Advantage
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Contents

Helicopter logging on the Queen Charlotte Islands: productivities and costs of a Sikorsky S-64E Skycrane in clearcuts, patch cuts and single-tree selection cuts

Abstract

In 1992 the Forest Engineering Research Institute of Canada (FERIC) studied a heavy-lift helicopter logging operation on the Queen Charlotte Islands in British Columbia. The study was part of a Fish-Forestry Interaction Program project to investigate the feasibility of using alternative harvesting and silvicultural systems to harvest timber from potentially unstable terrain. The study provided information on the productivities and costs of helicopter logging in clearcuts, patch cuts, and single-tree selection cuts, using a Sikorsky S-64E Skycrane equipped for choker logging. Information on basal area removal levels, damage to residual stems, and ground disturbance was also collected. Production and cost functions were derived from detailed-timing and shift-level data to predict helicopter yarding productivity and cost by harvesting treatment for yarding distances of 100 to 1 500 m.

Keywords

Helicopter logging, Sikorsky S-64E Skycrane, Partial cutting, Clearcut, Patch cut, Single-tree selection, Productivity, Costs, Ground disturbance, Residual stand damage, Coastal British Columbia.

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Executive summary

In 1992 the Fish-Forestry Interaction Program sponsored a helicopter logging trial on two sites on the Queen Charlotte Islands. The purpose of the trial was to examine the operational and environmental feasibility of using alternative logging and silvicultural systems to harvest timber on unstable terrain. This report focuses on the performance of the helicopter yarding operation. It describes the falling, yarding, and loading phases and compares productivities, costs, and site and stand impacts of helicopter logging on difficult terrain in clearcut, patch cut, and single-tree selection prescriptions.

A Sikorsky S-64E Skycrane equipped for choker logging performed the yarding phase. The harvesting treatments were clearcuts, small patch cuts (50% and 25% of treatment area harvested in 0.2-ha to 0.3-ha patches), and single-tree selection (15% and 25% of stand basal area harvested). Forest cover on both sites was old-growth hemlock-spruce with volumes of 600–800 m^3/ha. Both sites were considered too unstable for conventional clearcutting and cable yarding.

The helicopter operation harvested 34 950 m^3 from the two sites. The falling phase averaged 376 m^3/shift in 93 shifts worked, the helicopter yarding phase averaged 930 m^3/shift in

37.6 shifts, and the loading and hauling phase averaged 514 m^3/shift in 68 shifts. Falling, including helipad construction and snag removal, was \$10.78/m^3 (13% of total cost), helicopter yarding was \$63.93/m^3 (78%), and loading was \$7.52/m^3 (9%), for a total of \$82.23/m^3. The S-64E Skycrane cost was estimated at \$40.02/m^3, or 63% of the yarding cost and 49% of the total cost.

Falling productivity was low due to the steep broken slopes, numerous gullies, and partial cutting treatments. It averaged 71 m^3 per faller per 6.5-h shift overall and ranged from 43 m^3/shift in single-tree selection cuts on Block 2 to 88 m^3/shift in the helicopter clearcut on Block 1. Compared to the helicopter clearcuts, fallers working in the partial cuts spent a larger proportion of working time moving between worksites, opening up new falling faces, and planning falling sequences. As a result, falling productivity was 9–29% lower in the 25% patch cuts and 18–42% lower in the 25% single-tree selection cuts, relative to the clearcuts.

The Skycrane's productivity in this study was influenced by the partial cutting treatments, flight path parameters (yarding distance and flight path slope) and landing features, and weight-to-volume and cull factors. Compared to the clearcuts, increases in hookup times reduced productivity by 7–8 m^3/cycle for 25% patch cuts and 15–16 m^3/cycle for the single-tree selection cuts, and increases in delays reduced productivity by about 2 m^3/cycle in the 25% patch cuts and about 4 m^3/cycle in the 25% single-tree selection cuts. However, average turn weights were very similar for all harvesting treatments in this study, which suggests that the ability of the experienced rigging crews to estimate turn weights and to build optimum turns was not affected by the partial cutting treatments.

Both straight-line horizontal distance and elevation difference between the hookup site and the landing were found to significantly influence the Skycrane's empty and loaded travel times. This suggests that forest engineers need to consider both parameters when laying out blocks and choosing landings for helicopter logging operations.

Yarding production and cost functions were developed to compare the harvesting treatments. Clearcutting was the most productive treatment. For the same distance, yarding productivities in 25% patch cuts and 25% single-tree selection cuts were about 5% and 12% less, respectively, than in clearcuts. For yarding distances of 100 to 1 500 m, a 100-m increase in yarding distance reduced yarding productivities by 5 m^3/flight-hour for clearcuts, 4.5 m^3/flight-hour for patch cuts, and 4 m^3/flight-hour for single-tree selection cuts. Compared to clearcuts, yarding costs were 4–6% higher for 25% patch cuts and 11–17% higher for 25% single-tree selection cuts. For the same range of distances, helicopter yarding costs increased at a rate of \$1.56/m^3 per 100-m increase in horizontal distance.

The trial demonstrated that helicopter logging using partial cutting systems is a technically and operationally feasible method for harvesting timber from steep, potentially unstable terrain. Compared to clearcutting, falling and yarding productivities showed minor to moderate decreases and harvesting costs showed corresponding increases as retention levels increased. Damage to residual trees in the partial cutting treatments was relatively minor. Soil disturbance was negligible. All of the partial cutting and tree-marking treatments were equally successful at harvesting the stand profile. For the terrain and stand conditions in this trial, patch cut systems were more efficient than single-tree selection systems from an operational perspective; however, both harvesting treatments were applied successfully.

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Introduction

Helicopter logging has become an integral part of forest harvesting operations in British Columbia during the past decade. FERIC performs case studies of helicopter logging operations in British Columbia to provide information on the performances of helicopters in different harvesting situations. These case studies also provide information on site, stand, organizational, and operational factors that influence the productivity and cost of helicopter logging. This report presents productivities and estimates harvesting costs for a Sikorsky S-64E Skycrane working in clearcuts and partial cuts on the Queen Charlotte Islands. The report expands upon previously reported results for this harvesting trial (Krag and Clark 1996; Krag 1998).

Background

In 1979, the federal Department of Fisheries and Oceans and the British Columbia Ministries of Forests and Environment established the multidisciplinary Fish-Forestry Interaction Program (FFIP). This initiative was formed in response to concerns that road-building and timber harvesting were accelerating landslide rates on steep slopes on the Queen Charlotte Islands. One of FFIP's objectives was to "...investigate the feasibility and success of using alternative logging methods to reduce traditional environmental problems associated with logging. These methods include skyline and helicopter use, and improved planning of logging roads and logging layout in sensitive areas" (Poulin 1984). FERIC performed a series of studies for FFIP during the early 1980s that suggested improved planning, road-building, and cable yarding practices could reduce the risk of landslides on many harvest sites (Krag et al. 1986; Sauder and Wellburn 1987, 1989). For very sensitive sites, however, alternatives to conventional harvesting practices needed to be developed.

In a series of trials in Naden Harbour in the late 1980s, Husby Forest Products Ltd. and Canadian Air-Crane Ltd. successfully demonstrated that selective harvesting of timber from sensitive floodplain areas using a heavy-lift helicopter (a Sikorsky S-64E Skycrane) was environmentally and economically feasible (Moore 1991). FFIP, Husby and Canadian Air-Crane agreed to an operational trial in Rennell Sound to examine the feasibility of performing partial cutting and helicopter logging on steep, potentially unstable slopes. Study cooperators included the British Columbia Ministry of Forests (BCMOF) Research Branch, Vancouver Region Forest Sciences Group, and Queen Charlotte Islands Forest District; Husby; Canadian Air-Crane; Slarktooth Logging; Coast Forest Management Ltd; and FERIC.[1]

The Rennell Sound trial included research on regeneration and hillslope responses to the harvesting treatments, as well as the operational performance of the helicopter system. FERIC's report focuses on the trial's operational aspects, particularly the feasibility and costs of helicopter logging on difficult terrain and in non-clearcut harvesting prescriptions. Readers interested in the effects of the harvesting treatments on natural and planted regeneration development should consult D'Anjou (2000), and those interested in erosion and mass-wasting responses should consult Millard and Chatwin (2001).

Objectives

FERIC's objectives were to:

- Describe the harvesting operation, and determine overall productivities and costs for the falling, helicopter yarding, and loading phases.
- Compare harvesting productivities and costs for the harvesting treatments.
- Document proportions of basal area of live trees removed, damage to residual trees, and ground disturbance for the various harvesting treatments.
- Identify features of the sites, stands, and harvesting system and organization that may have influenced harvesting productivity and cost.

[1] FERIC's study was partially funded by the South Moresby Forest Replacement Account.

Site and stand descriptions

The study took place on Crown land in Rennell Sound on the west coast of Graham Island (Figure 1). The two harvest sites were within the Coastal Western Hemlock Very Wet Hypermaritime subzone (CWHvh2) (Green and Klinka 1994). Forest cover consisted mostly of old-growth western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), with minor components of western red cedar (*Thuja plicata*) and yellow cedar (*Chamaecyparis nootkatensis*). Net merchantable volumes averaged 816 m^3/ha on Block 1 (Hangover Creek) and 629 m^3/ha on Block 2 (Gregory Creek) (Table 1). Both sites had high levels of natural windthrow as a result of exposure to frequent high winds associated with fall and winter storms. Block 1 occupied the midslope area of a mountain shoulder on the west side of Hangover Creek and was characterized by mostly steep, open slopes broken by frequent rock bluffs. Block 2 was 5 km to the southeast and occupied the mid- to upper-slope area on the north side of Gregory Creek. It was dissected by numerous steep, bedrock-based gullies ranging from 2 to 15 m deep and 100 to 400 m long. Overall, the terrain was very steep and difficult—43% of Block 1 and 31% of Block 2 were classified as unstable (Terrain Stability Classes IV and V) (Millard and Chatwin 2001). Due to the high proportions of unstable terrain, both sites were considered inoperable for conventional road development and cable yarding. At the time of this study, sites like these were excluded from the operable forest land base and did not contribute to the allowable annual cut.

Harvesting prescription and treatments

BCMOF researchers developed the silvicultural prescriptions for the trial (Pendl and D'Anjou 1991). The following harvesting treatments were applied to each block:

- unharvested control
- clearcut
- 50% patch cut (50% ± 5% of treatment unit area harvested in uniformly distributed 0.2-ha to 0.3-ha patches)
- 25% patch cut (25% ± 5% of treatment unit area harvested in uniformly distributed 0.2-ha to 0.3-ha patches)

Figure 1. Location of the study sites.

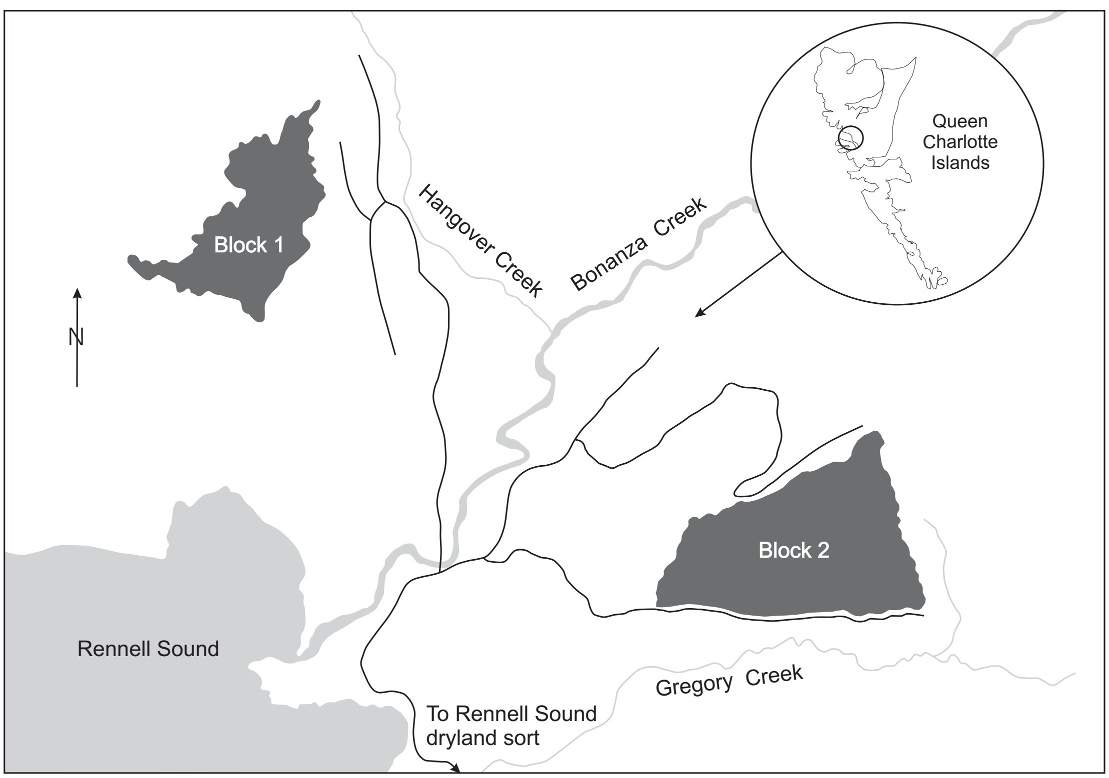


Table 1. Site and stand descriptions

	Block 1 Hangover Creek	Block 2 Gregory Creek
Total cutblock area (ha)	45.7	79.9
Ecological classification [a]	CWHvh2	CWHvh2
Site characteristics		
Terrain features	open slopes, frequent rock bluffs and slope breaks	numerous gullies and slope breaks
Slope		
Range (%)	20–140	20–110
Average (%)	65	60
Soils		
Texture	silty loam	silty loam
Depth (m)	<1.0	<1.0
Area distribution by Slope Stability Class [b] (%)		
Classes I, II, III	57	69
Classes IV, V	43	31
Stand characteristics [c]		
Species composition [d]	51% hemlock 46% spruce 3% red/yellow cedar	65% hemlock 28% spruce 7% red cedar
Live trees		
Density (no./ha)	294	294
Average diameter (cm)	57.7	53.4
Average total height (m)	41.9	41.1
Merchantable volumes		
Per hectare (m^3/ha)	816	629
Per tree (m^3/tree)	2.78	2.14

[a] Green and Klinka (1994).
[b] Millard and Chatwin (2001).
[c] From operational timber cruise.
[d] Based on merchantable volume.

