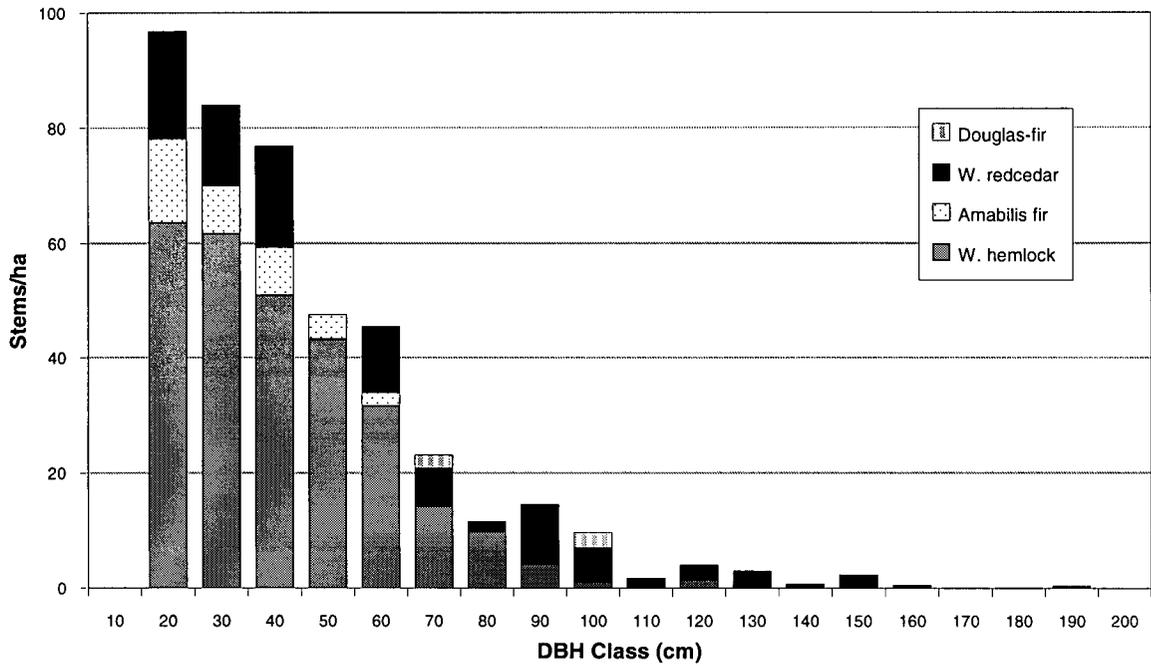
Figure 8. Pre-harvest diameter distribution for 70% retention unit.
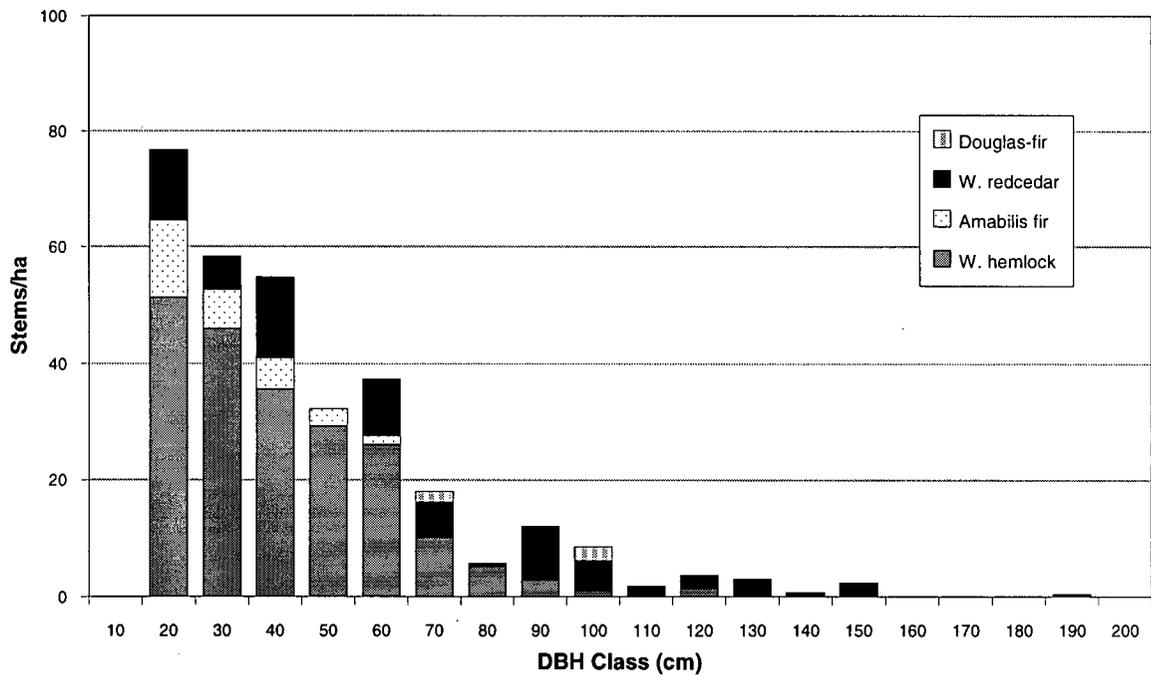
Figure 9. Post-harvest diameter distribution for 70% retention unit.

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3.2 Harvesting System Description

3.2.1 Falling phase

The falling phase of the trial was done by a contractor[3] and all falling was done manually. The fallers were experienced, highly skilled and well-motivated. The small size of the units meant that only one faller at a time could work in all except the 65% retention unit. (If more than one faller is employed in a unit then a safe working distance of two tree lengths or more must be maintained between fallers.) All cutting units except the 65% retention unit were closely spaced on one mountain slope and fallers could monitor each other as they worked in neighbouring units, as required by the Worker's Compensation Board of British Columbia (WCB).

In the 65% retention unit, the lower cutting boundary ran at an oblique angle across the contours. One faller worked for the first 6 shifts, accompanied by the principal researcher, until the working area had moved up the slope and become wide enough to accommodate a second faller. (See Figure D-2 in Appendix D for an aerial view of the unit after 6 shifts of falling were completed).

The fallers worked up the slope progressing back and forth over a section of the stand. The traditional tools, a chainsaw, axe and wedges, were used to fall and buck timber in the retention units. Practices were the same as for conventional falling: fallers worked with the tree's natural lean to fall timber across the slope, the limbs were removed and the trees were bucked to INTERFOR's preferred lengths within the stand, and trees were wedged over when necessary (Figure 10).

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[3] Shiels Holdings Ltd., Nanaimo, B.C.

All the snags were felled concurrently with the marked green trees. The trees marked within the yarding corridors were also felled as the faller progressed up the slope. 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, for example, in a herringbone pattern, can not be contemplated for large old-growth timber on steep slopes).

Figure 10. Faller wedging a tree in the 65% retention unit.

3.2.2 Yarding Phase

INTERFOR crews, using company-owned equipment, were responsible for the yarding and loading phases. A Cypress 7280B swing yarder (Figure 11), rigged in a running skyline configuration, was used to harvest the retention units and the clearcut. This swing yarder, weighing 72,700 kg,

is in the large size-class that is used extensively for yarding clearcuts in coastal old-growth timber.

A system of yarding corridors was used in the retention units. Selected trees were rigged as backspars to achieve the required deflection in the running lines. Exceptions were the four longest corridors in 65% retention unit (see Figure 3) where stumps were rigged as tailholds because their location, across a gully in an opposite cutover, provided the required deflection and running line clearance for yarding. Logs were extracted laterally (that is, parallel to the slope contour) to each skyline corridor and brought up to the roadside through the corridor. A Johnson mechanical slackpulling (MSP) carriage was used to provide the necessary lateral yarding capability (Figure 12).

In the clearcut, backspars were also used. 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. The yarder worked on single-width roads, and swung logs onto the road surface for unhooking, in the retention units and the clearcut.

A Madill 171 tower yarder, rigged in a slackline configuration, was used to harvest the two strip clearcuts. A MSP carriage was also used in this system. Good deflection was assured in each strip cut by anchoring the skyline on a ridge, 600 m slope distance, below the yarder. The tower yarder was rigged up in large landings above each strip cut making it easy to land logs and unhook chokers in front of the machine.

Figure 11. Cypress 7280B swing yarder.

Figure 12. MSP (dropline) carriage used with the swing yarder.

For the strip cuts, the slackline tower yarder was the most suitable machine because, during the engineering phase, deflection line analyses had shown that timber in the lower portions of each strip was inaccessible to conventional high-lead and running skyline systems. The live skyline configuration was used to span the broken terrain in the strips and retrieve all the timber.

Droplines, used with the MSP carriages, were 45 m long and 22 mm in diameter. 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.

Crew complements were slightly different in the retention units compared to the strip cuts and clearcut. A rigging slinger[4] and one choker setter hooked chokers in the retention units. Two choker setters accompanied 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 the rigging slinger communicated with hand-held radios. The rigging slinger monitored the carriage as it moved from roadside down the yarding corridor and told the operator to stop the carriage as it reached the best position for log hookup. The crew then pulled the dropline and chokers laterally to the logs. After the chokers were set, and the crew had walked a safe distance from the yarding lines, the rigging slinger directed the operator to yard the logs laterally into the corridor.

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[4] A "rigging slinger" supervises the choker setters, chooses the logs for choking, and participates in choker setting.

The ability of swing yarders to operate on the width of a single-lane road is important for cable yarding on steep slopes. (Road widths must be kept to a minimum in this type of terrain). A swing yarder can move easily along a road between parallel yarding corridors and rig-up usually only involves setting two guylines. Steep slopes demand that a machine have swing capability especially as logs are brought to roadside. Logs can then be landed on the road surface or passed to an accompanying log loader. These factors led to the choice of a swing yarder for the retention units in the Chamiss Bay trial.

3.3 Engineering and Tree Marking

FERIC and INTERFOR, led by the principal researcher, worked on the engineering and tree marking phases of the trial. Field engineering work in the retention units was done in September and October 1994. Trees were marked in January 1995. Input from INTERFOR's woods foreman, the falling contractor, and the WCB was obtained in the field and incorporated into the design and engineering of cutting treatments and the tree marking criteria.

3.3.1 Engineering Procedures

The engineering procedures used in the retention units are described in this sub-section. Procedures used in the clearcut and strip cuts are straightforward and will not be covered here.

All cutting units were designed for uphill yarding. First, cutting unit boundaries were located, surveyed, and mapped. Second, potential backspar trees or tailhold stumps along with suitable tieback trees or stumps were located and preferred yarder positions on the road were identified. These points were then connected in a closed traverse and mapped. Third, a centre-line for each yarding corridor was located to match the preferred yarder position on the road with the selected

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backspar tree or stump, while also meeting cable system deflection requirements, and a desired maximum spacing of 30 m between corridors. Finally, deflection lines were surveyed and load path analyses conducted for each corridor. Required tailhold elevations for the backspars were determined from these analyses.

The trial's maximum slope yarding distance, laid out in the 65% retention unit, was 320 m (see Table 4). The distance to the tailhold on this particular corridor was 380 m.

A mapping scale of 1:2000 was found to be most suitable for the field location work. At this scale, backspars (and tailhold stumps) and yarder positions, could be plotted accurately which in turn enabled accurate bearings to be calculated for location of each corridor centre-line.

The relatively close corridor spacing of 30 m was specified because the terrain was steep and the trees were large. The propensity for logs to roll downhill during lateral yarding and hang-up behind residual trees was a prime concern. In practice, a rigid specification for corridor spacing cannot be maintained on sites like those at Chamiss Bay. Sometimes the spacing was increased, up to a maximum of 40 m, when rock bluffs interfered with the desired corridor location or the preferred backspar trees were widely spaced.

Four-metre wide yarding corridors were specified for the trial. The 4-m width was established during the tree marking phase when all trees that fell within 2 m of the corridor centre-line, on either side of the line, were marked for cutting.

Logs were to be partially suspended during the lateral and corridor yarding sequences. Enough clearance between the ground and the running lines was needed to yard logs laterally and move

them into the corridor without damaging the trees bordering the corridor. However, too much clearance would allow the lines to lift out of the corridor and damage tree tops. This required that the harvesting system be designed so that the running lines were confined within each yarding corridor, below the top of the canopy and approximately 10 to 15 m above the ground surface.

Four, nine, and five yarding corridors were laid out to harvest the 55, 65, and 70% retention units, respectively (see Table 4). Note that the 65% retention unit has a parallel corridor configuration while terrain features such as ridges and gullies, and the orientation of the haul road and unit boundaries, dictated fan-shaped corridors (that is, several corridors radiating from one yarder position) in the other 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. Parallel corridors, oriented perpendicular to the contours, were preferred because they provide the best opportunity to control the logs and reduce hang-ups during yarding.

Table 4. Cable yarding system parameters by cutting unit.