- 25% single-tree selection cut (25% ± 5% of basal area of live trees removed, distributed proportionally among species and diameter classes)

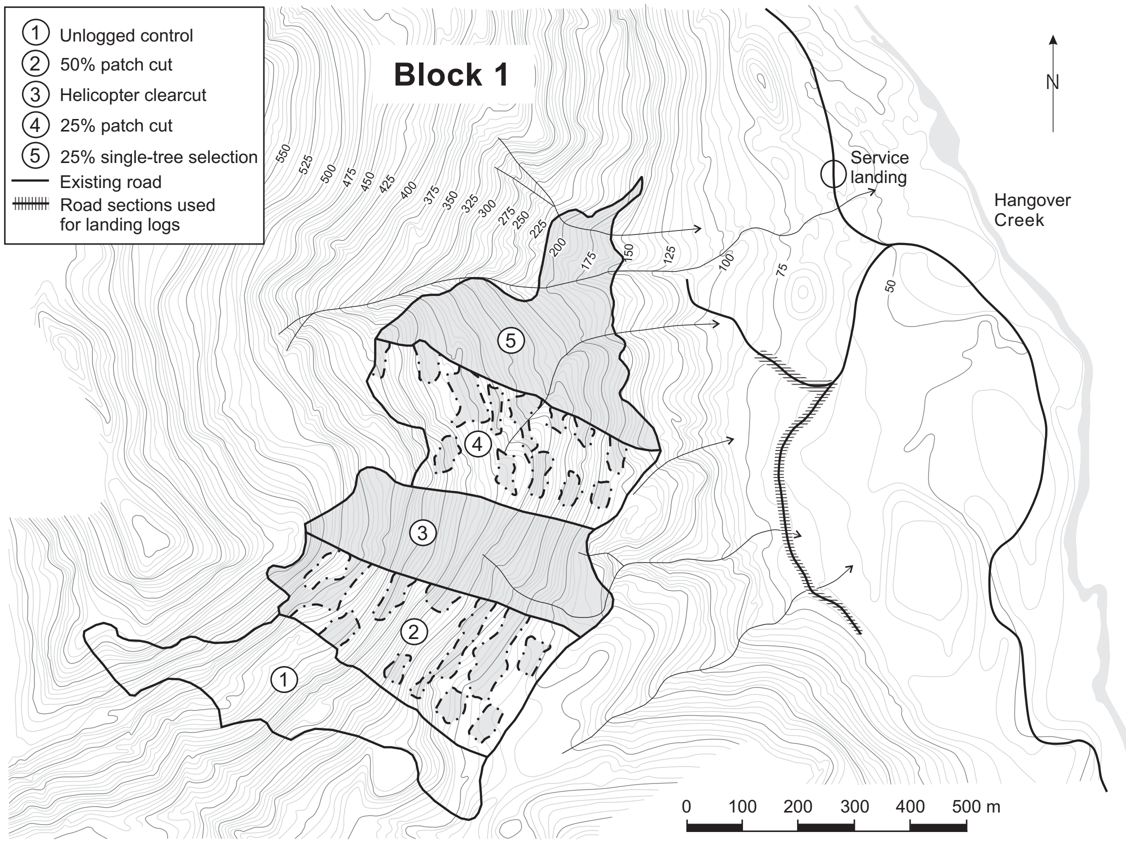
All treatments were harvested to Close Utilization standards.[2] Two future entries were proposed for the 50% patch cut treatments and three future entries were proposed for the 25% patch cut and 25% single-tree selection treatments, all at 25-year intervals.

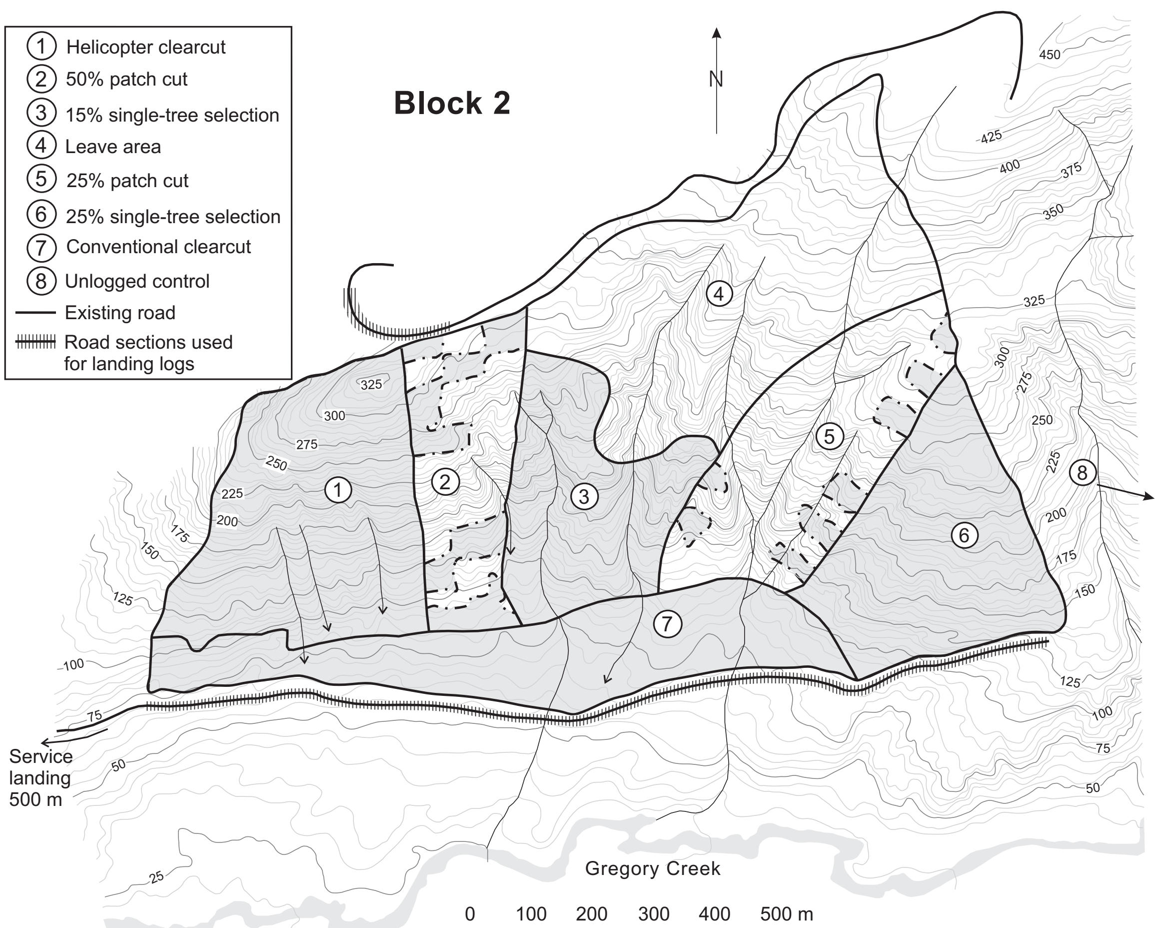
Helicopter logging with a heavy-lift helicopter was prescribed, with harvesting operations scheduled for late summer to coincide with favourable weather and daylight conditions. Existing roads below the study sites served as log landings and old cable-yarding landings nearby were used for service landings.

Prior to harvesting, the study sites were subdivided into a series of treatment units ranging from 8 to 11 ha in size, with no buffers between the units. On each site one unit was designated as the unharvested control, and the four harvesting treatments were randomly assigned to the remaining units. Figure 2 shows the arrangement of treatment units on Blocks 1 and 2 and the actual shapes and sizes of patches after harvesting was completed. Figure 3 shows Block 1 during harvesting.

[2] Utilization specifications for this trial included harvesting of all conifer trees larger than 17.5 cm diameter at breast height (dbh) and containing 50% or more sound wood by gross volume, between a 30-cm-high stump and 15-cm-diameter top, as well as chunks and slabs longer than 3.1 m (net length) having a minimum 15-cm top diameter.

Figure 2. Layout of treatment units at Block 1, Hangover Creek and Block 2, Gregory Creek.





A large area of complex terrain in the middle of Block 2 was originally designated as a leave area due to slope stability concerns. Shortly before helicopter operations started, the lower part of the leave area was determined to be stable enough to permit a light harvest, so a 15% single-tree selection unit was established there. Also, a 100- to 200-m-wide band of gently sloping stable ground along the lower edge of Block 2 was prescribed for clearcutting and grapple yarding. These harvesting treatments were not replicated on Block 1.

Each patch cut treatment was subdivided on a map into 0.2–0.3-ha rectangular patches using a 30–40-m by 60–70-m grid, with the long axis of the patch oriented approximately parallel to the ground contour. The patches proposed for harvesting were designated by the BCMOF silviculture researcher. The harvest and retention patches on the 50% patch cut units alternated in a checkerboard pattern. On the 25% patch cut units, the harvest patches were surrounded by retention patches to form a pattern of well-distributed, unconnected openings. To satisfy the project's research requirements, no adjustments were made during initial field layout to modify the "map" patch cut boundaries to "on-the-ground" terrain and stand conditions.[3] However, the patch cut units were subsequently reviewed in the field by the study cooperators. As a result of this review, several harvest patches in both 50% patch cut units and in the 25% patch cut unit in Block 2 were removed from the harvest plan because of concerns for faller safety and slope stability. Except for minor adjustments to the 50% patch cut unit in Block 2, deleted harvest patches were not replaced with retention patches.

The objective of the single-tree selection prescription was to harvest a specified percentage of the stand basal area while ensuring that the harvested portion was representative of the original stand in terms of species composition, diameter distribution, and tree quality. Two tree-marking strategies were used in this study. On Block 2, all live trees

Figure 3. View of Hangover site—falling complete, yarding in progress.

with a diameter at breast height (dbh) larger than 17.5 cm that were to be harvested were marked. On Block 1 only live trees larger than 50 cm dbh that were to be harvested were marked, and the stand was undermarked by 40 to 50 percent. The latter marking strategy, developed over a period of four years by Husby working in conjunction with its forest engineering consultant and fisheries biologist, was found to be effective at meeting removal targets in similar stands in the Naden Harbour area.

Helicopter specifications

A Sikorsky S-64E Skycrane performed the helicopter yarding operation. The Sikorsky S-64E Skycrane is a twin-turbine, heavy-lift helicopter and is one of the largest helicopters used for logging in British Columbia (Figure 4). Its rated maximum payload is 20 000 lb. (9 072 kg) and its target payload in helicopter logging operations is typically 15 000–16 000 lb. with a hook

Figure 4. Sikorsky S-64E Skycrane.

[3] The 25% patch cut unit in Block 2 was an exception. The harvested patches in this unit were systematically arranged to avoid a large gully system running through the middle of the unit.

system. As of 2002, approximately twenty S-64E Skycranes were certified for commercial use worldwide (Helicopter Association International 2002). Key specifications for the S-64E and other helicopters used for logging in British Columbia are shown in Appendix I. More information about the S-64E is presented in Dunham (2002).

Study methods

Harvesting productivity and cost

FERIC researchers observed the falling and helicopter yarding phases and part of the loading phase. During the harvesting operation, FERIC frequently discussed events and progress with Slarktooth Logging, Husby, and Canadian Air-Crane personnel to identify site, stand, layout, and organizational factors that influenced productivity. The falling, helicopter yarding and loading phases were monitored on a shift-level basis using time-cards and other daily reports supplied by the cooperators. For the helicopter yarding phase, the shift-level data were supplemented with extensive detailed-timing data. Canadian Air-Crane supplied production and time information on a daily basis for the Skycrane and the support helicopter. A consecutive record was created from the shift-level information documenting the treatment unit, turn weight, number of logs, and occurrences of aborts and delays for each turn flown. Shift-level and detailed-timing records were combined to summarize average turn times, flight distances, number of turns, and total weight of logs yarded from each harvesting treatment. Scale summaries supplied by Husby were used to convert weights to volumes.

Detailed timing was performed to examine the effects of the different harvesting treatments on helicopter yarding productivity. The yarding turn was subdivided into five time elements using visual keys to define start and end points for each timing element:

Travel Empty: fly from the landing to the hookup site

Position and Hookup: make visual contact with the hooktender, lower the hook into position to secure chokers on the hook, and hover until the hooktender is at a safe distance from the turn

Breakout: lift the turn clear of surrounding trees and start moving toward the landing

Travel Loaded: fly from the hookup site to the landing with the turn, lower the turn to the ground, and release the chokers from the hook[4]

In-Flight Delays: full or partial aborts and other minor delays that occur during the yarding cycle

Position and hookup and *Breakout* collectively form the *Hookup* phase of the turn.

The following additional information was recorded for each timed turn:

- log landing segment in which Travel Empty began (start of turn)
- treatment unit where the turn was hooked up
- approximate location of the hookup site within the treatment unit (lower, middle, or upper third)
- log landing segment in which the turn was landed (end of turn)
- occurrence of in-flight delays with known or suspected causes
- number of logs
- horizontal distance and elevation change for Travel Empty and Travel Loaded elements

Analysis of Variance (ANOVA) and Bonferroni's Multiple Range Test were applied to the detailed-timing data to determine if harvesting treatment influenced turn times, turn weights, and abort and delay frequencies. To standardize yarding distances among the treatment units, multiple regression techniques were used to develop time-versus-distance relationships for Travel Empty and Travel Loaded. The independent variables

[4] FERIC also attempted to record Unhook time (the time required at the end of Travel Loaded to lower the turn to the ground and release the chokers from the hook). However, the Unhook activity was very short and could not be observed clearly from all vantage points, so it was included in Travel Loaded in this analysis.

tested were horizontal distance and elevation change for Travel Empty, and horizontal distance, elevation change, number of logs, and turn weight for Travel Loaded. Finally, the results of these analyses were combined to create production and cost functions for clearcut, patch cut and single-tree selection treatments.

Costs for the Skycrane and the support helicopter were estimated using a modified version of the costing methodology in Guimier and Wellburn (1984), supplemented with information from The Official Helicopter Blue Book (HeliValue$, Inc. and Helibooks Ltd. 1999) (Appendix II). Hourly costs for the other machines involved in the harvesting operations were calculated using FERIC's standard costing methods (Appendix III). Labour costs were based on the IWA British Columbia Coast Master Agreement. All machine and labour costs reflect current (2002) values.

The costs presented in this report do not reflect stumpage or profit. The costs are FERIC's estimates only and are not the actual costs incurred by either the licensee or the heli-logging contractor.