	55% Retention	65% Retention	70% Retention	Strip Cuts	Clearcut
Equipment used	swing yarder	swing yarder	swing yarder	tower yarder	swing yarder
Corridor configuration	fan-shaped	parallel	fan-shaped	n/a	n/a
No. of corridors	4	9	5	n/a	n/a
Max. yarding distance (m)	190	320 [a]	260	250 [b]	240

[a] The slope distance to the tailhold was 380 m for the longest yarding corridor in the 65% retention unit.
[b] The maximum slope distance to a skyline anchor was 600 m in the strip

3.3.2 Tree Marking Criteria and Procedures

There were several goals for the post-harvest condition of the stands and these goals influenced the tree marking criteria used in the retention units. Five goals were specified. First, maintain a continuous high-forest cover (the need to plant any gaps, such as yarding corridors, would be evaluated after harvesting). Second, retain a high proportion of residual stems in a relatively uniform distribution to prevent wind from penetrating the stand and causing windthrow. Third, retain approximately the same proportion of tree species and diameter classes, found in the natural untreated stands, in the residual stands. Fourth, retain some of the forest structures, such as large trees and downed wood, that have important implications for biological diversity. And finally, consider the long-term health of forest by giving trees with dwarf mistletoe (*Arceuthobium tsugense*) or other diseases priority for removal.

To achieve these goals, criteria were developed to guide tree marking. Tree retention and removal levels were based on basal area of live trees. Unit basal area, measured in m^2/ha, was reduced by marking trees for cutting in all diameter classes so that the post-harvest proportions of these diameter classes remained similar to the proportions in the untreated stands. (Refer to the pre- and post-harvest diameter class distributions on pages 36 to 38).

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

- western hemlock infected with dwarf mistletoe (*Arceuthobium tsugense*) and all species displaying conk or other pathological indicators.

- all snags, to comply with WCB safety regulations.

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- trees displaying poor form, and those thought to be dying.

- trees thought to be subject to windthrow, as discussed in Stathers, Rollerson and Mitchell (1994).

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

Falling feasibility relative to the adjacent residual trees and the immediate terrain conditions was important. Several trees were usually evaluated simultaneously because cutting one tree often meant that others had to be taken to prevent hang-ups and brushing of residuals during falling.

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.

A 100% sample of marked trees was taken to control the marking process. Species, DBH, and pathological indicators were recorded for the marked live trees in each retention unit. Also, species and DBH were recorded, and height estimates were made, for all snags. This information was entered into a handheld computer in the field as tree marking progressed. Data were downloaded and analyzed at the end of the workday to ensure that the basal area retention targets were being met. Tree marking data summaries are contained in Appendix A.

Three people worked as a tree marking team; two people measured DBH and marked the selected trees with paint, and one person entered data in the handheld computer. The marking sequence was to: first, mark two adjacent 4-m-wide yarding corridors and, second, mark the segment of the stand in-between the two corridors. Because corridor centre-lines 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 (m²/ha) 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 at short intervals as each stand segment was completed. Tree marking, using paint, did not proceed unchecked for a full work day until markers were confident that basal area targets could be met.

Tree selection was done conservatively, that is, units were marked 3 to 5% above the final target for stand basal area, to allow for additional removals during the falling phase for safety reasons and so that any stems damaged during falling or yarding operations could be removed.

Volumes for the marked trees were estimated so that the timber volume available for yarding could be predicted. Equations for tree height, by species, were produced by regression analysis of the height and diameter information contained on the operational cruise cards. Estimates of tree volume were made from the basal area and height information using a paraboloid formula.

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 since a forester must weigh many objectives simultaneously and make tradeoffs during the marking process. The marking system must be coordinated with the natural lean of the trees to minimize damage to the residual stand during

falling. Perhaps most importantly, markers must try to visualize the 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. This ability is not likely to be a part of the marker's skill set and input from an experienced faller is invaluable at this stage. In the end, the fallers must have the option to exchange marked trees with similar unmarked stems for safety reasons.

3.3.3 Engineering and Tree Marking Costs

The time spent on engineering and tree marking was recorded for all personnel and used to calculate costs. Unit costs were calculated for corridor layout and tree marking in the 65 and 70% retention units. Conventional engineering activities such as cutting unit boundary layout and boundary traversing were not included. Unit costs were based on the volume harvested and scaled in each unit ($/m^3) and on cutting unit area ($/ha).

One-third of the total hours (person-h) spent on each activity, that is, corridor layout and tree marking, were charged out at $56.25/h and two-thirds of person-h were charged out at $31.25/h. This apportionment represents a reasonable crew structure for doing the work, that is, a field engineer/forester and two assistants.

3.4 Harvesting Productivity and Cost

Productivities and costs for the falling and cable yarding phases were determined for the 65 and 70% retention units, the strip cuts, and clearcut. Falling and bucking were completed in all cutting units in July and August 1995. Cable yarding was done in the 65 and 70% retention units and in the strip cuts in August and September 1995. The clearcut was yarded in August 1996.

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The falling and cable yarding production information was accumulated in two-stages. First, shift-level records for falling and cable yarding were collected for the shifts worked in each cutting unit. Shift-level data are the basis for the productivity and cost analyses presented in this thesis. Second, detailed timing of yarding cycle elements, and delays, was done for samples of yarding cycles in the 65 and 70% retention units using a handheld computer. Slope yarding distance, lateral yarding distance, number of logs per cycle, each log's individual code number, and crew size were also recorded. Log volume information was obtained by numbering and tagging the logs, and scaling in the setting prior to yarding. This information will be used to develop production functions for cable yarding in retention cutting units. These results will be reported by FERIC at a later date.

To collect the shift-level data, report forms were drawn up specifically for the falling and yarding phases and distributed to the falling and cable yarding crews. The forms were completed daily by the fallers and yarder operators in each cutting unit. A 100% sample of the shifts worked was taken from each cutting unit for the falling and cable yarding phases. The following information was recorded on the shift report forms:

Falling Shift Report Form:

- date, faller's name, and location worked.

- hours worked.

- production, measured as the number of logs manufactured in the shift.

- estimates of delay time for wind, hang-ups, saw maintenance, etc.

- number of residual trees scarred.

- number of unmarked trees felled (as substitutes for marked trees unable to be felled).

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Cable Yarding Shift Report Form:

- date, operator's name, and location worked.

- shift start and finish time.

- number of turns (yarding cycles).

- number of pieces (logs yarded).

- time distribution, according to the time spent on yarding, rigging/changing roads, mechanical downtime, and other delays.

- log loader location; that is, working with the yarder, partial shift with the yarder, or no loader (yarder decking wood).

- other comments.

Each faller carried a counting device and registered logs as they were manufactured. Yarder operators were issued with two counters for recording piece and turn counts.

Summaries of the shift-level data for the falling and yarding phases are presented by cutting unit. A breakdown of yarding time for each unit was produced showing productive time, and mechanical and non-mechanical delays as outlined by Bérard *et al.* (1968).

Several measures of productivity were calculated for each phase. Productivities based on the number of shifts and hours worked were calculated for the falling phase. Productive machine hours (PMH) and scheduled machine hours (SMH) were used in productivity calculations for cable yarding. PMH include yarding time and the time required to change yarding roads or corridors. All other activities and delays were excluded from PMH. SMH represent the time spent on all activities during the study period including delays (with the exception of long-term mechanical delays). The volume of timber yarded (m^3) from each cutting unit was tracked by individual

cutting unit and scaled at the Chamiss Bay dry land sort. These scaled timber volumes were used to calculate m^3/shift and m^3/h for falling, and m^3/PMH and m^3/SMH for cable yarding.

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 (see Appendix B). An hourly cost for an individual faller was also developed. These hourly costs were applied to the productivity measures to generate unit harvesting costs for each phase. Costs for log loading are also summarized together with the yarding phase. In this project, yarding and loading were integrated since operating conditions in the steep terrain did not permit separation of these phases.

The principal researcher was on-site during the falling and yarding operations to: 1) explain the harvesting plan to the crews and to implement the plan, 2) conduct the detailed-timing studies with the help of an assistant (and to scale logs within sample yarding corridors for the detailed-timing study) and, 3) coordinate the shift-level study and ensure that reports were completed accurately.

3.5 Residual Stand Damage

Surveys were designed to quantify the level of damage to residual trees from harvesting in the 65 and 70% retention units. The surveys were conducted in September 1995.

A sampling scheme was used based on the principles of cluster sampling, combined with systematic selection of the clusters. A randomly-oriented grid was superimposed over the study sites. Grid points were spaced on a 35 m by 35 m pattern to provide 34 and 17 plot centres evenly distributed over the 65 and 70% retention units, respectively. At each plot centre a

circular fixed-area plot was established with a radius of 11.28 m and area of 0.04 ha. Maps showing the layout for the post-harvest surveys are contained in Appendix C.

The species and diameter of all trees in each plot were recorded. On trees with scarred boles, measurements were made for the following variables: species, diameter, width and length of individual scars, scarring severity, and location of each scar. Scarring severity was categorized as either a gouge extending through the cambium into the wood or simple sloughing of the bark. The distance from the ground to the bottom of the scar was measured and recorded as the scar's location. Location was estimated for those scars occurring out of the surveyor's reach.

3.5.1 Variables of Interest

Two variables of interest were selected for the analysis: the number of scarred trees per ha, and the proportion of residual trees damaged. These variables were selected because they are common measures, easy to understand, and clearly indicate the overall impact of the harvesting system on the residual stand. Cluster sampling formulae were used to calculate means and standard errors for each variable.

The following notation is used:

No. of observations in the i-th cluster	$y_i \bullet$
No. of elements in the i-th cluster	m_i
Population of potential plots	N
Plots sampled	n

To calculate the number of damaged trees/ha, the following formulae for the mean (Eq. 1) and standard error (Eq. 2) of equal-sized clusters was used (Cochran 1977):

$$\bar{y}_c = \frac{\sum_{i=1}^{n} y_i \cdot}{n}$$

[1]

$$S_{\bar{y}_c} = \sqrt{\frac{\sum_{i=1}^{n} y_i \cdot^2 - \frac{\left(\sum_{i=1}^{n} y_i \cdot\right)^2}{n}}{n(n-1)} \left(\frac{N-n}{N}\right)}$$

[2]

To calculate estimates for the proportion of residual stems damaged, formulae for the mean (Eq. 3) and standard error (Eq. 4) of the elements, or unequal cluster sizes, was used (Cochran 1977):

$$\hat{p} = \bar{y} = \frac{\sum_{i=1}^{n} y_i \cdot}{\sum_{i=1}^{n} m_i} = \frac{\bar{y}_c}{\bar{m}}$$

[3]

$$S_{\hat{p}} = S_{\bar{y}} = \sqrt{\frac{1}{n(\bar{m})^2} \left(\frac{\sum_{i=1}^{n} y_i \cdot^2 - 2\bar{y}\sum_{i=1}^{n} y_i \cdot \times m_i + \bar{y}^2 \sum_{i=1}^{n} m_i^2}{n-1}\right) \left(\frac{N-n}{N}\right)}$$

[4]

A sampling error (SE) of 20%, expressed as a percentage of the mean for the damaged trees/ha variable, was chosen as the goal for this survey and should be adequate for this type of descriptive data. There must be a balance between the time and cost expended on the survey, and the benefits produced by improving the sampling error for information that is supplementary to the main study about harvesting productivity.

3.6 Soil Surface Conditions

Post-harvest soil surface conditions were surveyed in the 65 and 75% retention units in conjunction with the residual stand damage surveys. The grid points laid out for the residual stand damage surveys were also used as plot centres for the soil disturbance measurements. 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. The second transect was run on a bearing calculated by adding 90 degrees to the random bearing. The 17-m transects maximized the area covered around each gridpoint, but they did not extend into the zone of influence of neighbouring gridpoints.

Cluster sampling, using clusters of equal sizes, was the sampling method applied to the soil surveys. The length occupied by a particular soil disturbance class, along each transect, was measured. For each grid point, the length of the segments for a disturbance class, over both transects, was summed. A proportion for each disturbance class was calculated based on the combined 34-m length of both transects, at each grid point. Means and standard errors were calculated using the formulae for equal cluster sizes (Eq. 1 and 2).

3.7 Changes to Landscape Visual Conditions

The need to minimize the impact of harvesting and road building on some scenic landscapes has spurred investigations of partial cutting on sites that have traditionally been clearcut. This was one of the driving forces behind the Chamiss Bay harvesting trial. Although the trial sites themselves did not have special visual landscape management objectives, they can be used to assess whether high-retention partial cutting will create visual conditions that meet Visual Quality Objectives (VQO's) in other sensitive areas. (For VQO definitions refer to the Forest Practices Code of British Columbia, Visual Impact Assessment Guidebook).

Photographs were taken of the cutting units and surrounding landscape before and after harvesting. Viewpoints from aircraft, along forest roads within the operation, and from a boat in Kashutl Inlet were used. (The sites are visible in the westerly direction from the inlet.) It is most difficult to satisfy VQO criteria when sites are viewed from the air. For this study the aerial views were used to show the level of alteration to the landscape but note that this is an overly stringent practice, not adopted for conventional Visual Impact Assessments (VIA). VIAs are usually done from a terrestrial viewpoint.

4. RESULTS AND DISCUSSION

The harvesting study results are divided into eight sections. The first six sections address the specific objectives of the thesis by presenting information about engineering costs, tree marking costs, falling productivity and cost, cable yarding productivity and cost, residual stand damage and post-harvest soil surface conditions. The sections on engineering, tree marking, residual stand damage, and soil surface conditions focus on the 65 and 70% retention units.

A consistent reporting format is used throughout the sections on falling and cable yarding. Productivity and cost results are presented for the 65 and 70% retention units, the strip cuts, and the clearcut in a side-by-side arrangement. The 100% sampling of the shifts in these phases enabled comparisons to be made between the trial cutting units.