Ground disturbance and damage to residual trees

After harvesting was completed, FERIC mapped both sites to establish final boundaries and areas for all treatment units and patch cuts. Two to three uniformly distributed, fixed-radius (12.62-m or 0.05-ha) plots per hectare were established within each treatment unit to estimate basal area removals and to survey damage to residual trees and ground disturbance. Within each plot, all residual trees with a diameter at breast height of 17.5 cm or larger were measured and the dimensions and locations on the stem of all logging-related damage were recorded. For stumps within plots, the species, height above point of germination, diameter inside bark (dib), and tree class (live or dead at time of harvest) were recorded, and the diameter at breast height was estimated using the appropriate equations in Omule and Kozak (1989). Ground surface condition was recorded at one-metre intervals along each of four 15-m transects originating from the plot centre. Each sample point was classified as disturbance caused by harvesting (falling and yarding) operations, undisturbed, pre-harvest exposed mineral soil (e.g., windthrow, gully sidewalls, and mass wasting), slash, or other (e.g., trees, stumps, exposed rock, and large boulders). The first transect was established by randomly selecting a compass bearing and the second, third, and fourth transects were oriented at 90°, 180°, and 270°, respectively, to the first.

Results and discussion

Description of the harvesting operation

Table 2 describes the personnel involved in the falling, yarding, and loading phases of the harvesting operation.

Table 2. Crew complements for falling, yarding, and loading phases

Phase and crew description	Crew position	Crew members (no.)
Falling	bullbucker	1–2
	faller	2–13
Subtotal		3–15
Helicopter yarding		
Flight crew	Skycrane pilot	1
	Skycrane co-pilot	1
	Bell 206B pilot	1
Aircraft maintenance	flight engineer	3
Rigging crew	heli-log bullhooker	1
	heli-log hooker	4
	heli-log strip runner	4
	heli-log chokersetter	4
Landing crew	front-end loader operator	1
	hydraulic loader operator	1
	heli-log head chaser	1
	heli-log chaser	3
Subtotal		25
Loading	cable loader operator	1
	second loader	1
Subtotal		2
Project supervision	project manager	1
Total crew		31–43

Falling

Slarktooth Logging performed the falling. Most of the fallers involved in the trial had previously worked with Husby and had experience in partial cutting and helicopter logging in old-growth hemlock-spruce stands. The falling phase began with the fallers hiking into each block to open sites and build helipads for the support helicopter using on-site materials (Figure 5). Once the first helipads were established, a Bell 206B Jet Ranger ferried the fallers to and from their falling sites daily for all of Block 1 and most of Block 2. As falling progressed, the fallers built additional helipads for the falling and rigging crews, as dictated by access and safety considerations.

Trees were felled and bucked to match the Skycrane's target payload of 15 000 lb. (Figure 6). Large stems were bucked into logs according to grade and weight specifications, while smaller stems were left tree-length. Wherever possible, logs were carefully limbed to reduce the amount of unmerchantable material flown to the log landings. Although the largest stems had to be bucked into logs as short as 3.1 m so as not to exceed the Skycrane's maximum payload, no ripping was required on either study site.[5]

The fallers directed trees with falling wedges and sometimes used hydraulic jacks in the smaller patch cuts. In the single-tree selection units, the fallers made the final decision as to whether or not a marked tree could be felled safely. If not, the fallers were instructed to substitute a nearby unmarked tree of the same species and similar size and quality.

On both blocks, snags within the treatment units and along the external block boundaries were felled in accordance with safety regulations in effect at the time of the trial. The snags in the leave patches of the patch cut units were considered hazards to the fallers and rigging crews and therefore were also felled. Before yarding began, the bullbucker and the bullhooker jointly inspected the partial cutting units to identify other potential hazards to the rigging crews such as brushed and damaged residual trees. Trees that were deemed to be a significant hazard were felled prior to yarding, while trees that had suspected damage, such as broken branches, were flagged to warn the rigging crews.

Figure 5. Helipad in Block 1 patch cut.

Figure 6. Felled and bucked timber in Block 1 25% single-tree selection.

Yarding

Canadian Air-Crane performed the helicopter yarding. The flight, rigging, and landing crews had experience at partial cutting in similar stand types. The yarding phase was scheduled to operate 10 h per shift, seven days per week. Actual shifts ranged from 2 to 12 h/day depending upon weather conditions and hours of daylight.

[5] If a log bucked to the minimum acceptable length will exceed the helicopter's maximum payload, the log is "ripped", or cut lengthwise into two pieces, to meet weight restrictions.

Equipment used in the yarding phase consisted of the Sikorsky S-64E Skycrane, a Bell 206B Jet Ranger (to ferry fallers and rigging crews to and from work sites and to return chokers to the hookup sites), one front-end log loader and one hydraulic log loader, plus on-site service trailers and fuelling facilities. The 25-member crew included two pilots and three flight engineers for the Skycrane and one pilot for the support helicopter; a bullhooker and four rigging teams on the hillside consisting of one hooktender, one strip-runner, and one chokersetter each; and two log-loader operators and four chasers at the log landing.

The S-64E Skycrane was configured for choker logging with a double hook (Figure 7) and a 200- or 250-foot steel longline. The double-hook system allowed partial aborts in the event of overweight turns or difficult breakouts. The pilots preferred to use a 200-foot longline but the combination of tall trees and steep slopes in the single-tree selection and most of the patch-cut treatment units required the use of a 250-foot line for most of the study.

The Skycrane typically yarded 20 to 30 turns in a 55- to 60-minute yarding cycle, with 5- to 10-minute visual inspection and refuelling breaks between cycles. Yarding began at the top of the treatment units and progressed downhill. During a yarding cycle, the Skycrane rotated among the four rigging crews. The Skycrane would take two consecutive turns from one hooktender, then move to the next hookup point for two turns from the next hooktender, and so on. The rigging crews were dispersed roughly along a level line across the width of the study site, and were spaced well apart to ensure that they didn't work beneath the Skycrane's flight path. On Block 1, two rigging crews usually worked full-time in the clearcut unit, the third crew worked in the 50% patch-cut unit, and the fourth crew alternated between the 25% patch-cut and 25% single-tree selection units. On Block 2, crew placement was more flexible because the treatment units were more dispersed.

Figure 7. Example of double hook used for choker logging.

Figure 8. View of log landing from hillside in Block 1.

Logs were landed on or beside existing roads along the bottoms of both sites (Figure 8). Husby chose to separate yarding and loading activities to eliminate interference between the two phases. This decision required a hydraulic log loader to be added to the yarding phase, but it reduced congestion at the log landings during yarding operations. The front-end loader operator kept the road clear and helped the chasers to unhook chokers, while the hydraulic loader followed behind and decked the unchoked logs on the downhill side. The two log loaders and the chasers worked as a unit, moving back and forth along the road during the yarding operation and always maintaining a clear zone for the Skycrane to land turns.

Loading

Husby used its own Madill 075 cable loader (Figure 9) and two-person crew for the loading phase. Loading started on Block 1 when the Skycrane moved to Block 2. The logs were loaded onto highway log trucks and hauled about 20 km to a dryland sort on Rennell Sound, where they were sorted, manufactured, bundled, boomed, and then loaded onto log barges. Some bucking and

Figure 9. Madill 075 log loader in Block 1.

trimming was done at the landings, but most log manufacturing was done at the sortyard.

Shift-level productivity and cost

In total, 34 950 m^3 was harvested from the two sites—17 650 m^3 from Block 1 and 17 300 m^3 from Block 2. Overall, the falling phase averaged 376 m^3/shift with production[6] (SWP), the helicopter yarding phase averaged 930 m^3/SWP, and the loading phase averaged 514 m^3/SWP (Table 3). The total per-unit cost was estimated at \$82.23/m^3 (Table 4). Falling accounted for 13%, helicopter yarding for 78%, and loading for 9% of the total cost. Costs directly related to equipment and labour accounted for 84% of the cost.

Dunham (2002) reported a similar total per-unit cost (\$77.27/m^3) and cost distribution (11% for falling, 81% for helicopter yarding, and 8% for loading) in a study of S-64E and S-64F Skycranes on southern Vancouver Island. The operations in the two studies were similar in most respects, and differed in that Dunham's involved only clearcutting and the use of the larger S-64F Skycrane and a helicopter grapple for parts of the operation. This study involved both clearcutting and partial cutting, and used only the S-64E with chokers. However, the similar results suggest that the differences in prescription and equipment had a relatively minor effect on overall productivities and costs.

Table 3. Shift-level summaries and productivities for the falling, yarding, and loading phases

	Blocks 1 and 2 combined
Falling	
Scheduled shifts worked (no.)	93
Total faller shifts worked (no.)	491
Average fallers per shift (no.)	5.3
Volume per scheduled shift (m^3)	376
Volume per faller per 6.5-h falling shift (m^3)	71
Helicopter yarding	
Logging helicopter—total shifts scheduled (no.)	47
Shifts worked on Blocks 1 and 2 (no.)	37.6
Shifts worked on non-study sites (no.)	3.4
Shifts lost to weather (no.)	6
Shifts lost to mechanical problems (no.)	0
Average flight-hours per productive yarding shift (no.)	5.5
Volume per productive yarding shift (m^3)	930
Loading	
Total shifts worked (no.)	68
Volume per 10-h loading shift (m^3)	514

Falling

The fallers worked a total of 491 faller-shifts during 93 SWP between mid-June and early October, for an average of 5.3 fallers per shift. Also, the Bell 206B Jet Ranger recorded a total of 76.4 flight hours of support, or 0.8 flight hours/SWP, for the falling phase. The decision to create the 15% single-tree selection unit extended falling operations on Block 2 into early October, and caused the falling and helicopter yarding phases to overlap for a two-week period. Eight to 13 fallers worked each shift during the period of peak activity from early July to late August, when both blocks were active. Once Block 1 was completed and there was less work space and volume available, the number of fallers was reduced to three to five per shift.

Average falling productivity was much higher for Block 1 than for Block 2 (84.0 versus 61.6 m^3 per 6.5-h faller-shift, respectively) (Table 5). The generally uniform open slopes of Block 1 presented easier falling circumstances, even though slopes were slightly steeper, than the gullied terrain on Block 2. Also, Block 1 had less stand defect,

[6] For a given harvesting phase, a Shift With Production (SWP) was defined as a scheduled day of work in which that phase (falling, helicopter yarding, or loading) performed a minimum of 0.5 hours of productive activity. Scheduled workdays that were lost because of weather, mechanical or other reasons were not counted as Shifts With Production.

brush and pre-existing windthrow, and higher average volumes per hectare and per tree (Table 1).

Both blocks displayed the same trend with the clearcuts having the highest falling productivities, followed by the 50% patch cuts, then the 25% patch cuts, and finally the 25% single-tree selection cuts with the lowest productivities. Falling productivities were identical for the 25% and 15% single-tree selection cuts on Block 2. Compared to the clearcuts, fallers working in the 50% patch cuts spent a larger proportion of working time moving between harvest patches and opening up falling faces. Likewise, the 25% patch cuts had a higher proportion of moving and opening-up time relative to production falling time than the 50% patch cuts. In the single-tree selection units, the fallers had to spend considerable time on reconnaissance and planning to decide on the placement of each marked tree and the falling sequence. This resulted in low productivities.

In conversations with FERIC researchers during the field study, the fallers estimated that compared to clearcuts their falling productivities were reduced by 15–20% in

Table 4. Estimated costs for falling, yarding, and loading

	Falling ($/m³)	Yarding ($/m³)	Loading ($/m³)	Total ($/m³)
Prime costs				
Logging helicopter	-	40.02	-	40.02
Support helicopter	1.23	2.61	-	3.84
Log loaders	-	2.08	4.40	6.48
Chainsaws	0.80	0.13	0.11	1.04
Service landing equipment	-	0.22	-	0.22
Choker replacement	-	0.49	-	0.49
Labour	6.03	9.15	1.82	17.00
Subtotal	8.06	54.70	6.33	69.09
Other costs				
Mobilization	-	0.90	0.61	1.51
Crew transport	0.60	0.44	0.22	1.26
Supervision	1.61	0.73	-	2.34
Room and board	-	2.22	-	2.22
Overhead	0.51	4.18	0.36	5.05
Project costs	-	0.76	-	0.76
Subtotal	2.72	9.23	1.19	13.14
Total	10.78	63.93	7.52	82.23

Table 5. Shift-level falling productivity and cost by harvesting treatment

Block/treatment unit	Volume (m³)	Faller-shifts with production (no.)	Volume produced (m³/shift)	Falling cost (prime only) ($/m³)
Block 1				
Helicopter clearcut	8 450	96	88.0	6.52
50% patch cut	4 700	55	85.5	6.71
25% patch cut	2 250	28	80.4	7.14
25% single-tree selection	2 250	31	72.6	7.90
Subtotal	17 650	210	84.0 [a]	-
Block 2				
Helicopter clearcut	10 250	140	73.2	7.84
50% patch cut	2 150	32	67.2	8.54
25% patch cut	1 450	28	51.8	11.08
25% single-tree selection	2 600	61	42.6	13.46
15% single-tree selection	850	20	42.5	13.50
Subtotal	17 300	281	61.6 [a]	-
Total	34 950	491	71.2 [a]	8.06 [a]

[a] Weighted average.

patch cuts and 30–40% in single-tree selection cuts. The productivity differences for Block 2, where stand and terrain conditions were generally similar for all treatment units, were consistent with these estimates. However, differences between treatment units on Block 1 were much less, probably because stand and terrain conditions in the 25% single-tree selection and 25% patch cut units were generally more favourable for falling than in the clearcut and 50% patch cut units.

The average falling productivity for this study (71 m^3/faller-shift) is considerably less than the 94 m^3/faller-shift reported by Dunham (2002), and the prime cost (labour and equipment only) is correspondingly higher (\$8.06/m^3 versus \$6.43/m^3). Steep, broken terrain was obviously an important factor in both studies. Terrain conditions on Block 1 were similar to those of Dunham's study site, and falling productivity and cost for the Block 1 clearcut are somewhat lower but still comparable to Dunham's results. The lower productivity and higher cost for the Block 2 clearcut are attributed to the numerous deep, closely spaced gullies in the lower half of the unit, where the fallers had to direct the trees downhill rather than cross-slope. This reduced breakage losses that would have occurred if the trees had been felled across the gullies. However, limbing and bucking took longer because trees felled downhill often slid a considerable distance, and frequently came to rest in positions that made limbing and bucking difficult or unsafe.

Good falling is very important to efficient helicopter logging operations (Pertile 1996). The heli-riggers reported that the quality of falling and bucking in this operation was generally very good given the steep, broken ground. The most frequent falling-related problem encountered by the rigging crews was large trees that could not be bucked by the fallers because of the steep slopes and broken ground. Unbucked trees often caused difficult extractions or hangups during yarding. Occasionally the Skycrane had to reposition unbucked trees to more stable positions so they could be safely bucked.