The final two sections in this chapter contain some observations about changes to the landscape visual conditions and the windfirmness of the residual stands.

4.1 Engineering

4.1.1 Costs

The time and costs for corridor layout in the 65 and 70% retention units are shown in Table 5. Activities included in corridor layout are: locating and mapping backspars, tailholds and tie-backs; locating and flagging corridor centre-lines; and running deflection lines and conducting load path analyses for each corridor. Person hours (person-h) represent the combined time for all members of the engineering crew. One-third of the total hours spent on corridor layout, that is, 117 and 60 person-h in the 65 and 70% retention units, respectively, were charged out at $56.25/h and two-thirds of total person-h were charged out at $31.25/h.

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Table 5. Time and cost of field work for retention units.

	65% Retention			70% Retention		
	person-h	$/m^3	$/ha	person-h	$/m^3	$/ha
Corridor layout	117	2.57	908.09	60	2.66	989.58
Tree marking	91	2.00	706.29	32	1.42	527.78
Total	208	4.57	1614.38	92	4.08	1517.36

Two unit cost measures for corridor layout, $/m^3 and $/ha, are presented. The costs were similar for the two retention units. Costs expressed in $/m^3, the most common measure for forest operators, were $2.57/m^3 and $2.66/ m^3 for the 65 and 70% retention units, respectively.

4.1.2 Other Observations

An accurate cutting unit base map is imperative for yarding corridor layout. This requires careful surveying of roads, cutting boundaries, backspar locations, and yarder positions. Corridors are initially drawn on this map so that bearings can be calculated for field location. Because the corridors were narrow (4 m) and distances to the tailhold extended up to 380 m, the flagged line connecting the yarder positions with the backspars had to be perfectly straight. This was to ensure that, after falling, the yarder's lines would run without obstruction to the backspar. Without accurate bearings, several attempts are needed to connect corridor end points, accompanied by a considerable increase in time and physical effort to complete the work.

The relatively narrow, 4-m wide corridors in the Chamiss Bay project worked well. During lateral yarding the running lines would often lightly contact some of the trees bordering the

corridor. Logs made a smooth transition from their lateral cross-slope position into the corridor provided that 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.

Narrow corridors were specified to reduce the visual impact of harvesting and to prevent wind from penetrating the stand. Examples of the corridors are shown in the accompanying photographs. A corridor in the 65% retention unit, viewed after falling but prior to yarding, is shown in Figure 13. The tailhold stump shown in the foreground was one of four located across
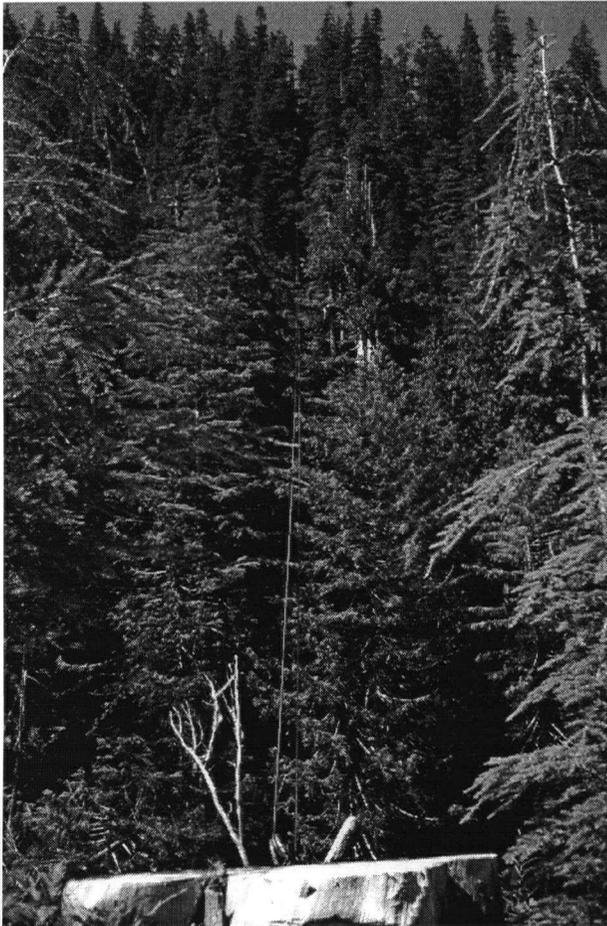
Figure 13. Yarding corridor in the 65% retention unit immediately prior to yarding (tailhold stump in foreground).
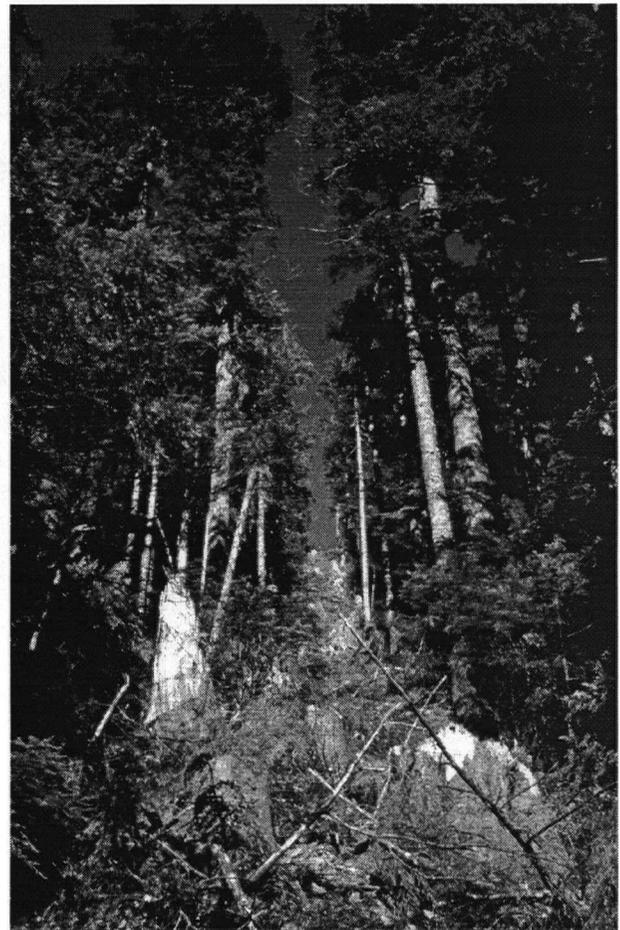
Figure 14. Yarding corridor in the 65% retention unit after yarding was completed (ground level view, looking up the slope).

a creek, on a slope opposite the cutting unit (see Figure 3). A post-harvest view, looking up the slope from within the corridor, is shown in Figure 14.

4.2 Tree Marking

4.2.1 Costs

Unit tree marking costs based on the scaled volume from each retention unit and on unit area are also shown in Table 5. Costs were $2.00/m^3 ($706.29/ha) and $1.42/m^3 ($527.78/ha) for the 65 and 70% retention units, respectively. The higher costs in the 65% retention unit can be attributed to two factors. First, this unit had the longest yarding distances and the steepest, most rugged terrain. Therefore a greater proportion of hiking time was required to complete the marking. Second, it was the unit where the marking procedures were first put to use and refined, and the initial experience probably reduced the time required for the 70% retention unit.

4.2.2 Other Observations

Tree markers must understand the sequence and direction in which trees will be felled if brushing and damage of residual trees is to be avoided. Fallers must be able to fall the marked stems without having them hang-up in residual trees. Large old growth trees in steep terrain are usually felled across the slope. (Downhill may be the only option for green trees with a heavy downhill lean. Even a slight downhill lean in trees with considerable butt rot, and in snags, means that they must be felled downhill.) 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.

Eliminating tree marking and relying on fallers to select trees for cutting is not recommended at this time. This is not because fallers do not have the necessary skills, many do, but rather it is time consuming to apply the tree selection criteria in structurally-variable old-growth stands. Foresters and forest engineers must develop a site specific plan and follow through, preferably with input from an experienced faller, to implement it. It would not be fair to burden fallers with the added responsibility of interpreting a complex cutting treatment since they have to concentrate on falling and bucking activities.

The marking procedures developed for the Chamiss Bay trial worked well operationally and on-site input from the falling contractor and the woods foreman was helpful. By the time engineering and tree marking were completed, these individuals were assured that a workable plan was in place and they were determined to make it succeed. Evidence of the successful marking scheme is that very few marked trees were left standing and substituted by the fallers with alternate unmarked trees.

4.3 Falling Phase

4.3.1 Production Summary

Falling time and the volume felled by individual faller are shown in Table 6. The table also

shows that one faller in particular assumed much of the responsibility for falling in the trial units.

Table 6. Falling and bucking production summary by individual faller.

	65% Retention			70% Retention	Strip Cuts			Clearcut
	faller #1	faller #2	combined	faller #1	faller #1	faller #3	combined	faller #3
total hours worked	59.5	34.0	93.5	32.5	39.0	39.0	78.0	74.0
total shifts worked	9.2	5.2	14.4	5.0	6.0	6.0	12.0	11.4
total m³ felled	1151	648	1799	894	964	827	1791	2069

4.3.2 Shift-Level Productivity and Cost

Four productivity measures for falling and bucking by cutting unit are presented in Table 7. A

"piece" is a manufactured log or top, ready for yarding. The measures based on timber volume,

m^3/shift and m^3/h, are the most common.[5] Compared to the trial's small clearcut, falling

productivities were 31.2% lower in the 65% retention unit, 1.6% lower in the 70% retention unit,

and 17.9% lower in the strip cuts.

The comparison between the 65% retention unit and the clearcut provides the best indication of

the relative difference in falling productivity for partial cutting compared to clearcutting under

the trial conditions (that is, 31.2% lower falling productivity for the retention unit). This is

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[5] A faller's shift length is 6.5 hours.

Table 7. Falling and bucking productivity by cutting unit.

	65% Retention	70% Retention	Strip Cuts	Clearcut
pieces/shift	63.8	112.4	95.7	109.8
m^3/shift	125.1	178.8	149.3	181.7
pieces/h	9.8	17.3	14.7	16.9
m^3/h	19.2	27.5	23.0	28.0

[a] A faller's shift length is 6.5 h.

because species composition and volumes per ha were very similar in the 65% retention unit and the small clearcut (see Table 2).

It was interesting to observe the relatively high productivity in the 70% retention unit, that is, 27.5 m^3/h or 178.8 m^3/shift. This was only 1.6% lower than the falling productivity in the clearcut. This result can be attributed mainly to differences in timber type. The 70% retention unit had the tallest, most uniform timber and the highest net volume per hectare of all the units in the study; key factors contributing to the high falling productivity.

The lower falling productivity in the strip cuts compared to the clearcut is logical. When a faller's working area is confined to a 50 to 60 m-wide strip, more time must be spent trying to direct trees into the strip along each side boundary. However, the lower productivity in the strip cuts must also be attributed, in part, to differences in timber type. Even though the clearcut and strip cuts were closely spaced on one mountain slope, the strip cuts were in a relatively low volume cedar-hemlock stand and the clearcut was in a higher volume hemlock-amabilis fir stand.

Table 8. Falling and bucking unit costs by cutting unit.

	65% Retention ($/m³)	70% Retention ($/m³)	Strip Cuts ($/m³)	Clearcut ($/m³)
Falling and bucking	3.82	2.67	3.20	2.63

The unit costs for falling and bucking are shown in Table 8. (Note that allowances for crew transportation, overhead and profit were not included in the faller's hourly cost. See Appendix B). Compared to the trial's small clearcut, unit falling costs were 45.3% higher in the 65% retention unit, 1.6% higher in the 70% retention unit, and 21.7% higher in the strip cuts.

4.3.3 Other Observations

The fallers instituted a methodical approach to their falling and bucking activities in the retention units and maintaining safe work practices was their paramount concern. All snags were felled concurrently with marked green trees without incident. Potential problems such as hang-ups, brushing of standing timber during falling and limbs hanging up in the residual canopy were minimal. 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.

Partial cutting prescriptions add to the complexities of falling old-growth timber. There is usually a preferred falling direction for a selected tree that will minimize damage to the residual stand. A faller must evaluate whether a tree can be felled safely, and in the preferred direction. Tree size, species, quality, and the magnitude of its natural lean, the steepness of the terrain, the density of underbrush, and the faller's level of experience all influence this decision-making process.

4.4 Yarding Phase

4.4.1 Production Summary

A summary of cable yarding production is shown in Table 9 (Cable yarding productivity is discussed in Section 4.4.3). Scheduled machine hours (SMH) is time that the yarder was staffed with a crew and available for work. It includes productive yarding time plus mechanical and non-mechanical delays. Yarding shift lengths were variable in each unit. However, converting total SMH to the equivalent number of full 8-h shifts shows that 15.7, 7.0, 16.1, and 12.3 shifts were needed to yard the 65 and 70% retention units, the strip cuts, and the clearcut, respectively.

The largest average volume/piece, at 1.1 m^3, was recorded in the 65% retention unit. This was expected because this unit had the highest average diameter-at-breast-height (DBH) of the trees selected for cutting. The average number of pieces/cycle in the strip cuts and clearcut, at 2.6 and 2.7, respectively, were higher than the average pieces/cycle recorded in the retention units. This

Table 9. Cable yarding production summary.

	65% Retention	70% Retention	Strip Cuts	Clearcut
total PMH [a]	109.7	51.0	99.5	82.8
total SMH [b]	125.4	56.0	128.8	98.5
total volume yarded (m^3)	1799	894	1791	2069
avg. volume/piece (m^3)	1.1	0.8	0.9	0.8
avg. no. of pieces/cycle	2.3	2.4	2.6	2.7

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

is also logical because an extra choker and choker setter were used in the strip cuts and clearcut compared to the retention units.

The timber volume removed from the retention units was greater than the predictions made in the tree marking summaries for green tree removal (see Appendix A). This was due mainly to the number of snags removed. The snags provided additional merchantable volume, both sawlog and pulp grades, not included in the estimates for green trees. (The 65 and 70% retention units contained 35 and 55 snags/ha, respectively.)

4.4.2 Time Distribution

Table 10 shows the breakdown of total SMH for cable yarding in each cutting unit. The *yarding logs* component took up 77.6, 83.4, 69.9, and 76.9% of total SMH in the 65 and 70% retention units, the strip cuts, and the clearcut, respectively. In the strip cuts, the time available for yarding logs was reduced because 12.6% of SMH was taken up by *other delays*. These other delays were due to failures of guyline stumps and a skyline anchor stump.

Yarding road changes accounted for 9.0, 7.6, 6.6%, and 7.1% of SMH in the 65 and 70% retention units, the strip cuts, and the clearcut, respectively. (For the retention units, yarding roads refer to the yarding corridors; 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. However the average time per road change was longest in the strip cuts because the skyline anchor and the tower yarder were both repositioned.

Table 10. Time distribution for cable yarding operations.

	Proportion of SMH (%)			
	65% Retention	70% Retention	Strip Cuts	Clearcut
Yarding logs	77.6	83.4	69.9	76.9
Change yarding roads	9.0	7.6	6.6	7.1
Rig-up/dismantle	4.0	6.3	7.4	8.4
Repair running lines	8.2	2.7	3.5	0.0
Other delays	1.2	0.0	12.6	7.6

Rig-up/dismantle was defined as the time required for the initial setup, and subsequent tear down, of the cable yarder in each cutting unit. There was one occurrence in each retention unit and the clearcut, and two occurrences in the strip cuts, one for each strip. This category accounted for 4.0, 6.3, 7.4, and 8.4% of SMH in the 65 and 70% retention units, the strip cuts, and clearcut, respectively.

The major category within mechanical delays was *repair running lines*. Downtime associated with broken wire rope and subsequent splicing of the yarder's operating lines was assigned to this category. The largest proportion of SMH for line repairs, at 8.2%, was recorded in the 65% retention unit. On several occasions the haulback[6] broke at the point where it was secured to the drum. This happened at the start of the project, in the first and the longest corridors yarded. The problem was eventually rectified and there were no further occurrences.

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

4.4.3 Shift-Level Productivity and Cost

Productivity results for the cable yarding phase are shown in Table 11. Measurements of turns (that is, the number of yarding cycles), pieces, and timber volume (m^3) are expressed in terms of PMH and SMH. Productivity measured in m^3/PMH shows the average volume of timber yarded when the machines were involved in yarding and changing yarding roads; m^3/SMH is the measure that indicates the system's overall productivity after delays have been included.

The relative differences in yarding productivity between the cutting units are best examined using m^3/PMH because mechanical and non-mechanical delays have been excluded from PMH. The results show that yarding productivities, in m^3/PMH, were 34.4% lower in the 65% retention unit, 30.0% lower in the 70% retention unit, and 28.0% lower in the strip cuts, compared to the trial's small clearcut.

Table 11. Cable yarding productivity by cutting unit.

	65% Retention	70% Retention	Strip Cuts	Clearcut
turns/PMH[a]	6.8	7.5	7.1	7.7
turns/SMH[b]	6.1	6.8	5.5	6.7
pieces/PMH	15.6	18.2	18.0	21.6
pieces/SMH	13.7	16.6	14.2	19.0
m³/PMH	16.4	17.5	18.0	25.0
m³/SMH	14.3	16.0	13.9	21.0

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

Based on SMH, yarding productivity ranged from a low of 13.9 m³/SMH in the strip cuts to a high

of 21.0 m³/SMH in the small clearcut. The 65 and 70% retention units had yarding productivities

of 14.3 and 16.0 m³/SMH, respectively. The lower production per SMH in the strip cuts, compared

to the retention units, was attributed to the guyline and skyline anchor stump failures that

occurred in the strips. These occurrences resulted in a larger proportion of delay time compared

to the other units.

Unit costs for the yarding and loading operations are presented in Table 12. In this study a

generic hourly equipment cost was calculated for the three types of machines used (see Appendix

B). Hourly costs were divided by m³/SMH to generate unit costs for the Chamiss Bay cutting

units. No attempt was made to duplicate the costs incurred by INTERFOR.

Table 12. Yarding and loading unit costs by cutting unit.

	65% Retention ($/m³)	70% Retention ($/m³)	Strip Cuts ($/m³)	Clearcut ($/m³)
Yarding				
equipment	15.78	14.17	10.60	10.77
labour	11.08	9.95	13.40	7.57
total	26.86	24.13	24.01	18.34
Loading				
equipment	6.95	6.24	7.16	4.74
labour[a]	4.82	4.33	4.96	3.29
total	11.76	10.57	12.12	8.03
Total	38.62	34.69	36.13	26.37

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

Total unit costs for the yarding phase were $26.86, $24.13, $24.01, and $18.34 per m^3 for the 65 and 70% retention units, the strip cuts, and the clearcut, respectively. Yarding costs were 46.4% higher in the 65% retention unit, 31.6% higher in the 70% retention unit, and 30.9% higher in the strip cuts, compared to the clearcut.

The unit costs for log loading depended on the productivity of the yarding machines. The yarders and log loaders had to work together in the steep terrain. (In gentler terrain it is usually more productive for the swing yarder to deck logs by the roadside. When decked wood has been accumulated, loaders can work independently and load trucks from the log decks at a faster rate.) Total unit loading costs were $11.76, $10.57, $12.12, and $8.03 per m^3 for the 65 and 70% retention units, the strip cuts, and the clearcut, respectively.

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 and the yarding phase cost in the trial clearcut is higher than average yarding costs in most coastal forest operations. The relative difference in costs would likely be greater if, for example, INTERFOR's overall average yarding cost for the Chamiss Bay operation was used as the basis for comparison.

4.4.4 Other Observations

The supervisory personnel and harvesting crews responded very positively to the new challenge of yarding in the retention units. Rigging the yarding corridors and positioning the MSP carriage during each yarding cycle required additional skill and concentration to remove 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 are broken out of 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.

Initially, two choker setters 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.) Crews were anxious to maintain 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 choker setter, with two chokers, and steady production was achieved.

4.5 Residual Stand Damage

Results from the residual stand damage surveys are summarized in Table 13 and Table 14 for the 65 and 70% retention units, respectively. The variables of interest are *trees/ha* and *proportion of residual stems (%)* with scarring. Damage from the falling and yarding phases is combined in the tables. The analysis focused on scarring of tree boles; very little damage to tree crowns was observed in the cutting units. Two levels of damage are shown for each variable. The first level includes all scarred trees regardless of scar size. In the second level, the data were filtered to show the amount of scarring greater than or equal to the threshold level of 900 cm^2. Above this level 60 to 85% of scars on western hemlock and true firs usually become infected (Nevill, in press). In this study, 100 and 78% of the scarred trees in the 65 and 70% retention units, respectively, were either western hemlock or amabilis fir.

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Table 13. Residual stand damage in the 65% retention unit.

	Western hemlock	Amabilis fir	Total
Trees/ ha [a]			
with scars of any size	43	45	88
	(5)	(4)	(7)
with scars $\geq$ 900 cm^2	18	13	31
	(3)	(2)	(3)
Proportion of residual stems (%) [a]			
with scars of any size	16.5	17.0	33.5
	(2.0)	(1.8)	(3.0)
with scars $\geq$ 900 cm^2	7.0	4.7	11.7
	(1.1)	(1.0)	(1.6)

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

Table 14. Residual stand damage in the 70% retention unit.

	Western hemlock	Amabilis fir	Western redcedar	Other species	Total
Trees/ ha [a]					
with scars of any size	103	12	31	1	147
	(16)	(5)	(8)	(1)	(17)
with scars $\geq$ 900 cm^2	25	4	7	1	38
	(5)	(3)	(4)	(1)	(6)
Proportion of residual stems (%) [a]					
with scars of any size	26.1	3.0	7.8	0.4	37.3
	(4.3)	(1.4)	(2.1)	(0.3)	(4.8)
with scars $\geq$ 900 cm^2	6.3	1.1	1.9	0.4	9.7
	(1.5)	(0.7)	(0.9)	(0.3)	(1.7)

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

In the 65% retention unit, 88 trees/ha had at least one scar of any size and 31 trees/ha had at least one scar that was 900 cm^2 or greater. This represents 33.5 and 11.7% of the residual stems, respectively. Damage was evenly distributed over western hemlock and amabilis fir.

In the 70% retention unit, 147 trees/ha had at least one scar of any size and 38 trees/ha had at least one scar that was 900 cm^2 or greater. This represents 37.3 and 9.7% of the residual stems, respectively. Damage was concentrated on the western hemlock in this unit. Damage to western redcedar and amabilis fir accounted for 7.8 and 3.0% of residual stems, respectively.

The proportion of residual trees with scars was similar in the two retention units. The proportion of trees with scars greater than or equal to 900 cm^2 was close to 10%. This is a good result considering the findings from other studies, documented in the literature review, and the steep slopes and large timber in the Chamiss Bay units. However, approximately one-third of the trees in each unit had at least one scar regardless of size. Based on observations of the yarding operations, there is probably room for modest improvement in the damage levels experienced in this trial as crews gain more experience with partial cutting.

Some observations, but no measurements, of the spatial distribution of scarred trees were made during yarding operations and the post-harvest survey. Scarred trees were more prevalent along the sides of the yarding corridors. This is logical because many trees become rub trees as logs make the transition into the corridor during lateral yarding. The incidence of scarring was greater along corridors where the yarder's running lines were too low. This occurred in two corridors in the 70% retention unit when the haulback block was not hung at the optimal height in the

backspar tree. The rigging crew found it much more difficult to maneuver logs into the corridor, without damaging residuals, when the running lines were too low.

Trees/ha, with scars of any size, was the variable used for sampling error (SE) calculation. Sampling errors, expressed as percentages of the mean, were 15.5 and 24.0% for the 65 and 70% retention units, respectively. Sampling errors of 10% or less are difficult to attain in stand damage surveys. The inherent variability in numbers of damaged trees per plot leads to intensive sampling. In this study, 27 and 29% of the area in the 65 and 70% retention units, respectively, was covered by the cluster plots.

4.6 Soil Surface Conditions

Results from the soil surface surveys are presented in Table 15. Three types of soil surface conditions were identified in the 65 and 70% retention units following harvesting: 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. Exposed mineral soil was observed on only 1.4 and 1.5% of the surface area in these same units.

The category of *mixed organic material and mineral soil* describes the slight scuffing and mixing of soil surface layers that sometimes occurred when a log was dragged, partially suspended, over the soil. It was estimated to cover 8.8 and 2.6% of surface area in the 65 and 70% retention units, respectively. This surface condition does not increase the hazard of the critical soil degradation processes for these sites, namely mass wasting and soil surface erosion.

Table 15. Post-harvest soil surface conditions in the 65 and 70% retention units.

	Proportion of cutting unit area (%) [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.

Soil disturbance was observed only within the yarding corridors, and only portions of the corridors themselves were affected. Because the logs were partially suspended, the trailing end of a log often bounced and touched the ground at intermittent points as it was yarded up a corridor. In fact, full log suspension occurred along many segments of the corridors and the soil surface was not contacted. Finally, there was no gouging or channeling of the soil along the yarding corridors.

The impact of the harvesting system on the soil was minor. The levels of forest floor displacement are well below the limits specified for the most sensitive sites as described in the Soil Conservation Guidebook (BCMOF 1995).[7]

4.7 Changes to Landscape Visual Conditions

The series of annotated aerial photographs in Appendix D show the pre- and post-harvest condition of the trial units as well as views of the operations in progress (Figure D-1 to Figure D-

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[7] Guidebooks are components of British Columbia's Forest Practices Code.

6). It is difficult to detect any harvesting activity in the retention units. Someone familiar with the project could identify some of the yarding corridors, but only if they were flying directly over an individual cutting unit.

Figure D-2 shows the 65% retention unit after approximately 40% of the area was felled. This photograph contrasts felled and unfelled portions of the stand prior to yarding. The felled portion can not be differentiated from the untreated stand.

The yarding corridors in the 65% retention unit were visible from the air immediately after yarding was completed (Figure D-3). However, to see the corridors, the sun had to be positioned well above them. As the sun moved through a more oblique angle, shadows were cast and the corridors could not be detected. One year later, during another flight over the sites, the ground cover in these same corridors had blended into the landscape making the corridors very difficult to discern.

Evidence of harvesting in the 55 and 70% retention units was minimal during and immediately after harvesting even while flying directly overhead (Figure D-4). When viewed from an oblique angle, the forest operations could not be seen (Figure D-5).

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, it is probably easier to blend operations into a coastal old-growth stand because these stands usually have an irregular structure. This structure gives the stand a "ragged" appearance, as described by the USDA-FS (1978), compared to a uniform second-growth stand.