Yarding

Block 1 was yarded from late August to late September, and Block 2 was yarded from late September to mid-October. Yarding operations on Block 2 had to be delayed for a few days to allow the fallers to complete the 15% single-tree selection unit. Canadian Air-Crane was able to yard some nearby windthrow salvage sites during this period, so the Skycrane was not idled by the overlap between the falling and yarding phases. Of the 47 days available for yarding, the Skycrane worked 37.6 shifts on the study sites and 3.4 shifts on the windthrow salvage sites, and was grounded by low cloud and/or wind for six full shifts (Table 6). Overall, the Skycrane flew 219 cycles for an average of 5.8 cycles per operating shift.[7]

On Block 1, yarding production averaged 22.4 turns, 97 logs, and 154.8 m^3 per cycle. On Block 2, yarding production averaged 26.2 turns, 117 logs, and 164.8 m^3 per cycle. Although the average volume per turn was higher due to the larger average log size and number of logs per turn, the longer average flight distance for Block 1 (630 m horizontal distance, compared to 350 m for Block 2) resulted in 3.8 fewer turns and 6% less volume per cycle than on Block 2.

The Skycrane recorded 207.3 productive flight hours in 379.2 scheduled hours, for an average of 5.5 flight hours/SWP (Table 7). The ratio of flight hours to total hours was 55% for the entire study period and was similar for both blocks. Of the non-flight time, 20% was spent in service and repair, and 25% in non-mechanical delays. Scheduled and unscheduled maintenance were higher in Block 2, but Block 1 had more downtime due to weather delays—19% of scheduled time. Dunham (2002) reported 6 flight hours per scheduled 12-h shift for an S-64E Skycrane with chokers, for a ratio of 50%

[7] A cycle is defined as the period of continuous flight operations between refuelling and/or maintenance breaks, during which a series of turns is yarded. In helicopter logging, typically 25–45 turns are yarded in a 50–90 minute cycle.

Table 6. Production summary for the Sikorsky S-64E Skycrane

	Block 1	Block 2	Combined
Potential shifts (no.)	24.7	22.3	47.0
Non-operating shifts (no.)	5.0	1.0	6.0
Shifts worked at other sites (no.)	-	3.4	3.4
Shifts with production (SWP) (no.)	19.7	17.9	37.6
Net productive flight-hours	108.0	99.3	207.3
Production totals			
Cycles flown (no.)	114	105	219
Turns yarded (no.)	2 554	2 746	5 300
Logs yarded (no.)	11 065	12 310	23 375
Weight (lb.)	37 962 000	39 678 000	77 640 000
Volume yarded (m^3)	17 650	17 300	34 950
Production per SWP			
Cycles (no./SWP)	5.8	5.9	5.8
Turns (no./SWP)	129.6	153.4	141.0
Logs yarded (no./SWP)	562	688	622
Weight yarded (lb./SWP)	1 927 000	2 216 600	2 064 900
Volume yarded (m^3/SWP)	896	966	930
Production per cycle			
Turns (no./cycle)	22.4	26.2	24.2
Logs (no./cycle)	97	117	107
Weight (lb./cycle)	333 000	377 900	354 500
Volume (m^3/cycle)	154.8	164.8	159.6
Production per flight-hour			
Turns (no./flight-hour)	23.6	27.7	25.6
Logs (no./flight-hour)	102	124	113
Weight (lb./flight-hour)	351 500	399 600	374 500
Volume (m^3/flight-hour)	163.4	174.2	168.6

flight hours to total hours. A 12-h scheduled shift length was feasible in Dunham's study because the yarding phase began about a month earlier than in this study. The later start in this study, coupled with deteriorating weather as the yarding phase progressed, reduced the effective shift length to an average of about 10 h over the study period.

Average total turn times[8] calculated from the shift-level data were 2.54 min for Block 1 and 2.17 min for Block 2. The average turn time of 2.35 min for the entire study period was within the 2.0- to 2.5-min/turn range desired by heli-logging contractors. The longer average turn time for Block 1 compared to Block 2 is attributed to longer average yarding distance.

Average delay-free turn times from the detailed-timing study were 2.27 and 1.96 min for Blocks 1 and 2, respectively (Table 8). In-flight delays (aborts, hangups, and other rigging-related delays) accounted for an additional 0.19 min/turn for Block 1 and 0.13 min/turn for Block 2, and yielded total average turn times of 2.46 and 2.09 min/turn for Blocks 1 and 2, respectively. These are slightly less than the average turn times estimated from the shift-level data because turns flown by a trainee pilot and turns flown uphill on Block 2 were excluded from the detailed-timing averages.

The average horizontal distance flown per turn varied considerably between the blocks and treatment units, from 480 to 760 m on Block 1 and from 230 to 450 m

8 Net productive flight time in minutes divided by total number of turns flown (Table 6).

Table 7. Shift-level time distribution for the Sikorsky S-64E Skycrane

	Block 1	Block 2	Combined	Proportion of total time (%)
Flight time (h)				
Productive flight	108.0	99.3	207.3	55
Non-productive flight	0.2	0.1	0.3	<1
Subtotal	108.2	99.4	207.6	55
Non-flight time—service and repair (h)				
Warm-up and refuel	13.3	12.9	26.2	7
Scheduled maintenance	12.5	20.6	33.1	9
Unscheduled maintenance	4.2	11.7	15.9	4
Subtotal	30.0	45.2	75.2	20
Non-mechanical delays				
Weather	38.5	5.9	44.4	12
Crew deployment	11.8	12.3	24.1	6
Out of wood	7.1	11.2	18.3	5
End of day	2.5	3.6	6.1	2
Other	1.4	2.1	3.5	<1
Subtotal	61.3	35.1	96.4	25
Total scheduled time (h)	199.5	179.7	379.2	100
Ratio of flight-hours to total hours (%)	54	55	55	-
Shifts with production (no.)	19.7	17.9	37.6	-
Flight-hours/SWP (h)	5.5	5.6	5.5	-
Scheduled hours/SWP (average shift length) (h)	10.1	10.0	10.1	-

Table 8. Average turn times by treatment unit (from detailed-timing data)

Block/treatment unit	Turns (no.)	Average horizontal distance (m)	Turn element: Travel empty (min)	Position and hook (min)	Breakout (min)	Travel loaded (min)	Total delay-free turn time (min)
Block 1							
Helicopter clearcut	1 128	620	0.46	0.73	0.31	0.71	2.21
50% patch cut	625	760	0.51	0.71	0.34	0.75	2.31
25% patch cut	327	590	0.47	0.76	0.41	0.69	2.33
25% single-tree selection	327	480	0.39	0.88	0.41	0.56	2.24
Overall, Block 1	2 407	630	0.47	0.75	0.35	0.70	2.27
Proportion of turn time	-	-	21%	33%	15%	31%	100%
Block 2							
Helicopter clearcut	1 383	360	0.33	0.78	0.27	0.49	1.87
50% patch cut	292	370	0.28	0.78	0.25	0.39	1.70
25% patch cut	157	410	0.36	0.82	0.32	0.53	2.03
25% single-tree selection	324	230	0.33	0.88	0.36	0.53	2.10
15% single-tree selection	134	450	0.33	0.99	0.31	0.51	2.14
Overall, Block 2	2 290	350	0.32	0.83	0.33	0.48	1.96
Proportion of turn time	-	-	16%	42%	17%	25%	100%

on Block 2. Table 8 shows that average times for Travel Empty and Travel Loaded tended to increase with increasing average horizontal distance on Block 1, but not on Block 2.

Factors affecting helicopter yarding productivity

FERIC had frequent discussions during the trial with Canadian Air-Crane's project manager, pilots, engineers, and crews about factors that were important to efficient helicopter logging operations in general, and specific features of the two sites that affected helicopter logging productivity and cost in this study. The topics most frequently mentioned were the harvesting treatments, flight path and log landing characteristics, and weight and cull factors.

Harvesting treatment

In general, the pilots commented that turn times were longer in the patch cut and single-tree selection treatments than in the clearcuts due to increased hookup time. They also thought turn weights were lower and delays were more frequent in the partial cuts. The shift-level and detailed-timing data were analyzed to determine if the patch cut and single-tree selection treatments affected hookup times, turn weights, and frequencies of aborts and delays.

Many of the harvest patches in the 50% patch cuts opened onto the helicopter clearcuts or were connected through openings at the patch corners. Hookup times, delay times, and turn weights for the two treatments were not significantly different, so the 50% patch cuts were considered as part of the helicopter clearcuts and the data were combined.

Hookup time. This is the Position and Hookup phase and Breakout phase combined. The detailed-timing results in Table 8 support the pilots' comments that the hookup phase of the yarding cycle took longer in the patch cuts and single-tree selection units than in the clearcuts. For both blocks, the Hookup time generally increased as the level of stand retention increased. Compared to clearcuts, hookup times were 12% (7 seconds) longer per turn for 25% patch cuts, and 22% (14 seconds) longer per turn for single-tree selection cuts (Table 9). These differences were statistically significant. At the study average of about 25 turns per 60-minute cycle (2.4 min/turn), these increases in average turn times translate into reductions of about 1.2 turns and 7–8 m^3 per cycle for 25% patch cuts, and 2.4 turns and 15–16 m^3 per cycle for single-tree selection cuts.

Turn weights. Table 10 summarizes average turn weights by block and treatment unit and compares average turn weights for the 25% patch cut and the single-tree selection cuts with the clearcuts. Overall, turn weights averaged 14 860 lb. for Block 1 and 14 500 lb. for Block 2. These values represent 74.3% and 72.5%, respectively, of the Skycrane's rated maximum payload of 20 000 lb., and are slightly lower than the target of 15 000 lb. (75% of maximum payload) set for the study by Canadian Air-Crane.

Within each block, average turn weights were similar for all treatment units and, except for the 15% single-tree selection unit on Block 2, were not significantly different.

Table 9. Comparison of hookup times by block and harvesting treatment

Block and treatment unit	Samples (no.)	Average hook time [a] (min)
Clearcuts		
Block 2, 50% patch cut	266	1.03 a
Block 1, helicopter clearcut	954	1.04 a
Block 2, helicopter clearcut	1 263	1.04 a
Block 1, 50% patch cut	560	1.05 a
Group average	3 043	1.04
Patch cuts		
Block 2, 25% patch cut	139	1.14 b
Block 1, 25% patch cut	305	1.17 b
Group average	444	1.16
Single-tree selection cuts		
Block 2, 25% single-tree selection	300	1.23 c
Block 1, 25% single-tree selection	273	1.29 c
Block 2, 15% single-tree selection	123	1.30 c
Group average	696	1.27

[a] Averages followed by the same letter are not significantly different ($\propto = 0.05$).

Table 10. Average turn weights for the Sikorsky S-64E Skycrane

Treatment unit	Block 1 Gross turn weight (lb.)	Block 1 Change [a] (%)	Block 2 Gross turn weight (lb.)	Block 2 Change [a] (%)	Combined Gross turn weight (lb.)	Combined Change [a] (%)
Clearcut/50% patch cut	14 870	-	14 490	-	14 680	-
25% patch cut	15 030	+1.1	14 770	+1.9	14 930	+1.7
25% single-tree selection	14 650	-1.5	14 390	-0.7	14 510	-1.2
15% single-tree selection	n/a	n/a	13 480	-7.0	13 480	-7.0 [b]
Block averages	14 860	-	14 500 [c]	-	14 680 [c]	-

[a] Change is expressed in relation to the clearcut.
[b] 15% single-tree selection is compared against Block 2 clearcut rather than combined clearcut.
[c] Excludes 15% single-tree selection unit.

Compared to their clearcut counterparts, average turn weights were slightly greater (1.1–1.9%) for the 25% patch cuts and slightly lower (0.7–1.5%) for the 25% single-tree selection cuts. Overall, the similarity in average turn weights shows that the partial cutting treatments in this study had little effect on the ability of the rigging crews to accurately estimate turn weights or to build optimum turns. This is likely due to crew experience, as many of the hooktenders had several years' experience rigging for the Skycrane, and the bullhooker usually placed the most experienced workers in the patch cut and single-tree selection units. However, average turn weight for the 15% single-tree selection unit was 7% lower than for the Block 2 clearcut. This may indicate that, at very low removal levels, logs become too scattered for even experienced rigging crews to consistently achieve desired turn weights.

For a given harvesting treatment, average turn weights were consistently lower (by 1.7% to 2.6%) on Block 2 than on Block 1. Reasons for this are not clear, but the systematic pattern suggests that the differences are probably due to site rather than crew factors. Differences between the sites in terms of average tree sizes, species compositions, and perhaps even average wood densities may have caused the hooktenders to consistently underestimate or overestimate log weights on one site compared to the other.

Some hooktenders commented that building optimum turns in the 25% single-tree selection units was more difficult because there were fewer logs to choose from and the turns had to be more carefully assembled to reduce the risk of hangups during breakout. However, others commented that logs in the 25% single-tree selection units were more visible because there was less slash to cover them. As a result, the rigging crews were less likely to miss logs when setting chokers and this reduced cleanup yarding.

Delay and abort frequencies. Table 11 presents the frequency and average duration of in-flight delays and aborted turns, by treatment unit and block. Overall, a delay occurred about once every four to six turns, and the average time lost per occurrence ranged from 0.5 to 1.9 minutes. On both blocks, full aborts occurred about once in every 20 turns in the patch cut and single-tree selection units compared to about once in every 30 turns in the clearcut units. No trends were apparent for partial aborts and other delays. Full aborts resulted in substantial time loss (average 1.3 to 1.9 minutes per occurrence). Partial aborts averaged from 0.5 to 0.8 minutes per occurrence, or about half as much time as full aborts. However, partial aborts occurred about twice as frequently as full aborts, so they had about the same impact on productivity as full aborts. Other in-flight delays, representing a variety of mostly nonmechanical causes, were more

Table 11. Comparison of delay and abort frequencies by treatment unit

Treatment unit	Full abort	Partial abort	Other delay	All aborts and delays
Block 1				
Clearcut/50% patch cut				
frequency (occurrence/no. turns)	1:32	1:10	1:20	1:5.5
average time (min/occurrence)	1.75	0.59	0.76	0.83
25% patch cut				
frequency (occurrence/no. turns)	1:23	1:9	1:16	1:4.6
average time (min/occurrence)	1.31	0.47	0.76	0.71
25% single-tree selection				
frequency (occurrence/no. turns)	1:20	1:10	1:13	1:4.4
average time (min/occurrence)	1.93	0.68	1.02	1.07
Block 2				
Clearcut/50% patch cut				
frequency (occurrence/no. turns)	1:29	1:9	1:44	1:6.1
average time (min/occurrence)	1.39	0.52	0.62	0.72
25% patch cut				
frequency (occurrence/no. turns)	1:20	1:9	1:22	1:4.9
average time (min/occurrence)	1.44	0.57	0.70	0.81
25% single-tree selection				
frequency (occurrence/no. turns)	1:20	1:13	1:40	1:6.6
average time (min/occurrence)	1.35	0.54	1.24	0.92
15% single-tree selection				
frequency (occurrence/no. turns)	1:22	1:17	1:17	1:6.1
average time (min/occurrence)	1.50	0.77	1.01	1.06

variable in frequency and duration but overall occurred about as frequently as partial aborts.