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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. The retention units in the trial can meet a *Partial Retention* VQO, that is, activities are visible but remain subordinate. If a terrestrial viewpoint is used these units may satisfy a *Retention* VQO, that is, activities are not visually evident.

4.8 Windfirmness of the Residual Stands

Like many areas on Vancouver Island's west coast, the trial sites are subject to storm force winds and during the winter of 1995/96 particularly severe storms hit the Kyuquot Sound region. These storms caused many events of windthrow and mass wasting in the region's natural forests. However, windthrow did not occur in the retention cutting units at Chamiss Bay. This bodes well for the long-term stability of these partially cut units.

The initial, albeit preliminary, success of the retention units in terms of resisting windthrow can be attributed to several factors. First, the chosen retention levels and the relatively uniform distribution of the retained trees prevented wind from penetrating the stands. Sufficient canopy cover was maintained. Second, trees susceptible to windthrow, that is, those with defects and any trees that appeared to be rooted on unstable substrates, were removed in the harvest. Finally, the retained trees represented the full natural stand profile, including the dominants and emergents. Mitchell (1993) noted that, although the issue of leave tree selection is contentious, several studies have suggested that retaining dominants and emergents improved the windfirmness of residual stands.

5. CONCLUSIONS

This study investigated the harvesting feasibility of partial cutting in old-growth stands on steep slopes. The study showed the potential for harvesting timber on sensitive sites where clearcutting is restricted. 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.

In the 65% retention, unit falling productivity was 31% lower and unit falling cost was 45% higher than in the clearcut. However, falling productivity was reduced by only 1.6% in the 70% retention unit, compared to the clearcut, mainly because of a marked difference in timber type between this unit and the trial's clearcut.

Cable yarding productivity, measured in m^3/PMH, was 34 and 30% lower in the 65 and 70% retention units, respectively, than in the clearcut. Unit yarding costs, based on SMH, 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. The steep slopes and narrow roads meant that a log loader had to work beside the yarder in all the cutting units. The yarder could not deck logs along the roads.

Post-harvest surveys showed that 33.5 and 37.3% of the residual stems had at least one scar of any size, and 11.7 and 9.7% of the residual stems 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 modern interlock swing yarder equipped with MSP carriage is well-suited to yarding in partial cuts on steep slopes. The MSP carriage provides the necessary lateral yarding capability, and the yarder's ability to swing and land logs on the road is essential. This type of machine can be moved between yarding corridors and rigged-up quickly.

Although the benefits of swing yarders and running skyline systems have been known for over two decades these systems have been narrowly-applied in B.C. Swing yarders are usually configured for grapple yarding. However, these machines are not merely grapple yarders but rather technologically-advanced yarding cranes 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 a fully acceptable alternative for harvesting sensitive sites.

A strategy for falling timber in high-retention systems must be carefully constructed. The fallers were included in the planning and tree-marking processes at Chamiss Bay. When operations commenced they felt assured that a workable plan was in place and were determined to follow the marking scheme productively and safely.

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, deferred from harvesting, have already accumulated in coastal regions. And increasingly, forest operators are building new roads through long sections of sensitive terrain to gain access to conventional clearcut

management areas, further adding to the bank of deferred timber. These sections 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 medium levels of tree retention, where the trees are either dispersed or in clumps, and to riparian zones with special prescriptions.

Another benefit is that silviculturists can now think about alternative silviculture prescriptions on sites where partial cutting was considered operationally unworkable. The caveat here is that we have much to learn about stand responses to these cutting methods for the type of sites described in this trial. Treated stands should be monitored over the long-term and a process established to feedback the needed information about stand dynamics that will strengthen future prescriptions.

Several of the findings and recommendations about harvesting systems in the Clayoquot Sound Scientific Panel Report (CSP 1995) have been addressed by the Chamiss Bay harvesting trial. The trial was planned and laid out before the panel made its recommendations, and the study was not designed with the Clayoquot Sound situation in mind. However, because the terrain and vegetation in Clayoquot and Kyuquot Sounds are very similar, the trial provided an opportunity to observe the operational aspects of the silvicultural systems advocated by the panel, namely the high-retention end of their variable-retention gradient.

The partial cutting units at Chamiss Bay represented a difficult challenge for forest operators in coastal B.C. Implementing high-retention partial cutting requires close cooperation between foresters, forest engineers, harvesting supervisors, and loggers. Input from all disciplines must be coordinated if the stand management objectives are to be met. This cooperation and input was achieved in the trial. In addition, the fallers, and the yarding and loading crews adapted well and worked hard to make the project a success.

6. REFERENCES

Alexander, R.R. 1972. Initial partial cutting in old-growth spruce-fir. USDA Forest Service, Research Paper RM-76, Rocky Mtn. Forest and Range Exp. Station., Ft. Collins, CO. 10 pp.

BCMOF 1995. Soil conservation guidebook, April 1995. Co-published by B.C. Min. of Forests and B.C. Min. of Environment, Lands and Parks, Victoria, B.C. 17 pp.

BCMOF 1995. Visual impact assessment guidebook, April 1995. Co-published by B.C. Min. of Forests and B.C. Min. of Environment, Lands and Parks, Victoria, B.C. 25 pp.

BCMOF 1993. "Appendix 9-10B, Commercial Thinning, Summary of Standards, Schedule B (F.S. 763B)" in *Silviculture Manual, Volume 2*. Victoria, B.C.

Beese, W.J. 1995. Alternatives to clearcutting for montane forests in coastal B.C. *In* proceedings of the 76th Annual Meeting, Woodlands Section, Canadian Pulp and Paper Association, Montreal, Quebec. pp. 43-46.

Bennett, D.M. 1993. Partial cutting in a second-growth Douglas-fir stand in coastal British Columbia: Productivity, costs, and soil impacts. FERIC Technical Note TN-199, For. Eng. Research Inst. of Canada, Western Div., Vancouver, B.C. 12 pp.

Bérard, J.A., D.H.W. Dibblee, D.C. Horncastle. 1968. Standard definitions for machine availability and utilization. U.S.I. No. 2428 (B-1), Canadian Pulp and Paper Association, Woodlands Section; Montréal, Québec. 2 pp.

Binkley, V.W. and L.W. Starnes. 1988. Downhill yarding with skyline. *In* Proc. Intl. Mount. Logging and P.N.W. Skyline Symp. 1988. J. Sessions (editor). Ore. State Univ. Portland, Ore. pp. 63-70.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. John Wiley & Sons. 428 pp.

CSP Scientific Panel for Sustainable Forest Practices in Clayoquot Sound. 1995. Sustainable ecosystem management in Clayoquot Sound. Planning and practices. Secretariat, Cortex Consultants Inc., Victoria, B.C. 296 pp.

Daigle, P.W. 1996. Reducing the visual impact of timber harvesting cable corridors in partially cut stands. West. Jour. of Appl. For., 11(1), 1996. pp. 33-34.

Dykstra, D.P. 1976. Production rates and costs for yarding by cable, balloon, and helicopter compared for clearcuttings and partial cuttings. For. Res. Bulletin 22, For. Res. Lab., Ore. State Univ., Corvallis, Ore. 44 pp.

Edwards, R., L. Kellogg and P. Bettinger. 1992. Skyline logging planning and harvest cost in five alternative group selection systems. *In* Proc. Intl. Mount. Logging and 8th Pac. N.W. Skyline Symp. 1992. P. Schiess and J. Sessions (editors). Univ. of Wash., Bellevue, Wash. pp. 121-133.

Fieber, W.F., T.A. Durston and R. Varner. 1982. S.C.O.U.T. Hawkins logging study. USDA Forest Service, Division of Timber Management, Pacific Southwest Region. 52 pp.

Gardner, R.B. 1980. Skyline logging productivity under alternative harvesting prescriptions and levels of utilization in larch-fir stands. USDA Forest Service Research Paper INT-247. Intermountain Forest and Range Experiment Station, Ogden, Utah. 35 pp.

Gibson, D.F. 1975. Evaluating skyline harvesting productivity. Paper No. 75-1507 presented at American Society of Agricultural Engineers 1975 Winter Meeting, Chicago, Ill. 38 pp.

Green, R.N. and K. Klinka. 1994. A field guide for site identification and interpretation for the Vancouver Forest Region. B.C. Ministry of Forests, Vancouver, B.C. Land Management Handbook No. 28., 286 p.

Guimier, D.Y. 1980. Directional felling of large old-growth cedar trees. F.E.R.I.C. Tech. Rep. TR-43, Vancouver, B.C. 43 pp.

Hedin, I.B. and D.L. Delong. 1993. Comparison of harvesting phases in a case study of partial-cutting systems in southwestern British Columbia. F.E.R.I.C. Special Report SR-85, Vancouver, B.C. 16 pp.

Hedin, I.B. 1994. Shelterwood harvesting in coastal second-growth Douglas-fir. F.E.R.I.C. Technical Note TN-216, Vancouver, B.C. 10 pp.

Howard, A.F., D. Rutherford and G.G. Young. 1996. Optimal skyline corridor spacing for partial cutting in second-growth stands of coastal British Columbia. Can. Jour. of For. Res., Vol. 26, No. 3, pp. 368-375.

Howard, A.F. 1995. Damage to residual trees from partial cutting with two cable yarding systems in coastal British Columbia. Part II of the Final Report for Phase III of a Study on Alternative Harvesting Systems for Second Growth Stands of Coastal British Columbia. BCMOF Econ. and Trade Br., Victoria, B.C. (in press) 15 pp.

Howard, A.F., G.G. Young and D. Rutherford. 1993. Alternative silvicultural and harvesting systems for second-growth forests in British Columbia. F.R.D.A. II Rep. No. WP-6-003, B.C. Min. of Forests, Econ. and Trade Br., Victoria, B.C. 94 pp.

Hunt, D.L. and J.W. Henley. 1981. Uphill falling of old-growth Douglas-fir. U.S. Dep. Agric. For. Serv., Pac. Northwest For. and Range Exp. Stn., Gen. Tech. Report PNW-122, April 1981. 18 pp.

Keegan, C.E. and C.E. Fiedler. 1995. Cost of timber harvest under traditional and new forestry silvicultural prescriptions. West. Jour. of Appl. For., 10(1), 1995. pp. 36-42.

Kellogg, L.D., P. Bettinger and R.M. Edwards. 1996. A comparison of logging planning, felling, and skyline yarding costs between clearcutting and five group-selection harvesting methods. West. J. of Appl. For. 11(3):90-96.

Kellogg, L.D., S.J. Pilkerton and R.M. Edwards. 1991. Logging requirements to meet new forestry prescriptions. In Proc. 14th Annual C.O.F.E. Meeting, 1991. J.F. McNeel and B. Andersson (editors). Univ. of B.C. and F.E.R.I.C., Nanaimo, B.C. pp. 43-49.

Kellogg, L.D., E.D. Olsen and M.A. Hargrave. 1986. Skyline thinning in a Western hemlock-Sitka spruce stand: Harvesting costs and stand damage. Research Bulletin 53. Corvallis, OR. Oregon State University, College of Forestry, For. Res. Lab., 21 pp.

Klinka, K., R.E. Carter and G.J. Kayahara. 1994. Forest reproduction methods for coastal British Columbia: Principles, criteria, and a stand selection guide. The Forestry Chronicle, Vol. 70, No. 5, pp. 569-577.

Krag, R.K. and M. Clark. 1995. Helicopter logging in clearcut, patch-cut, and single-tree selection harvests: Queen Charlotte Islands, British Columbia. In Proc. of the technical sessions of Subject Group 3.06, I.U.F.R.O. XX World Congress, Tampere, Finland. Aug. 6-12, 1995. pp. 54-72.

Krag, R.K., E.A. Sauder and G.V. Wellburn. 1986. A forest engineering analysis of landslides in logged areas on the Queen Charlotte islands, British Columbia. B.C. Min. of For. and Lands, Land Mgmt. Rep. No. 43, 138 pp.

Lysons, H.H. and R.H. Twito. 1973. Skyline logging: An economical means of reducing environmental impact of logging. Journal of Forestry, Vol. 71, No. 9, pp. 580-583.

Mann, J.W. and S.D. Tesch. 1985. Coordinating silvicultural objectives with harvesting capabilities in southwest Oregon. In Proc. I.U.F.R.O. Mount. Logging Sec. and 6th Pac. N.W. Skyline Logging Symp. 1985. G.V. Welburn and G.G. Young (editors). F.E.R.I.C. and Univ. of B.C., Vancouver, B.C. pp. 27-32.

McNeel, J.F. 1994. Productivity of manual felling operations in selection and clearcut harvests: A case study. A.S.A.E. Paper No. 94-7515. A.S.A.E. Winter Mtg., Atlanta, GA., Dec. 1994. 13 pp.

McNeel, J.F., D. Briggs and B. Petersen. 1996. Damage to residual trees during partial harvests - Measurement, analysis, and implications. In proc. of the joint meeting of the Council on Forest Engineering and I.U.F.R.O. Subject Group S3.04-00, Marquette, MI, July 29-Aug. 1, 1996. pp. 73-81.

McNeel, J.F. and G.G. Young. 1994. Optimal yarding road width model for skyline yarding. For. Prod. Jour., Vol. 44, No. 2., pp. 45-50.

Mitchell, S. 1993. An assessment of windthrow potential in proposed uniform shelterwood cuts in the Kyuquot Sound area. Contract report for F.E.R.I.C., Western Div., Vancouver, B.C. 26 pp.

Moore, K. 1991. Partial cutting and helicopter yarding on environmentally sensitive floodplains in old-growth hemlock/spruce forests. F.R.D.A. report 166, B.C. Min. of For., Research Br., Victoria, B.C. 43 pp.

Nelson, J., D. Daust and S. Finn. 1990. A review of silvicultural systems and harvesting alternatives for old-growth forests of coastal British Columbia. Fac. of Forestry, Univ. of B.C., Vancouver, B.C. Contract report for MacMillan Bloedel Limited, Woodlands services, Nanaimo, B.C. 57 pp.

Nevill, R.J. (in press). A literature review on tree wounding and partial-cut harvesting. Contract report for the B.C. Min. of For., Prince Rupert For. Region, Smithers, B.C. 69 pp.

Peters. P.A. 1973. Estimating production of a skyline yarding system. Reprint from Planning and Decisionmaking As Applied to Forest Harvesting a symposium held Sept. 11-12, 1972. OSU School of Forestry, Corvallis, OR. 14 pp.

Peterson, J.T. 1988. Harvesting economics: Two case studies of a Cypress 7280B swing yarder. F.E.R.I.C. Technical Note TN-115, Vancouver, B.C. 20 pp.

Peterson, J.T. 1987. Harvesting economics: Handfalling coastal old-growth timber. F.E.R.I.C. Technical Note TN-111, Vancouver, B.C. 20 pp.

Peterson, J.T., N.G. Marshall and R.A. Kooistra. 1991. Harvesting economics: Case studies of a Cypress 7280B swing yarder and mobile backspar. F.E.R.I.C. Technical Note TN-157, Vancouver, B.C. 8 pp.

Pilkerton, S.J., Han, H.S., and L.D. Kellogg. 1996. Quantifying residual stand damage in partial harvest operations. In proc. of the joint meeting of the Council on Forest Engineering and I.U.F.R.O. Subject Group S3.04-00, Marquette, MI, July 29-Aug. 1, 1996. pp. 62-72.

Rutherford, D.A. 1996. Productivity, costs, and optimal spacing of skyline corridors of two cable yarding systems in partial cutting of second-growth forests of coastal British Columbia. M.Sc. thesis, Univ. of British Columbia. 91 pp.

Sanders, P.R.W. and D.J. Wilford. 1986. Silvicultural alternatives for the management of unstable sites in the Queen Charlotte Islands: A literature review and recommendations. Land Mgmt. Rep. 42, B.C. Min. of For., Inf. Serv. Br., Victoria, B.C. 42 pp.

Sauder, E.A. and G.V. Wellburn. 1989. Planning logging: Two case studies on the Queen Charlotte Islands, B.C. B.C. Min. of For. and Lands, Land Mgmt. Rep. No. 59, 47 pp.

Sauder, E.A. and G.V. Wellburn. 1987. Studies of yarding operations on sensitive terrain, Queen Charlotte Islands, B.C. B.C. Min. of For. and Lands, Land Mgmt. Rep. No. 52, 45 pp.

Sauder, E.A., R.K. Krag and G.V. Wellburn. 1987. Logging and mass wasting in the Pacific Northwest with application to the Queen Charlotte Islands, B.C.: A literature review. B.C. Min. of For. and Lands, Land Mgmt. Rep. No. 53, 26 pp.

Stathers, R.J., Rollerson, T.P. and S.J. Mitchell. 1994. Windthrow handbook for British Columbia forests. Research Program Working Paper 9401. B.C. Ministry of Forests, Victoria, B.C. 31pp.

Tesch, S.D., D.H. Lysne, J.W. Mann, and O.T. Helgerson. 1986. Mortality of regeneration during skyline logging of a shelterwood overstory. Jour. of For., Vol. 84, No. 6, June 1986. pp. 49-50.

U.S. Department of Agriculture, Forest Service. 1978. National Forest Landscape Management - Timber. Vol. 2. Chapter 5, Agriculture Handbook No. 559, Washington, D.C. pp. 174-185.

Weetman, G.F., E. Panozzo, M. Jull, and K. Marek. 1990. An assessment of opportunities for alternative silvicultural systems in the SBS, ICH and ESSF Biogeoclimatic Zones of the Prince Rupert Forest Region. Contract report for the B.C. Min. of For., Prince Rupert For. Region, Smithers, B.C. 154 pp.

Weetman, G.F. and A. Vyse. 1990. Natural regeneration *in* Regenerating British Columbia's forests. D.P. Lavender *et al.* (editors), Univ. of B.C. Press, Vancouver, B.C. pp. 118-129.

APPENDIX A: Tree Marking Summaries

Table A-1. Tree marking summary for the 55% retention unit.

Species		Western hemlock	Amabilis fir	Western redcedar	Other species	Total
Volume and Size Information for Marked Green Trees						
No. of stems		108	16	118		242
Stems/ha		64	9	69		142
% stems marked	%	32	55	33		32
Avg. green DBH	cm	38.0	40.2	50.8		44.4
Basal area	m^2	13.8	2.3	32.5		48.7
Basal area/ha	m^2/ha	8.1	1.4	19.1		28.6
% basal area marked	%	25	68	74		46
Net volume	m^3	121	23	241		385
Net vol/ha	m^3/ha	71	13	142		226
% net volume marked	%	21	38	67		37
Avg net vol/tree	m^3	1.12	1.42	2.04		1.59
Pathological Indicators for Marked Green Trees						
No. of marked trees affected by:						
Dwarf mistletoe		46	1			47
Scar or catface		21	1	46		68
Fork		9	3	10		22
Crook		10	2	4		16
Frostcrack		3				3
Broken top		33	4	42		79
Conk		3				3
Size Information for Marked Snags						
No. of snags		28	6	34		68
Snags/ha		16	4	20		40
Avg. snag DBH	cm	45.5	54.7	57.4		52.2
Basal area	m^2	5.0	1.6	12.1		18.7
Basal area/ha	m^2/ha	3.0	0.9	7.1		11.0

Table A-2. Tree marking summary for the 65% retention unit.

Species		Western hemlock	Amabilis fir	Western redcedar	Other species	Total
Volume and Size Information for Marked Green Trees						
No. of stems		313	259	4		576
Stems/ha		61	51	1		113
% stems marked	%	25	21	10		23
Avg. green DBH	cm	53.8	39.6	51.6		47.4
Basal area	m^2	94.6	41.8	1.0		137.3
Basal area/ha	m^2/ha	18.5	8.2	0.2		26.9
% basal area marked	%	36	41	4		35
Net volume	m^3	1104	434	8		1546
Net vol/ha	m^3/ha	217	85	2		303
% net volume marked	%	37	43	5		37
Avg net vol/tree	m^3	3.53	1.67	2		2.68
Pathological Indicators for Marked Green Trees						
No. of marked trees affected by:						
Dwarf mistletoe		169	1			170
Scar or catface		69	42			111
Fork		31	10			41
Crook		13	5			18
Frostcrack		40	13			53
Broken top		56	23	1		80
Conk		16	3			19
Size Information for Marked Snags						
No. of snags		126	47	3		176
Snags/ha		25	9	1		35
Avg. snag DBH	cm	72.4	53.4	96.7		68.3
Basal area	m^2	57.9	13.7	2.2		73.8
Basal area/ha	m^2/ha	11.3	2.7	0.4		14.5

Table A-3. Tree marking summary for the 70% retention unit.

Species		Western hemlock	Amabilis fir	Western redcedar	Other species	Total
Volume and Size Information for Marked Green Trees						
No. of stems		186	28	74	10	313
Stems/ha		79	12	31	4	133
% stems marked	%	33	9	77	24	31
Avg. green DBH	cm	43.4	49.3	46.0	81.8	44.9
Basal area	m²	33.5	6.5	16.4	4.8	62.4
Basal area/ha	m²/ha	14.3	2.8	7.0	2.0	26.6
% basal area marked	%	28	25	39	68	32
Net volume	m³	345	74	123	62	614
Net vol/ha	m³/ha	147	31	52	26	261
% net volume marked	%	25	22	41	63	29
Avg net vol/tree	m³	1.86	2.64	1.66	8.15	1.96
Pathological Indicators for Marked Green Trees						
No. of marked trees affected by:						
Dwarf mistletoe		75	3			78
Scar or catface		42	3	21	1	69
Fork		23	1	6	2	32
Crook		6	1	2	1	23
Frostcrack		8		1	1	10
Broken top		37	2	12		51
Conk		5				5
Size Information for Marked Snags						
No. of snags		73	15	32	1	129
Snags/ha		31	6	14	0	55
Avg. snag DBH	cm	44.1	39.4	40.3	20.3	41.8
Basal area	m²	13.1	2.0	4.8	0.0	20.7
Basal area/ha	m²/ha	5.6	0.8	2.0	0.0	8.8

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APPENDIX B: Hourly Costs for Equipment, Falling and Bucking

Table B-1. Hourly equipment costs for the 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	1350000	825000	600000
Mechanical slack-pulling carriage	9000	9000	
Depreciation period (D) yr	7	7	7
Scheduled hours per year (h)	1600	1600	1600
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) $	407700	250200	180000
Average investment (AVI)=((P+S)/2) $	883350	542100	390000
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(s)[b]	1200	800	
Haulback	15800	6100	
Other lines, chokers, etc.	3500	3900	
Annual cost of supplies and rigging materials (SR) $	10000	10000	2500
Annual repair and maintenance cost[c] (Rp) $	50000	35000	20000
Wages (W) $/hr			
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	
Chokermen[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 the author, with input from INTERFOR's operations personnel.

[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 chokerman was used on the swing yarder; two chokermen were used on the tower yarder.

Table B-2. Hourly falling and bucking cost.

FALLING AND BUCKING[a]

Wages for individual 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)) $/h	61.26
Saw, gas and oil, and supplies cost (Sw/Sl) $/h	12.31
Total falling and bucking cost per individual $/h	73.57

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[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. IWA rates effective June 15/96 have been used.

APPENDIX C: Post-Harvest Survey Layouts
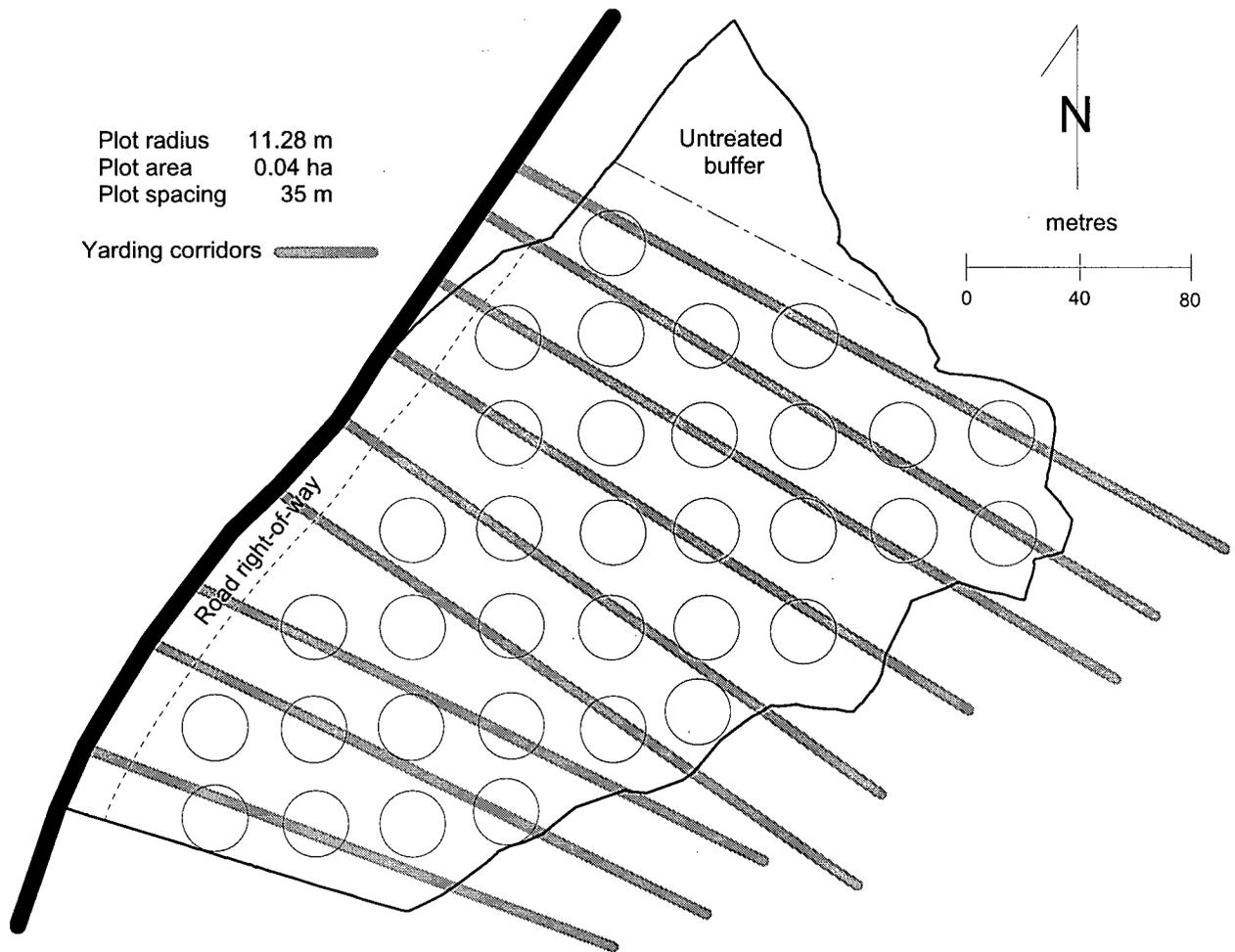
**Figure C-1. Location of sample plots in the 65% retention unit.**