The combined effects of full and partial aborts and other delays added an average of 0.13 min/turn for clearcuts, 0.16 min/turn for 25% patch cuts, and 0.19 min/turn for single-tree selection treatments. The differences per turn are small, but the cumulative effects are substantial. When extrapolated over a typical cycle (25 turns in 55–60 minutes), for example, cumulative delay time amounted to about three minutes for clearcuts, four minutes for 25% patch cuts, and almost five minutes for single-tree selection cuts. Compared to clearcuts, therefore, the increased delay time associated with partial cutting reduced yarding productivities by about 2 m^3/cycle (1.3%) in the 25% patch cuts and about 4 m^3/cycle (2.5%) in the 25% single-tree selection treatments.

Flight path and log landing characteristics

Yarding (or flight) distances, elevation differences, and landing features were identified as important factors that influenced the Skycrane's productivity in this study.

Yarding distance and flight path slope. Canadian Air-Crane prefers to operate the Skycrane at yarding distances of 600 to 800 m and flight path slopes of 35% or less for downhill yarding (Dunham 2002). According to the pilots and flight engineers, the Skycrane achieves the best balance of air speed, descent rate, and turn time when operating within this envelope, and aircraft vibration and crew fatigue are reduced.

On Block 1, all yarding was downhill. Yarding distances (measured as straight-line horizontal distance from the log landing to the hookup site) ranged from 300 to as much as 1 600 m, but more than 90% of the turns were yarded at distances between 400 and 900 m. However, elevation differences between the block and the landing ranged from 75 to 500 m, resulting in slope gradients of 25 to 55% along the apparent flight path (the straight line connecting the hookup site to the landing, which represents the most direct line of travel for the helicopter). For horizontal distances of 400 m or more, the average slope between the hookup site and the landing was 49%. Overall, therefore, yarding distances on Block 1 were favourable but apparent flight path slopes were too steep for optimum loaded flight for the Skycrane.

The Skycrane pilots dealt with the large elevation differences by taking longer, curved flight paths from the hookup site to the landing rather than the shortest straight-line paths. By lengthening the flight path, the Skycrane was able to maintain a preferred combination of air speed and descent rate, and the higher travel speeds compensated for the longer flight distances. This was a practical solution on Block 1 because the yarding distances were long enough to permit the Skycrane to attain optimum air speeds, and there were no obstructions to limit the choice of flight path.

Horizontal yarding distances and elevation differences on Block 2 were much less than on Block 1. For downhill yarding, horizontal distances ranged from less than 100 to 900 m and elevation differences ranged from 25 to 250 m. However, more than 80% of the yarding was less than 400 m. Due to the short yarding distances, apparent downhill flight path slopes were as steep as 50% and almost half of the downhill yarding was steeper than 35%. In these situations, the Skycrane usually flew the most direct route to the landing at a slow and steady air speed. According to the pilots and engineers, the combination of short yarding distances and steep descent angles is very hard on the logging helicopter and the pilots because the steep descent rates cause additional aircraft vibration and the helicopter descends into the turbulence generated by its rotorwash. Where the option is available, pilots will usually choose to fly a longer distance at a more favourable slope.

To reduce the amount of steep downhill yarding on Block 2, Canadian Air-Crane elected to fly wood uphill from the upper sections of the helicopter clearcut and 50% patch cut treatments. The pilots stated that, compared to the alternative of short, steep downhill yarding, the Skycrane's productivity was not reduced because the uphill yarding was over short yarding distances (<300 m) and moderate slopes (<30%). Travel Loaded times and average turn weights were compared and found to be the same for uphill and downhill yarding over the same range of yarding distances.

Multiple regression analysis of the detailed-timing data found significant linear relationships between travel time, horizontal distance, and elevation change for Travel Empty and Travel Loaded (Equations 1 and 2). The number of logs per turn and turn weight were not significant for Travel Loaded.

[1] $TE = 0.21486 + 0.00024 \times HD + 0.00037 \times DE$
(n = 4 509 turns, R^2 = 52%)

[2] $TL = 0.40324 + 0.00012 \times HD + 0.00084 \times DE$
(n = 4 509 turns, R^2 = 46%)

where:

TE	= travel empty
TL	= travel loaded
HD	= horizontal distance (m)
DE	= difference in elevation (m)
n	= number of turns
R^2	= coefficient of multiple determination

In a previous study in Oregon, Dykstra (1976) found empty and loaded travel times for the Sikorsky S-64E Skycrane to be strongly correlated with slope yarding distance and chordslope (percent slope measured along the line between the hookup site and the landing).[9] However, Equations 1 and 2 explain only 46 to 52% of the variability

[9] Number of logs per turn and turn volume were also significant predictor variables of travel loaded time in Dykstra's study, but they were not significant in this study.

in travel times in this study. This indicates that horizontal distance and elevation difference, while useful for predicting turn times and therefore yarding productivity, only approximate the actual flight path and distance. Therefore, forest engineers and planners should consider both horizontal distances and elevation differences when laying out areas for helicopter logging and choosing landing locations. In addition, they must carefully consider how the topography and other site factors might influence the helicopter's actual flight path.

Landing approaches. On Block 1, logs were landed on a 1.1-km-long section of existing spur road located along the base of the hillside in the middle of a clearcut. The landing area was clear of obstacles in all directions. Similarly, an existing road running along the lower edge of the block was used as the log landing for Block 2. Unlike Block 1, the area below the road was not harvested, but several tall spruce trees in a 30- to 40-m-wide band below the road were identified as potential hazards and felled prior to the start of helicopter yarding.

The landing areas were easily visible, the approaches were unobstructed, and the long road sections were clear of ground crews and equipment. Therefore, the pilots had considerable flexibility to select a flight path that optimized travel speed and distance, and to maneuver the helicopter while landing the turn to adjust for wind direction. As a result, the process of setting the turn on the ground and releasing the chokers from the hook (i.e., Unhook phase) was consistently fast (4–7 seconds based on limited sampling). Because the log landing area on Block 1 was clear of trees on both sides, the Skycrane was able to approach fast and let the turn swing or "flare out" to the low side without risk of striking standing trees. The trees on the low side of the road on Block 2 required the pilots to approach the landing area more slowly and to lower the turn to the ground more deliberately.

Weight-to-volume conversion factor and cull factor

Forest companies and helicopter logging contractors typically negotiate rates for helicopter logging projects on a per-unit volume basis, but the most direct measure of the logging helicopter's productivity is weight flown per hour (lb./flight-hour). Therefore, an understanding of the relationship between gross weight flown and merchantable volume is important to predicting helicopter logging productivity and costs.

The main factors influencing the weight-to-volume relationship are the blended average weight per unit volume of the wood to be flown (calculated from typical weight-to-volume conversion factors for each tree species), and the weight of unmerchantable material flown to the landing, expressed as a percentage of the total weight of wood flown (cull factor). In general, helicopter logging contractors use weight-to-volume conversion factors of 1 800 to 2 000 lb./m^3 and cull factors of 4 to 6% for estimating helicopter logging projects in coastal mixed species old-growth stands of average to fair quality. However, these parameters can vary significantly from site to site because of differences in stand composition and age, wood density and moisture content, and amount of defect and decay. Lower weight conversions, to 1 700 lb./m^3, may be appropriate for stands with a large component of sound cedar, while lower cull values of 2–3% may be appropriate for second-growth stands. Conversely, higher weight conversions of up to about 2 100 lb./m^3 or cull factors of 9–10% may be used if, for example, the stand has a very high component of hemlock or is very brushy or defective.

Prior to harvesting, Canadian Air-Crane estimated an overall conversion factor for this trial of 2 000 lb./m^3 including 7% for cull, based on the species composition from the timber cruise and the company's experience in harvesting similar stands on the Queen Charlotte Islands. The species distribution from the final scale (60% hemlock, 35% spruce, and 5% cedar/cypress) matched the cruise almost exactly. However, the species weight conversion factors in Appendix IV, plus the same cull allowance of 7%, yielded an expected overall conversion factor of between 2 050 and 2 130 lb./m^3 (based on mid-point and maximum species weights, respectively), or 2.5–6.5% higher than the original estimate. The actual conversion factor for this study (total weight of material flown divided by the final scaled volume) was 2 222 lb./m^3. This is 11% higher than the original conversion estimate of 2 000 lb./m^3 and 4% higher than the highest estimate of 2 130 lb./m^3 calculated from Appendix IV values. This suggests that the actual cull factor was probably higher than the original estimate of 7%, or that the values for species weights given in Appendix IV may be too low.

Using the production function for clearcuts for this study (Appendix V), the Skycrane's estimated productivity is about 385 000 lb./flight-hour at 700 m horizontal yarding distance. This translates into 192.5 m^3/flight-hour at a cost of \$47.79/m^3 (prime costs only) for a conversion factor of 2 000 lb./m^3, or 173.3 m^3/flight-hour at a cost of \$53.09/m^3 for a conversion factor of 2 222 lb./m^3. The difference between the original and actual conversion factors represents a productivity decrease of 10% and a cost increase of 11%.

Effects of harvesting treatment on helicopter yarding productivity and cost

The results of the shift-level and detailed-timing studies were used to develop equations to compare helicopter turn times, productivities, and costs for the various harvesting treatments (Appendix V). Figure 10 compares helicopter yarding productivities for the clearcut, 25% patch cut, 25% single-tree selection, and 15% single-tree selection treatments for horizontal distances of 100 to 1 500 m, using estimated turn times and turn weights for this study. Clearcutting was the most productive harvesting treatment. The average productivities in the 25% patch cut and 25% single-tree selection treatments were 5% and 12% less, respectively, than for the clearcut due to longer average turn times caused by increases in hookup time and in-flight delay time. Productivity in the 15% single-tree selection averages about 18% less than for the clearcut. These lower productivities were due to increased average turn times and decreased average turn weights.

For every 100 m of horizontal distance, helicopter yarding productivity per flight-hour decreases at average rates of about 5 m^3 for clearcuts, 4.5 m^3 for 25% patch cuts, and 4 m^3 for single-tree selection cuts. Productivity differences between the harvesting treatments decrease gradually as yarding distance increases because cumulative travel time (Travel Empty plus Travel Loaded) becomes a larger proportion of total turn time as yarding distance increases.

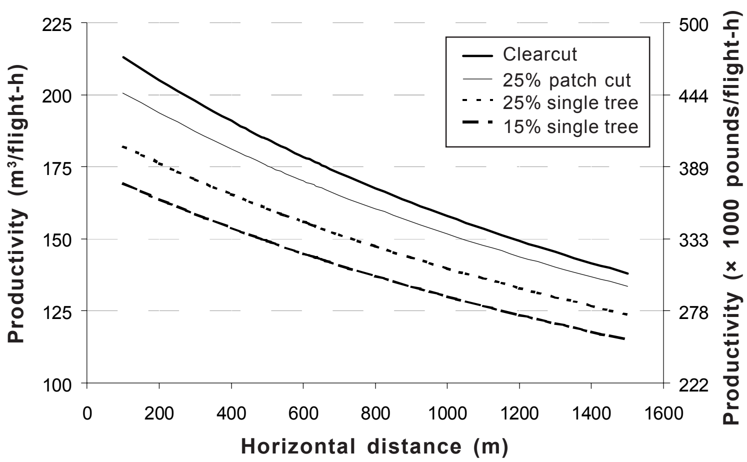


Figure 10. Yarding productivity versus horizontal distance for the Sikorsky S-64E Skycrane.

Figure 11 compares predicted helicopter yarding costs (prime costs only) by harvesting treatment for horizontal distances of 100 to 1 500 m. The graphs are based on a cost of \$9 200 per flight hour for the helicopter yarding system, which includes the Skycrane, support helicopter, log loaders, other equipment necessary to the yarding phase, and the entire yarding crew.[10] The clearcut had the highest productivity and therefore the lowest per-unit yarding cost. Compared to the clearcut, per-unit costs for the 25% patch cut, 25% single-tree selection cut, and 15% single-tree selection cut are 4–6%, 11–17%, and 20–26% higher, respectively, depending on yarding distance. Helicopter yarding cost increases linearly at a rate of \$1.56/m^3 per 100 m of horizontal distance.

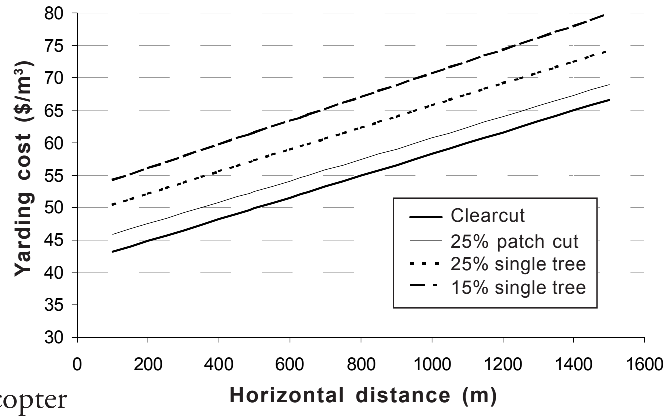


Figure 11. Yarding cost versus horizontal distance for the Sikorsky S-64E Skycrane.

Site and stand impacts

Ground disturbance

Table 12 summarizes post-harvest ground surface conditions for all of the treatment units. The occurrence of exposed mineral soil resulting from falling and yarding was very low, from <0.1% to 2.4% by treatment unit. In all helicopter-yarded units, harvesting disturbance was less than natural or pre-harvest levels of exposed mineral soil. After falling and yarding, 57–82% of the ground surface consisted of undisturbed duff and litter layers and large woody debris such as old windfalls. Logging slash, the second largest component of ground cover on the helicopter-yarded units, was heaviest on the clearcut units (33–37% cover), intermediate on the 25% single-tree selection units (22–25% cover), and lightest on the patch cut units (12–16% cover). Almost all of the slash cover on the patch cut units was concentrated in the patch cut openings, where slash loadings were similar to those of the clearcut units. The remainder of the ground surface consisted of natural non-soil components

[10] The flight-hour cost used in this analysis (\$9 200/flight-hour) was estimated by multiplying the total prime yarding cost of \$54.70/m^3 (Table 7) by the total volume harvested (34 950 m^3) and dividing by the total productive flight hours (207.3 flight hours, Table 6). This estimate does not include Other costs.