N

metres

0   40   80

Road right-of-way

Plot radius   11.28 m
Plot area   0.04 ha
Plot spacing   35 m

Yarding corridors
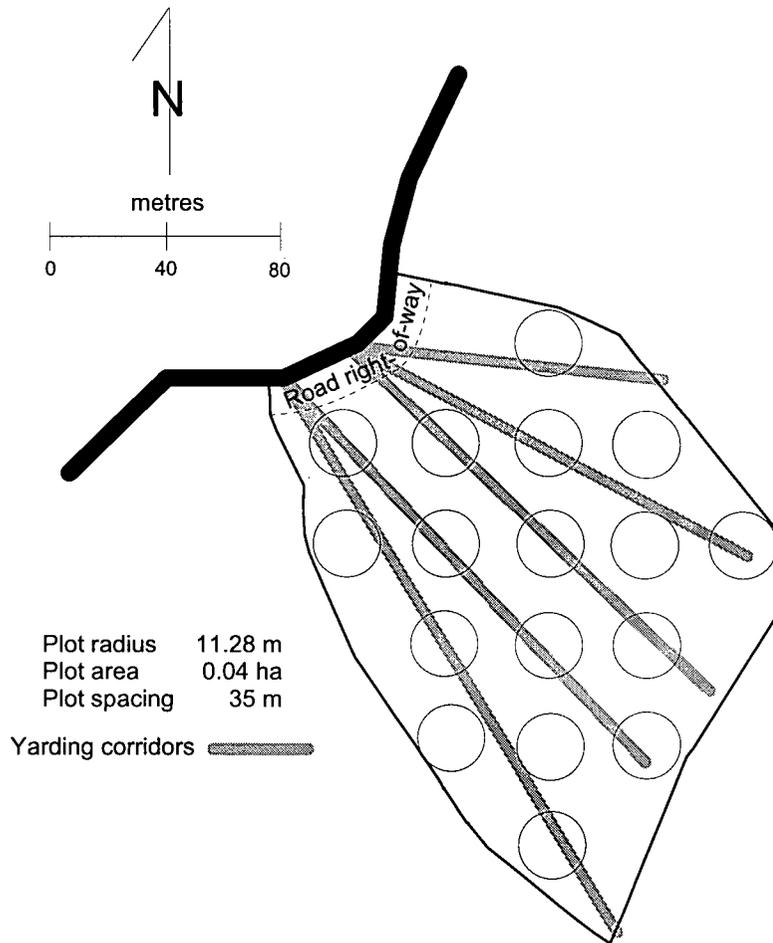
**Figure C-2. Location of sample plots in the 70%
retention unit.**

APPENDIX D: Annotated Aerial Views of the Cutting Units
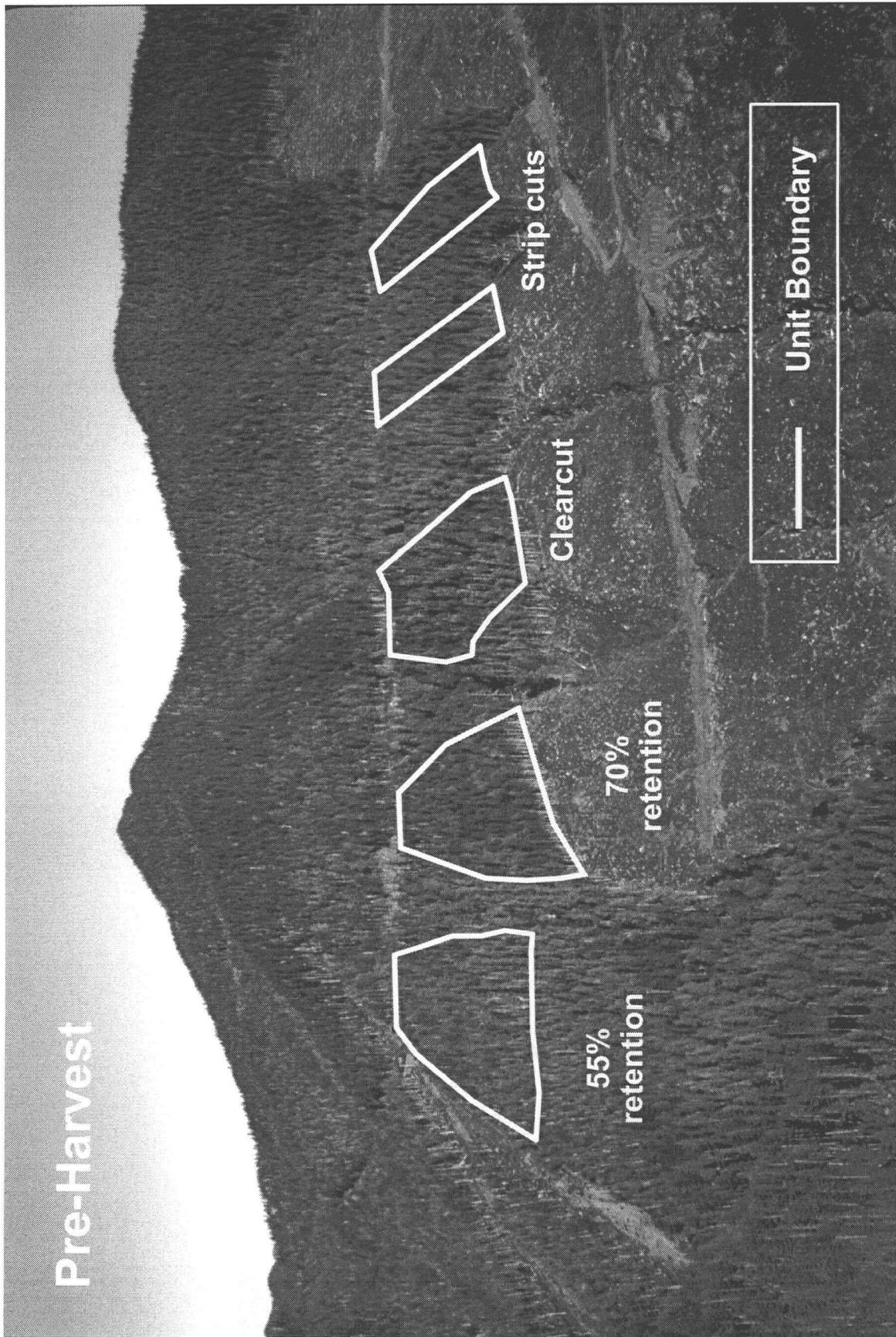
Figure D-1. Pre-harvest condition of cutting units.

65% retention unit

Location of falling face after six faller-shifts (falling completed below dotted line)

Unit boundary
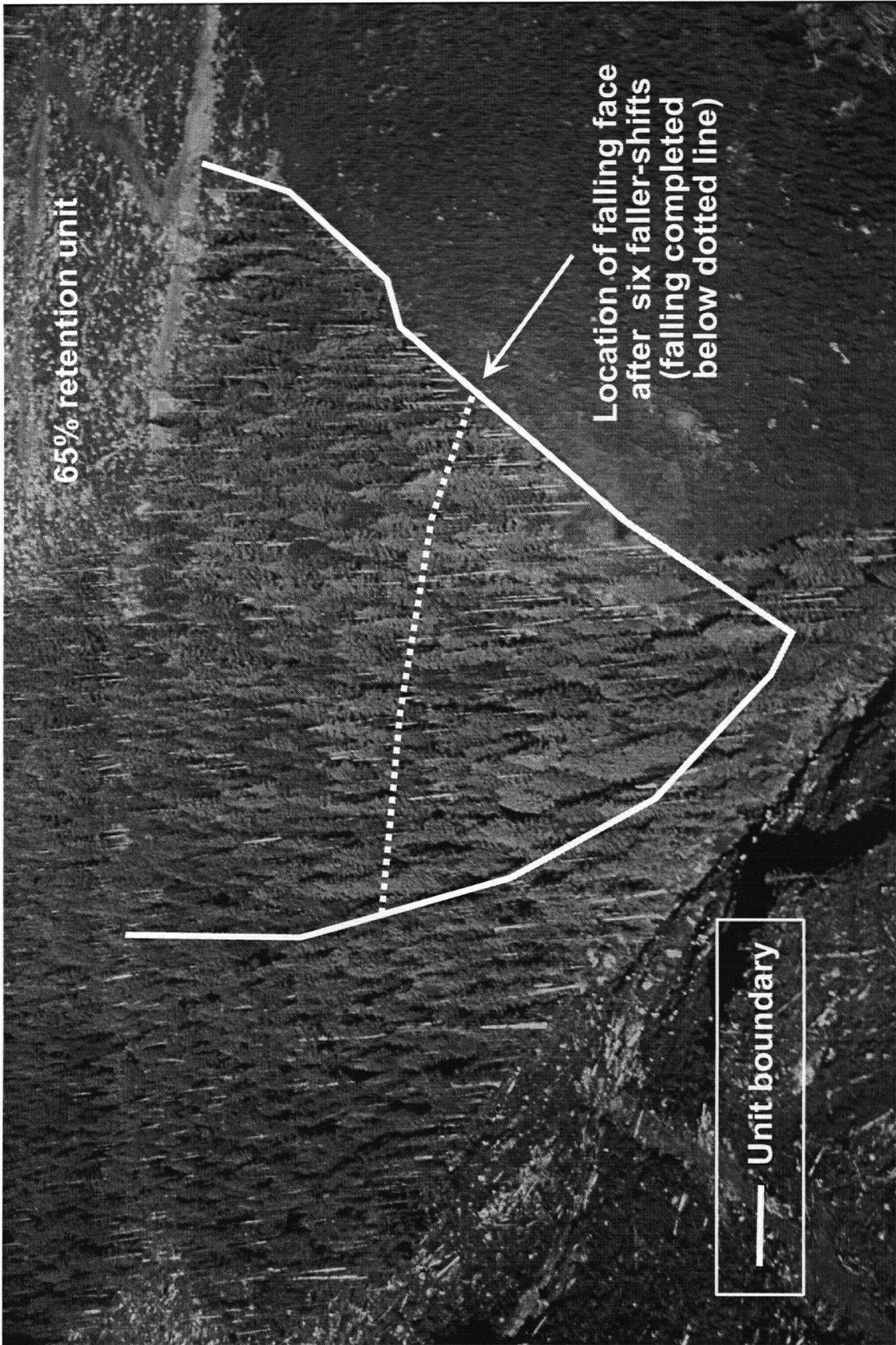
Figure D-2. 65% retention unit after six faller-shifts.

5.1 ha
65% retention
(by basal area)

Yarding Corridors
Unit Boundary
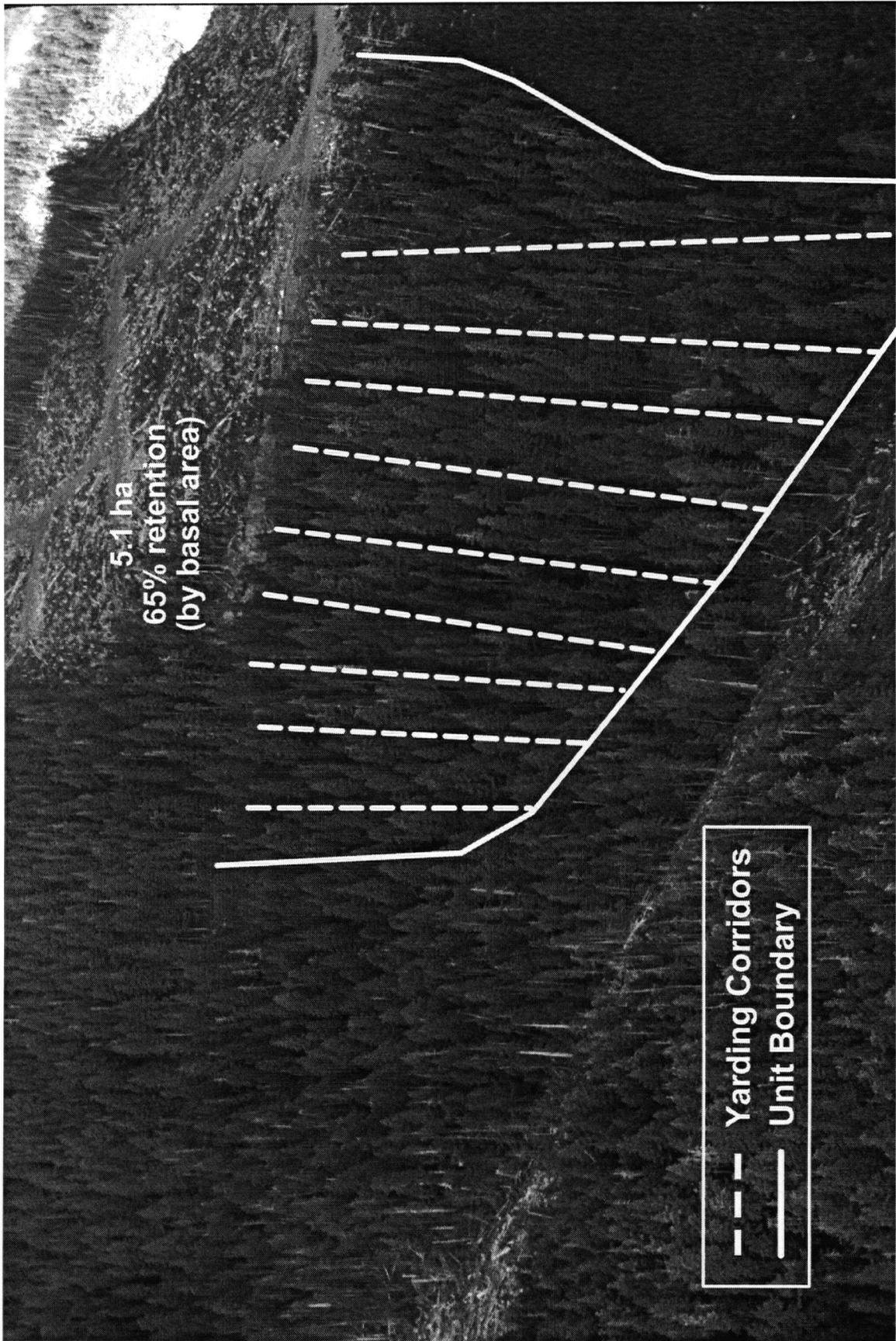
Figure D-3. 65% retention unit following harvest.