Table 12. Ground surface condition following helicopter yarding

	Ground surface condition				
Treatment unit	Undisturbed (%)	Pre-harvest exposed mineral soil (%)	Disturbance from logging (%)	Slash (%)	Other (%)
Block 1					
Clearcut	56.5	0.9	0.9	33.3	8.3
50% patch cut	67.4	3.9	1.6	16.3	10.7
25% patch cut	75.6	3.0	0.5	12.5	8.5
25% single-tree selection	60.8	3.6	2.4	21.7	11.4
Block 2					
Clearcut	57.2	1.1	<0.1	36.7	5.0
50% patch cut	80.0	1.8	1.1	12.3	4.8
25% patch cut	80.5	1.7	0.4	12.4	5.0
25% single-tree selection	65.8	2.6	1.1	24.9	5.6
15% single-tree selection	82.3	4.2	0.7	4.8	8.0
Conventional yarding					
Clearcut	35.6	1.0	8.0	43.5	11.9

such as exposed rock, roots, trees, snags, and stumps.

The conventional (grapple-yarded) unit on Block 2 was surveyed to provide a comparison for the helicopter-yarded units. Overall, the grapple-yarded unit had a substantially higher level of mineral soil exposure due to falling and yarding (8% compared to <0.1–2.4% for the helicopter units), and a lower level of undisturbed forest floor (36% compared to 57–82% for the helicopter units).

Damage to residual trees

Overall, 9–10% of residual trees in the 25% patch cuts, 11–18% in the 50% patch cuts, 23–26% in the 25% single-tree selection cuts, and 7% in the 15% single-tree selection cut were damaged to some degree during falling and yarding (Krag 1998). Seven percent of the damaged trees had broken tops and 93% had wounds to the main stem or, in a few cases, to large roots near the base of the tree. Most logging-related wounds were relatively small, with median sizes ranging from about 140 to 170 cm^2.

Table 13 shows the percentages of residual crop trees with unacceptable damage according to the damage criteria presented in the Tree Wounding and Decay Guidebook (BCMOF; BC Environment 1997).[11] Wounding levels for a given harvesting treatment were consistently higher on Block 1 than on Block 2, but there were no obvious explanations for the site-to-site differences. Wounds were more or less uniformly distributed through the single-tree selection treatments. In the patch cut treatments, damage tended to be concentrated along the lower edges of the openings. The low level of unacceptable damage in the 15% single-tree selection treatment probably reflects the fact that removals tended to be clustered rather than uniformly dispersed, and the actual removal level (10.2%) was less than the 15% removal target.

Based on field observations during the falling phase, snag falling was thought to be responsible for most of the scarring within the interiors of the leave areas on the patch

[11] For the purposes of this analysis, the appropriate management objectives and damage criteria are assumed to be long-term retention and Damage Type C for the patch-cut treatments, and uneven-aged management and Damage Type D for the single-tree selection treatments.

Table 13. Damage to residual trees[a] in patch cut and single-tree selection treatment units

Treatment unit	Site	Residual trees surveyed [a] (no.)	Number of trees with: wounds >400 cm^2	wounds >1/3 circumf.	wounds on support roots	broken tops [b]	No. of residuals with unacceptable damage [b]	Percent residuals with unacceptable damage [b]
50% patch cut	Block 1	278	20	0	2	(1)	22	7.9
	Block 2	207	10	0	1	(1)	11	5.3
	Combined	485	30	0	3	(1)	33	6.8
25% patch cut	Block 1	221	12	1	2	0	15	6.8
	Block 2	154	5	0	0	(2)	5	3.2
	Combined	375	17	1	2	(2)	20	5.3
25% single-tree selection	Block 1	328	21	0	9	10	40	12.2
	Block 2	275	22	0	2	2	26	9.5
	Combined	603	43	0	11	12	66	10.9
15% single-tree selection	Block 2	371	9	0	1	4	14	3.8

[a] Conifer trees 17.5 cm dbh and larger.

[b] The number of residual trees with broken tops in the patch cut treatments are included for completeness and enclosed in parentheses. However, for the hemlock and Sitka spruce, broken tops only constitute unacceptable damage for uneven-aged management regimes (the single-tree selection treatments in this study) and are not included in the total number or percent of residual trees with unacceptable damage for the patch cut treatments.

cut units, and for a portion of the damage within the single-tree selection units as well. However, no surveys were performed between the falling and yarding phases, so the relative contributions of falling and yarding to damage levels could not be estimated.

Other observations

Harvesting the stand profile

Harvesting the stand profile was an important consideration for the partial cutting treatments in this study.[12] For the 25% and 50% patch cut treatments, harvesting the profile was achieved by uniformly distributing the harvest patches throughout the treatment areas without reference to site and stand conditions. For the 25% single-tree selection treatments, harvesting the profile was achieved by selecting and marking individual trees for removal based on stand structure data collected during timber cruising and other preharvest surveys.

Two tree-marking systems were employed on the 25% single-tree selection units. On Block 2 all trees to be harvested that were larger than 17.5 cm dbh were marked, while on Block 1 only trees to be harvested that were larger than 50 cm dbh were marked. Block 1 was also deliberately undermarked by 40 to 50%. In earlier partial cutting trials in similar stands in Naden Harbour, Husby found it was almost always necessary to fall several small-diameter trees to create openings for the large-diameter marked trees. Furthermore, the faller decided whether a large marked tree could be felled safely. If it could not, then the faller would choose an unmarked tree (of the same species, size and quality) to fall and decide where to place it. This in turn determined which small-diameter stems had to be removed. Undermarking allowed for removal of small-diameter trees and for the occasional removal of unmarked large trees for safety reasons or because of damage during falling of marked trees.

Appendix VI-a compares the number of trees per hectare, by species and diameter class, before and after harvesting. Table 14 and Appendix VI-b summarize pre- and post-harvest basal area by treatment unit for all species combined as well as for the two primary species (western hemlock and Sitka spruce). Harvest levels were below target in the two 50% patch cuts and also in the 25% patch cut on Block 2 owing to the deletion of several proposed harvest patches for safety and slope stability concerns. For every treatment unit, however, the proportion of total basal area removed was not significantly different (at $\propto = 0.05$) from the unit's prescribed removal level. When western hemlock or Sitka spruce were considered individually, the percentage differences from target removals were larger than for all species combined, but

[12] For the purposes of this report, "harvesting the stand profile" refers to the process of selecting the trees to be harvested such that the residual stand closely approximates the original stand in terms of stand quality and species distribution by diameter class.

Table 14. Comparison of basal area removals for 25% single-tree and 25% patch cut selection treatments

	Basal area (m^2)					
	Block 1 25% single-tree selection		Block 2 25% single tree selection		Block 1 25% patch cut	
Species	Pre-harvest	Post-harvest	Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
Western red cedar	5.14	4.81	0.57	0.57	5.17	4.38
Yellow cedar	5.01	3.76	0.00	0.00	1.48	1.48
Western hemlock	40.87	30.07	65.63	45.51	38.02	26.85
Sitka spruce	17.00	10.89	14.62	11.86	15.00	11.11
Total basal area	68.02	49.53	80.82	57.94	59.67	43.82
Removal level	-	27.2%	-	28.3%	-	26.6%

again they were not statistically significant. Furthermore, Appendix VI-a shows that the harvest, in total as well as by species, was well distributed across the full spectrum of diameter classes. Overall, therefore, both the patch cut and single-tree selection prescriptions, as well as the two marking regimes in the single-tree selection units, appeared to be equally effective at meeting the objective of harvesting a representative proportion of the original stand.

Patch cut design

Most of the patches were oriented with the long axis along the contour. The patch boundaries were mostly straight and smooth, so the patches were well suited for falling trees cross-slope. Also, most of the patches were long enough (70–80 m or about 1.5 tree-heights) to allow trees within the patch to be felled away from the edges and back towards the middle. This reduced brushing and damage of residual trees adjacent to the patches, and provided more favourable situations for limbing and bucking. It also reduced the risk of hangups during yarding because fewer logs had to be extracted from among standing trees. These features contributed to safe and efficient falling operations in the patch cut treatments.

While the size and orientation of these patches were generally favourable for falling, they did not always result in favourable conditions for helicopter yarding. On steep slopes, felled and bucked trees often rolled downhill and accumulated against the standing trees along the bottom edge of the patch (Figure 12). This caused the logs to become interlocked and resulted in difficult breakouts and frequent hangups. Also, the logs then had to be lifted vertically above the trees along the lower edge of the opening, which increased turn times. Leaving high stumps during falling may reduce the problem of logs rolling downhill. However, leaving high stumps is not a generally accepted falling practice and may conflict with required utilization standards regarding maximum stump heights, so the appropriate agencies should be consulted before using this option. Also, locating patch boundaries to take advantage of natural gaps in the stand along the low sides can reduce the need for vertical lifting, and thus reduce turn times.

Figure 12. Felled and bucked logs in a small patch cut in Block 1.

Fallers observed that some of the harvest patches in the patch cut treatments were too small for safe and efficient falling. In most cases, the length of these patches was too short in relation to the direction the trees had to be felled (usually across the slope). If the patch length was less than the height of the average tree in the patch, most of the trees had to be felled into the standing timber along the edges. The fallers were concerned about working near brushed trees and bucking became increasingly difficult as slash and debris accumulated during falling. Patch length was particularly important on steep slopes because the fallers usually had little choice about falling direction. Most fallers suggested that patches should be at least 1.5 tree heights long to provide reasonable falling conditions. The depth of the patch (perpendicular to the direction of falling) was of less concern.

Many patches contained substantial rock bluffs, gullies or other terrain features that prevented the fallers from developing good falling faces. Also, the patch boundaries usually did not take the lean of the trees into account. The fallers were usually able to overcome these difficulties, for example by using hydraulic jacks to overcome unfavourable leans and by falling trees into natural stand openings when patches weren't long enough to accommodate the full height of the trees. However, these features made falling and bucking more difficult, and often resulted in difficult yarding as well. In most cases, these shortcomings could have been easily addressed by fitting the patch boundaries to the local terrain and by ensuring the patches were long enough in relation to the average height of the surrounding stand.[13]

Conclusions

The trial demonstrated that helicopter logging using partial cutting systems is a technically and operationally feasible method for harvesting timber from steep, potentially unstable terrain. The helicopter operation harvested a total of 34 950 m^3 from the two study sites. The falling phase averaged 376 m^3/SWP, the helicopter yarding phase averaged 930 m^3/SWP, and the loading phase averaged 514 m^3/SWP. The total per-unit cost was estimated at \$82.23/m^3. Falling accounted for 13%, helicopter yarding for 78%, and loading for 9% of the total cost. The total cost per cubic metre and the cost distribution are similar to those reported for the same helicopter operating in clearcuts on southern Vancouver Island.

Compared to clearcutting, falling and yarding productivities showed minor to moderate decreases and harvesting costs showed corresponding increases as retention levels increased. Falling productivity was influenced by the steep, difficult terrain and the partial cutting treatments, and was 9–29% lower in the 25% patch cuts and 18–42% lower in the 25% single-tree selection cuts. Increases in hookup times and, to a lesser extent, in-flight delay times reduced yarding productivity by 5% in the 25% patch cuts and 12% in the 25% single-tree selection cuts. However, average turn weights were unaffected by harvesting treatment. Overall, yarding costs were 4–6% higher for the 25% patch cuts and 11–17% higher for the 25% single-tree selection cuts.

Yarding distances were short to favourable overall, while average slopes between the hookup site and the landing were generally steeper than optimum. As a result, the Skycrane's actual flight path did not usually follow a straight line from the hookup site to the landing. However, yarding distance expressed as the straight-line horizontal distance from the landing to the hookup site, as well as elevation change, were found to be significant variables affecting helicopter travel times. Therefore, horizontal distance is a useful approximation of yarding distance. The results also indicate that forest engineers should consider both yarding distance and elevation change when selecting landings for cutblocks laid out for helicopter logging.

Damage to residual trees in the partial cutting treatments was relatively minor and ranged from 5.3% in 25% patch cuts to 10.9% in 25% single-tree selections. Soil disturbance due to falling and yarding operations was negligible.

All of the partial cutting and tree-marking treatments were equally successful at harvesting the stand profile. For all partial cutting treatments and tree-marking systems, the proportion of total basal area removed was not significantly different from the treatment units' prescribed removal levels, and the harvest was well distributed across diameter class and across species.

Overall, for the terrain and stand conditions in this trial, patch cut systems were more efficient than single-tree selection systems from an operational perspective; however, both harvesting systems were applied successfully.

Implementation

At the time of this study, almost all heavy-lift helicopter logging operations used chokers and large rigging crews. In recent years helicopter logging contractors have switched partly or entirely to the helicopter grapple system for safety and economic reasons. Those still using chokers operate with smaller hill crews and are organized

[13] These shortcomings were recognized by the cooperators at the time of the study, but the experimental design requirements for other component studies took priority in determining patch layout and locations.

differently. Nevertheless, many of the trends and factors that affected falling and yarding in this study still apply to helicopter logging operations today. Forest engineers and planners can enhance the safety and efficiency of proposed helicopter logging operations by considering some of the following points in their harvest planning and layout:

- If partial cutting is required to address environmental or visual concerns, patch cuts are more efficient for falling and yarding than single-tree selection treatments. Patches should fit the terrain and should be at least 1.5 tree-heights in length. From an operational point of view, fewer larger patches are preferable to many small ones. However, operational preferences must be balanced against other management objectives, such as visual quality and wildlife requirements, which will often indicate smaller sizes. If possible, incorporate natural gaps and openings in the stand into patch layouts to provide exit points for the logging helicopter.
- If single-tree harvesting is necessary, helicopter grapple techniques can be used, provided a spotter is present on the ground to guide the pilot. Standing stem techniques would also be an option and tree selection could focus on maximizing payload for the helicopter. However, if harvesting must be to the profile of the stand, difficulties arise for both techniques. The grapple can be used to accumulate small-diameter stems to achieve a reasonable payload, but this would increase the terminal time and reduce productivity. With the standing stem technique, harvesting lower canopy trees would be very difficult, and in fact for small diameters, it may be impossible. As well, the largest trees in a stand may also present problems because they would likely be too heavy. A two-pass system using large and small helicopters may improve efficiency. However, with appropriate safety measures, a choker system may be the best option.
- When developing helicopter logging projects on steep and difficult terrain, involve the fallers and heli-logger in the planning and prescription development process. This will help to ensure the final harvesting prescription is feasible from the falling and heli-logging perspectives. In this study, for example, many of the falling difficulties encountered in the patch cuts and single-tree selection cuts could have been identified by involving the falling contractor, and addressed with minor changes to layout and prescriptions.
- Marking of trees was effective for the operation, and the objective of harvesting to the stand profile was achieved. Both strategies—marking all trees to be harvested, and marking only the trees larger than 50 cm and under-marking by 40–50 percent—were successful. Fallers must be clear on the latitude they have to vary from the marked trees, and on the rules for substitution.
- As this study demonstrates, yarding distance has a significant effect on yarding productivity and cost, so it is important to consider how yarding distance will affect overall production and how to ensure a balanced flow of wood over the duration of the operation. The average yarding distance was within the 600–800 m range that is generally considered to be ideal for the S-64E Skycrane. However, actual yarding distances ranged from about 100 to almost 1 600 m. Due to the design of the cutblocks, it was necessary to complete all of the long yarding first. As a result, when yarding distances became very short, it was difficult for the rigging and landing crews to keep up with the Skycrane's production, and on a few occasions the Skycrane had to shut down to allow the workers to get ahead. When estimating yarding productivity, consider the effects of stand composition and quality and utilization standards on weight-to-volume conversions and cull factors.

- In this study, all material meeting Close Utilization standards was yarded and the primary point for log manufacturing was the sortyard. The helicopter logging contractor was pleased with the quality of falling, limbing, and bucking on this project. However, the high conversion factor suggests that the cull factor was probably higher than average, suggesting that more fibre could have been left on site.
- Helicopter yarding productivity can only be increased—and yarding cost decreased—by either increasing the merchantable payload or decreasing the cycle time. Generally, once the cutblock boundaries and log landing sites are determined, there is little opportunity to affect the travel time components of the yarding cycle. Therefore, efforts to improve the efficiency of the yarding operation should focus on measures to reduce helicopter time at the hookup site and the landing. At the hookup site, layout personnel should try to incorporate natural gaps and openings in the stand into the lower edges of the harvest openings; this can help reduce the time the yarding helicopter must spend lifting turns vertically to clear the residual trees before beginning forward movement to the landing. At the landing, layout personnel should design the landings around the most favourable approach paths for the helicopter, taking local and daily wind patterns into account and allowing for alternate approach paths where possible. In this study, for example, the use of existing roads in old clearcuts as landings provided the yarding helicopter with unobstructed approaches to the landing area and always allowed the pilot to find a spot that was clear of log loaders and chasers to place the turn. As a further precaution on Block 2, several tall spruce trees in a 30- to 40-m-wide band below the road were identified as potential hazards and felled prior to the start of yarding. As a result of these factors, unhook times in this study were very fast and the yarding helicopter's productivity was not affected by activity or congestion at the landing area.
- Ensure the log landings are designed to accommodate the volume of wood that must be processed each shift. In this study, the wood was stockpiled in continuous windrows along existing roads so that yarding and loading operations could be separated. This added a hydraulic log loader to the yarding phase. However, it also eliminated interference between the yarding and loading phases and avoided incurring the cost of building large centralized landings. Average yarding distances were also reduced.

References

British Columbia Ministry of Forests (BCMOF); BC Environment. 1997. Forest practices code of British Columbia: Tree wounding and decay guidebook. Victoria, B.C. 19 pp.

D'Anjou, B. 2000. Alternative silvicultural systems on steep-sloped old-growth forests on the Queen Charlotte Islands–project overview and regeneration development: South Moresby forest replacement account research and demonstration, final report, Project 13.3–EP 862.34. B.C. Ministry of Forests Research Section, Vancouver Forest Region. 34 pp. Report accessed at www.for.gov.bc.ca/rco/research/silvReports/ep862_34_SMFRA.pdf.

Dunham. M.T. 2002. Helicopter logging in British Columbia: clearcut harvesting with the Sikorsky S-64E and S-64F Skycrane helicopters. FERIC, Vancouver, B.C. Advantage Report Vol. 3, No. 19. 20 pp.

Dykstra, D.P. 1976. Production rates and costs for yarding by cable, balloon, and helicopter compared for clearcuttings and partial cuttings. Forest Research Laboratory, Oregon State University, Corvallis, Ore. Research Bulletin 22. 44 pp.

Green, R.N.; Klinka, K. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. Research Branch, Ministry of Forests, Victoria, B.C. Land Management Handbook No. 28. 285 pp.

Guimier, D.Y.; Wellburn, G.V. 1984. Logging with heavy-lift airships. FERIC, Vancouver, B.C. Technical Report No. TR-58. 115 pp.

Helicopter Association International. 2002. 2002 Helicopter Annual. Alexandria, Va. Edition 20. 344 pp.

HeliValue$, Inc.; Helibooks Ltd. 1999. The official helicopter blue book and helicopter equipment lists & prices (HELP). Lincolnshire, Ill. Volume XXI, Edition I.

Krag, R.K. 1998. Productivities, costs, and site and stand impacts of helicopter-logging in clearcuts, patch cuts, and single-tree selection cuts: Rennell Sound trials. Pages 201–213 *in* Hogan, D.L., Tschaplinski, P.J.; Chatwin, S. (eds.). Carnation Creek and Queen Charlotte Islands fish/forestry workshop: applying 20 years of coast research to management solutions. B.C. Ministry of Forests, Research Branch, Victoria, Land Management Handbook No. 41.

Krag, R.K.; Clark, M. 1996. Helicopter logging in clearcut, patch-cut, and single-tree selection harvests: Queen Charlotte Islands, British Columbia. Pages 54–72 *in* Sessions, J. (ed.) Caring for the forest: research in a changing world: Proceedings of the technical sessions of subject group 3.06, forest operations under mountainous conditions. IUFRO XX World Congress, Tampere, Finland, 6–12 August 1995.

Krag, R.K.; Sauder, E.A.; Wellburn, G.V. 1986. A forest engineering analysis of landslides in logged areas on the Queen Charlotte Islands, British Columbia. Ministry of Forests and Lands, Victoria, B.C. Land Management Report No. 43 and FERIC Special Report SR-39. 138 pp.

Millard, T.; Chatwin, S. 2001. Using helicopter harvesting on steep slopes to reduce erosion, preliminary results: case study on Queen Charlotte Islands, British Columbia. B.C. Ministry of Forests, Vancouver Forest Region, Nanaimo, B.C. Extension Note EN-010. 8 pp.

Moore, K. 1991. Partial cutting and helicopter yarding on environmentally sensitive floodplains in old-growth hemlock/spruce forests. Forestry Canada and B.C. Ministry of Forests, Victoria, B.C. Canada–B.C. Forest Resource Development Agreement, FRDA Report No. 166. 43 pp.

Omule, S.A.Y.; Kozak, A. 1989. Stump and breast height diameter tables for British Columbia tree species. Forestry Canada and B.C. Ministry of Forests, Victoria, B.C. Canada–B.C. Forest Resource Development Agreement, FRDA Report No. 062. 67 pp.

Pendl, F.T.; D'Anjou, B.N. 1991. Alternative silvicultural systems for environmentally sensitive sites on steep slopes: operational trial. BCMOF Forest Sciences Section, Vancouver Forest Region, Nanaimo, B.C. Unpublished working plan for South Moresby Forest Replacement Account Project 13.3. 22 pp.

Pertile, A. 1996. Alternative systems for environmentally sensitive sites. Pages 102–107 *in* Addressing today's social and environmental issues, proceedings: A joint symposium of IUFRO 3.06 forest operations under mountainous conditions and the 9th Pacific Northwest skyline symposium, Campbell River, B.C., May 13–16, 1996. FERIC, Vancouver, B.C. FERIC Special Report SR-116.

Poulin, V.A. 1984. A research approach to solving fish/forestry interactions in relation to mass wasting on the Queen Charlotte Islands. Ministry of Forests, Victoria, B.C. Land Management Report No. 27. 16 pp.

Sauder, E.A.; Wellburn, G.V. 1987. Studies of yarding operations on sensitive terrain, Queen Charlotte Islands, B.C. Ministry of Forests and Lands, Victoria, B.C. Land Management Report No. 52 and FERIC Special Report SR-43. 45 pp.

Sauder, E.A.; Wellburn, G.V. 1989. Planning logging: two case studies on the Queen Charlotte Islands, B.C. Ministry of Forests, Victoria, B.C. Land Management Report No.59 (FERIC Special Report SR-57). 47 pp.

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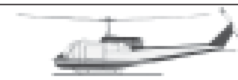
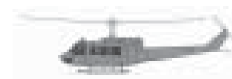
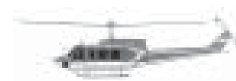
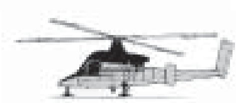
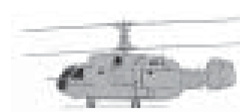
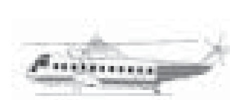
Appendix I

Specifications for helicopters commonly used for logging in B.C. [a]

Manufacturer	Model	Rated payload capacity (kg)	Engines (no.)	Engine power [b] (kW)	Diameter main rotor (m)	Diameter tail rotor (m)	Diagram
Bell	204B	1814	1	820	14.6	2.6	
Bell	205A	2268	1	1044	14.6	2.6	
Bell	212	2268	2	671 (each)	14.7	2.6	
Bell	214B	3636	1	2185	15.2	2.6	
Boeing	V-107 II	4773	2	932 (each)	15.5	n/a	
Boeing	CH-234LR	12727	2	3039 (each)	18.3	n/a	
Sikorsky [c]	**S-64E**	**9072**	**2**	**3356 (each)**	**22**	**5**	
Sikorsky [c]	S-64F	11340	2	3579 (each)	22	5	
Eurocopter	SA-315B Lama	1134	1	640	11.0	1.9	
Kaman	K-1200	2722	1	1342	14.7 (×2)	n/a	
Kamov	KA-32A	5000	2	1645 (each)	15.9 (×2)	n/a	
Sikorsky	S-58T	2268	2	700 (each)	17.1	2.9	
Sikorsky	S-61N	3629	2	1044 (each)	18.9	3.2	
Sikorsky	S-61N Shortski	4084	2	1044 (each)	18.9	3.2	

[a] Helicopter capabilities will vary with flight conditions and installed options.
[b] Engine power at takeoff.
[c] Now manufactured by Erickson Air-Crane Inc.

Appendix II

Helicopter costs [a] ($/flight-hour)

	Sikorsky S-64E Skycrane	Bell 206 B Jet Ranger
OWNERSHIP COSTS		
Total purchase price (P) $	19 800 000	475 000
Expected life (Y) y	10	10
Expected life (H) h	25 000	10 000
Scheduled hours/year (h)=(H/Y) h	2 500	1 000
Net flight-hours/year (fh) h	2 000	800
Salvage value as % of P (s) %	40	50
Interest rate (Int) %	9	9
Insurance rate (Ins) %	12	12
Salvage value (S)=((P•s)/100) $	7 920 000	237 500
Average investment (AVI)=((P+S)/2) $	13 860 000	356 250
Loss in resale value ((P-S)/(fh•Y)) $/flight-hour	594.00	29.69
Interest ((Int•AVI)/fh) $/flight-hour	623.70	40.08
Insurance ((Ins•AVI)/fh) $/flight-hour	831.60	53.44
Total ownership costs (OW) $/flight-hour	2 049.30	123.21
OPERATING COSTS		
No. of pilots required for the operation (pil)	5	1
Annual pilot base salary (PS) $/y	50 000	35 000
Annual flight hours/pilot (pilh) h/y	800	800
Flight-hour rate (pil$) $/h	125	35
Annual pilot flight pay (PF)=(pilh•pil$) $/y	100 000	28 000
Wage benefit loading (WB) %	45	40
No. of engineers (eng)	5	0
Engineer salary (ES) $/y	112 500	0
Fuel consumption (F) L/flight-hour	2 080	98
Fuel (fc) [b] $/L	0.85	0.85
Oil as % of fuel (fp) %	1.5	1.5
Annual parts inventory (Inv) = % of P	2.5	2.5
Wages for the operation, including fringe benefits		
Pilot (((PS•pil)+((pil$•pilh•pil))/fh)•(1+(WB/100))) $ /flight-hour	543.75	110.25
Engineer ((ES•(1+WB/100))•eng)/fh $/flight-hour	407.81	0.00
Total wages (W) $/flight-hour	951.56	110.25
Fuel (F•fc) $/flight-hour	1 768.00	83.30
Oil ((fp/100)•(F•fc)) $/flight-hour	26.52	1.25
Maintenance $/flight-hour	1 700.00	225.00
Parts inventory ((Inv/100)•(P/fh)) $/flight-hour	247.50	14.84
Helicopter registration fees $/flight-hour	1.61	2.38
Total operating costs (OP) $/flight-hour	4 695.19	437.02
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/flight-hour	6 744.49	560.23

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

[b] Includes cost of barging fuel to remote location.

Appendix III

Machine costs [a] ($/scheduled machine hour (SMH))

	Front-end log loader (20–25 tonne)	Hydraulic log loader (45–50 tonne)	Madill 075 cable log loader
OWNERSHIP COSTS			
Total purchase price (P) $	400 000	550 000	1 450 000
Expected life (Y) y	6	5	10
Expected life (H) h	12 000	10 000	16 200
Scheduled hours/year (h)=(H/Y) h	2 000	2 000	1 620
Salvage value as % of P (s) %	30	30	30
Interest rate (Int) %	9	9	9
Insurance rate (Ins) %	3	3	3
Salvage value (S)=((P•s)/100) $	120 000	165 000	435 000
Average investment (AVI)=((P+S)/2) $	260 000	357 500	942 500
Loss in resale value ((P-S)/H) $/h	23.33	38.50	62.65
Interest ((Int•AVI)/h) $/h	11.70	16.09	52.36
Insurance ((Ins•AVI)/h) $/h	3.90	5.36	17.45
Total ownership costs (OW) $/h	38.93	59.95	132.46
OPERATING COSTS			
Wire rope (wc) $	-	-	8 000
Wire rope life (wh) h	-	-	2 000
Fuel consumption (F) L/h	25	30	64
Fuel (fc) $/L	0.40	0.40	0.40
Lube & oil as % of fuel (fp) %	10	10	10
Annual tire consumption (t) no.	1.5	-	-
Tire replacement (tc) $	3 000	-	-
Annual repair & maintenance (Rp) $	45 000	65 000	100 000
Wire rope (wc/wh) $/h	-	-	4.00
Fuel (F•fc) $/h	10.00	12.00	25.60
Lube & oil ((fp/100)•(F•fc)) $/h	1.00	1.20	2.56
Tires ((t•tc)/h) $/h	2.25	-	-
Repair & maintenance (Rp/h) $/h	22.50	32.50	61.73
Total operating costs (OP) $/SMH	35.75	45.70	93.89
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH	74.68	105.65	226.35

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

Appendix IV

Weight-to-volume conversion factors used by helicopter logging contractors in coastal B.C.