Legend:
- - - - Yarding Corridors
——— Unit Boundary
○ Swing Yarder

2.3 ha clearcut

2.4 ha 70% retention

1.7 ha 55% retention (by basal area)
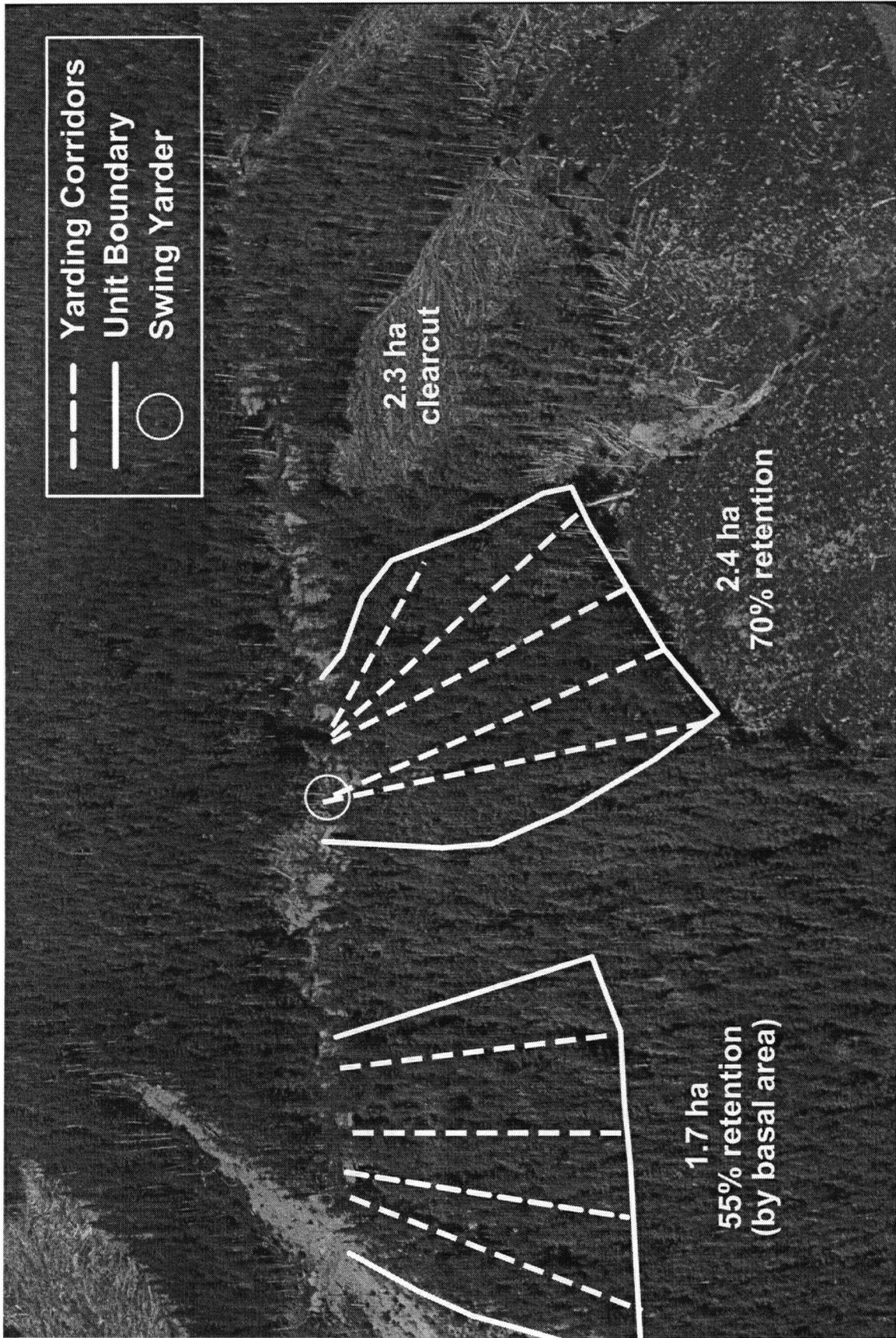
Figure D-4. 55 and 70% retention units during harvest.

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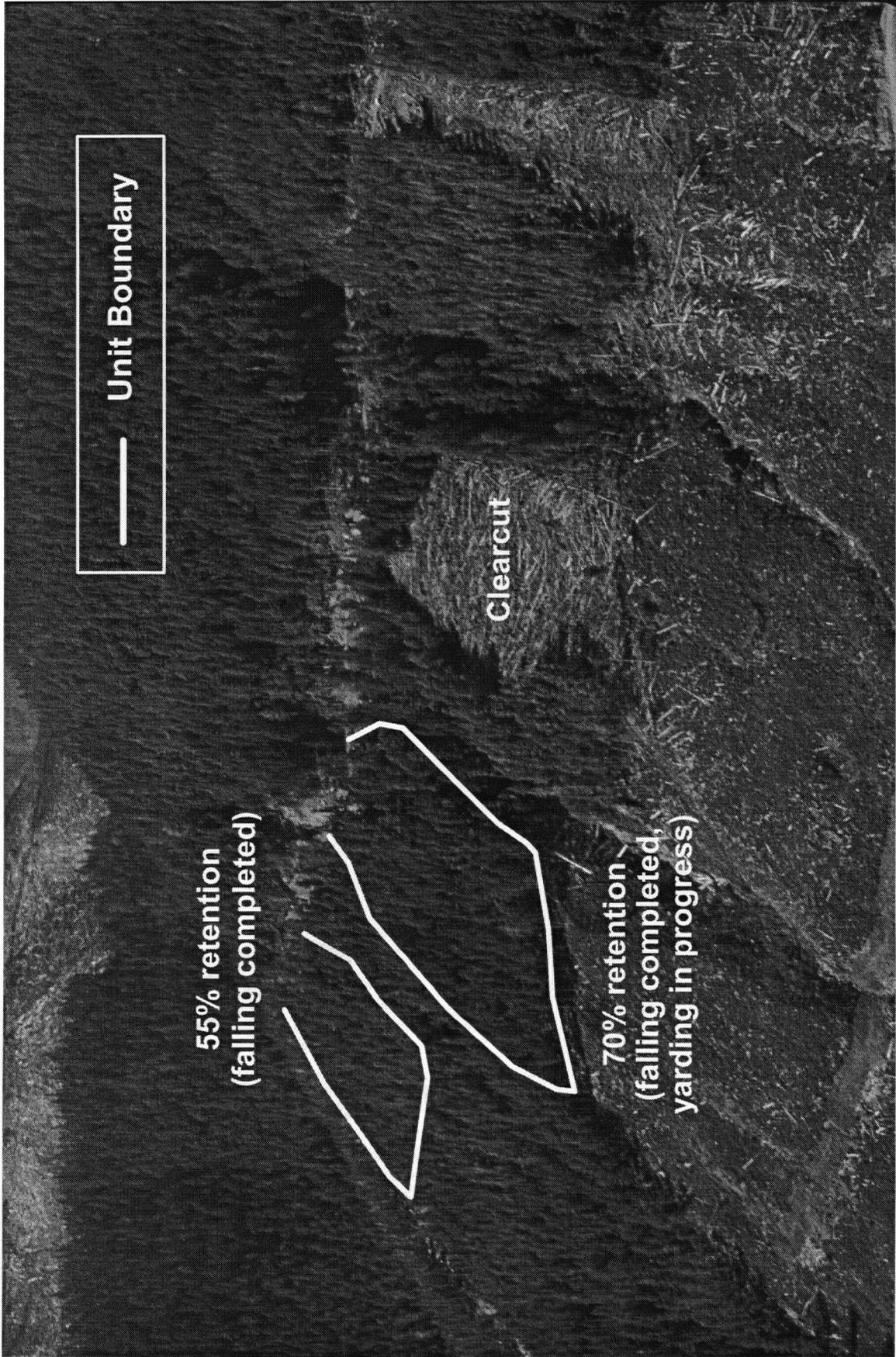
Figure D-5. 55 and 70% retention units during harvest (oblique angle).

Tower yarder

Strip cuts - ~1.4 ha each
(yarding in progress)

Clearcut - 2.3 ha
(falling in progress)
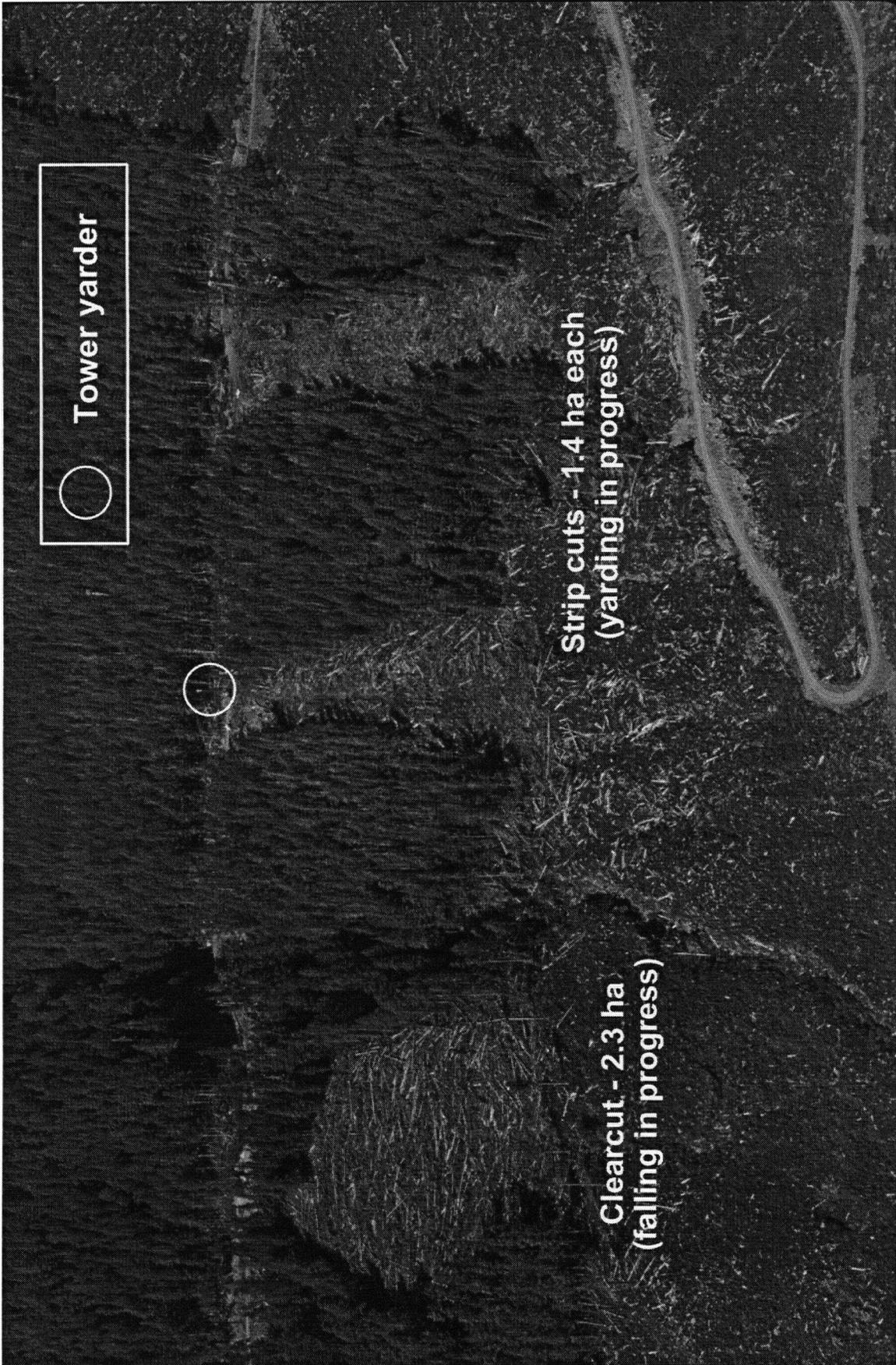
Figure D-6. Small clearcut and strip cuts during harvest.