Species	Range	Average
Western hemlock	2 000–2 200 lb./m^3 (910–1 000) kg/m^3)	2 100 lb./m^3 (950 kg/m^3)
Western red cedar	1 450–1 550 lb./m^3 (660–700 kg/m^3)	1 500 lb./m^3 (680 kg/m^3)
Douglas-fir	1 750–2 000 lb./m^3 (790–910 kg/m^3)	1 900 lb./m^3 (860 kg/m^3)
Amabilis/grand fir	1 750–1 850 lb./m^3 (790–840 kg/m^3)	1 800 lb./m^3 (820 kg/m^3)
Sitka spruce	1 600–1 700 lb./m^3 (730–770 kg/m^3)	1 650 lb./m^3 (750 kg/m^3)
Yellow cedar	1 700–1 800 lb./m^3 (770–820 kg/m^3)	1 750 lb./m^3 (790 kg/m^3)

Appendix V

Regression and productivity equations

1. Linear regression equations for Travel Empty and Travel Loaded

$TE, TL = a + (b \times HD) + (c \times DE)$ [n, R^2]

where

TE, TL	=	Travel Empty and Travel Loaded times, respectively (minutes)
a	=	y-axis intercept
b, c	=	regression coefficients
HD	=	horizontal distance between log landing and hookup site (100 to 1 500 m)
DE	=	difference in elevation between log landing and hookup site (0 to 450 m)
n	=	number of turns used in regression analysis
R^2	=	coefficient of multiple determination

Travel Empty: $TE = 0.21486 + (0.00024 \times HD) + (0.00037 \times DE)$ [Equation 1]

n = 4 509 turns R^2 = 52%

Travel Loaded: $TL = 0.40324 + (0.00012 \times HD) + (0.00084 \times DE)$ [Equation 2]

n = 4 509 turns R^2 = 46%

2. Predicted total turn time by treatment unit

$TT_{xx} = TE + Hookup + TL + Delays$ [Equation 3]

where

TT_{xx}	=	predicted total turn time by treatment unit (minutes) for a given horizontal distance (HD) and difference in elevation (DE)
TE, TL	=	Travel Empty, Travel Loaded times from Equations 1 and 2, respectively
Hookup	=	average hookup time per turn by treatment unit (from Table 9)
Delays	=	average in-flight delay time per turn by treatment unit (0.13 min for clearcut, 0.16 min for patch cut, and 0.19 min for single-tree selection)

For example, for HD = 700 m and DE = 210 m:

Clearcut/50% patch cut: $TT_{cc} = (0.46 + 1.04 + 0.66 + 0.13) = 2.29$ min/turn

Patch cut (25%): $TT_{pc} = (0.46 + 1.16 + 0.66 + 0.16) = 2.44$ min/turn

Single-tree selection (25%): $TT_{sts} = (0.46 + 1.27 + 0.66 + 0.19) = 2.58$ min/turn

3. Productivity by treatment unit

$$\text{Productivity}_{xx} = (60 \times \text{GTW}_{xx})/(\text{TT}_{xx}) \qquad \text{[Equation 4]}$$

where

Productivity_{xx}	=	predicted productivity by treatment unit (in lb./flight-hour) for a given horizontal distance HD and difference in elevation DE
GTW_{xx}	=	average gross turn weight (lb.) by treatment unit (from Table 10)
TT_{xx}	=	predicted average turn time (min) by treatment unit (from Equation 3)

For example, for HD = 700 m and DE = 210 m:

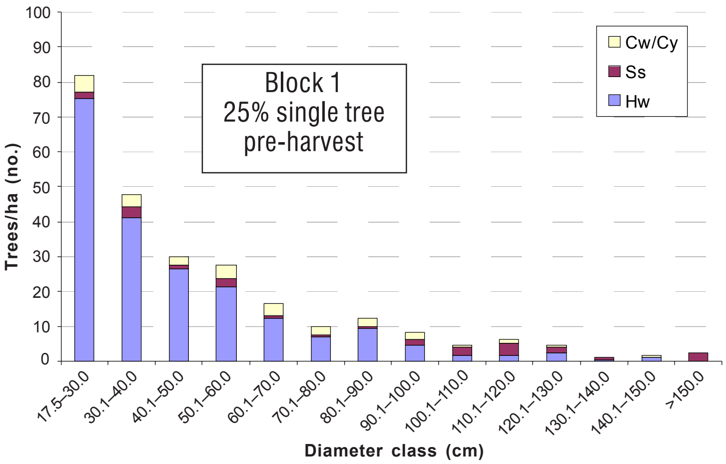
Clearcut/50% patch cut: Productivity_{cc} = (60 min/h × 14 680 lb.)/2.29 min
= approx. 385 000 lb./flight-hour

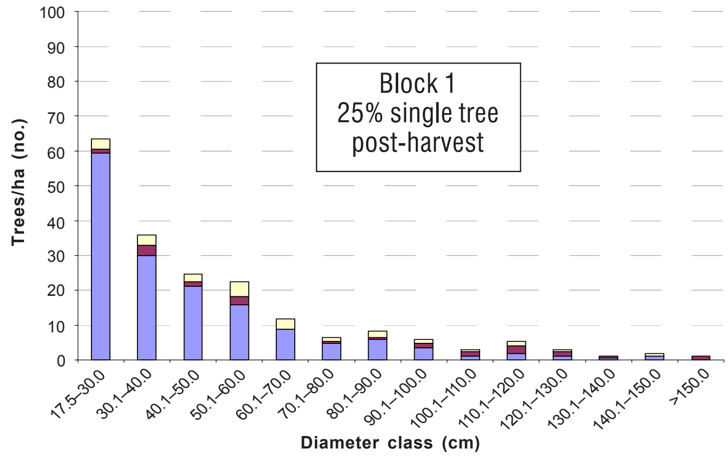
Patch cut (25%): Productivity_{pc} = (60 min/h × 14 930 lb.)/2.44 min
= approx. 367 000 lb./flight-hour

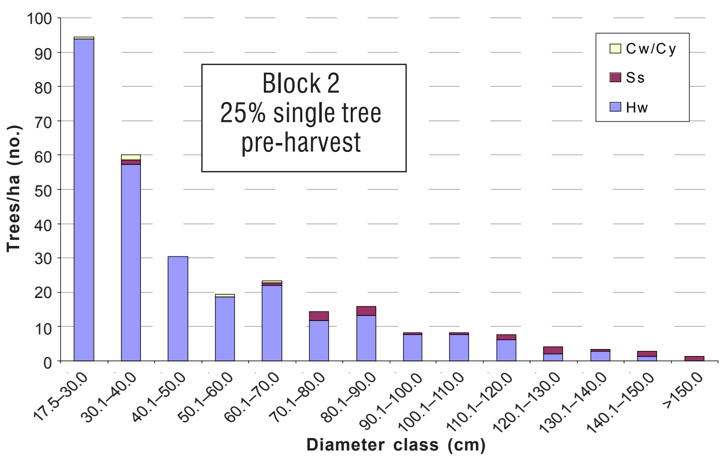
Single-tree selection (25%): Productivity_{st} = (60 min/h × 14 510 lb.)/2.58 min
= approx. 337 000 lb./flight-hour

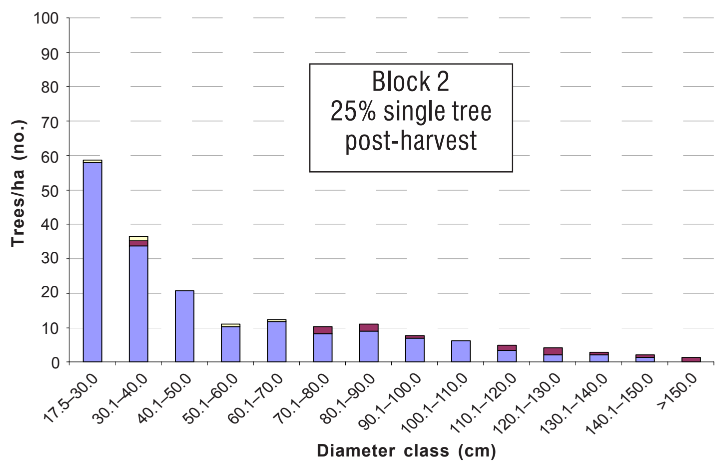
Appendix VI-a

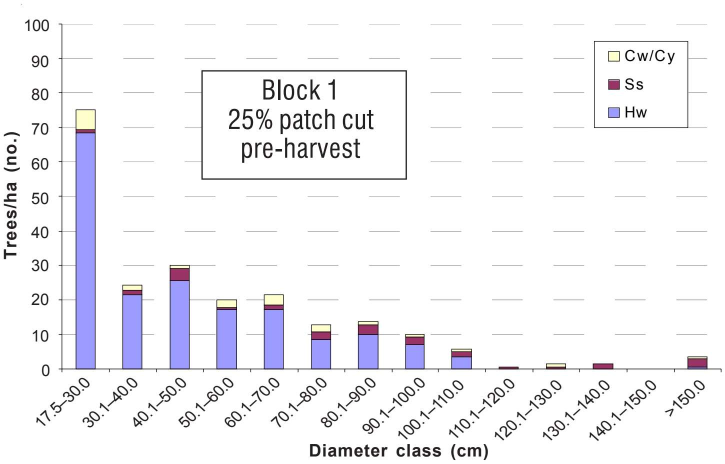
Number of stems per hectare by diameter class and species: pre- and post-harvest

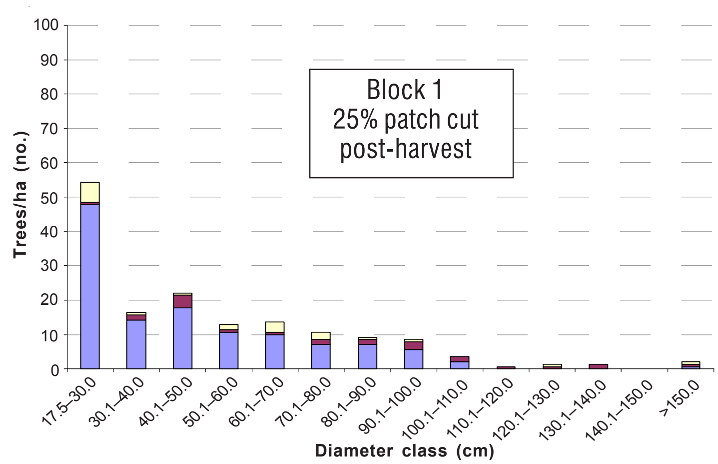


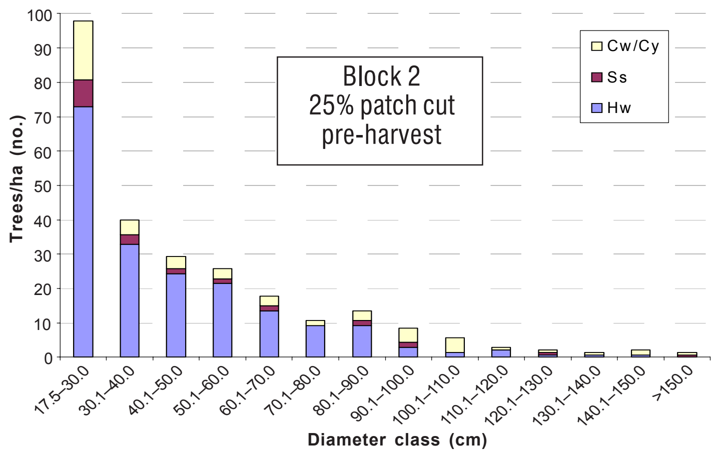


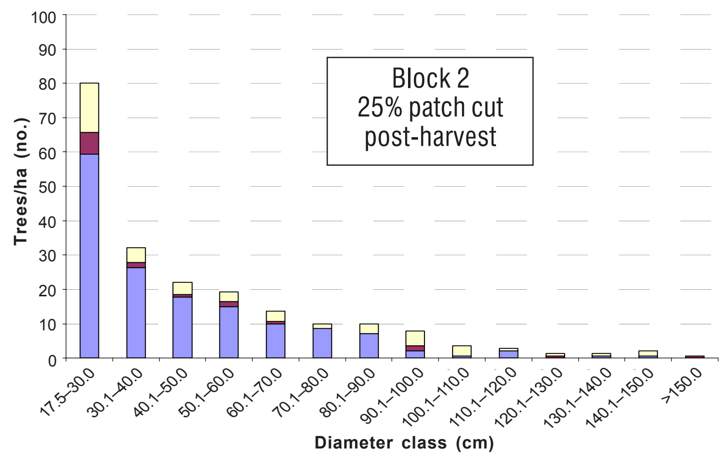


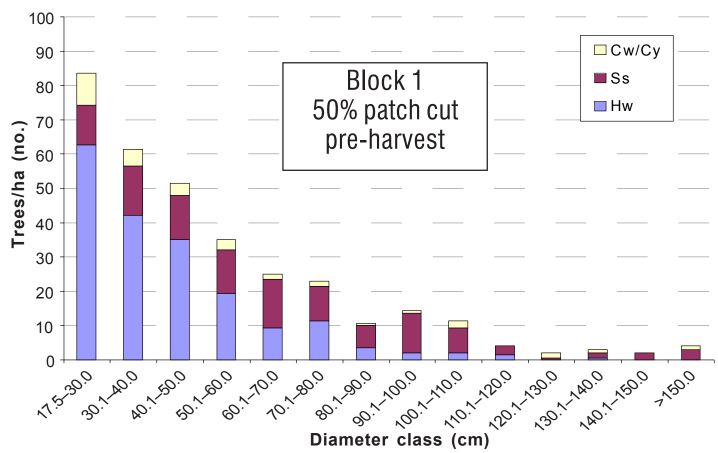


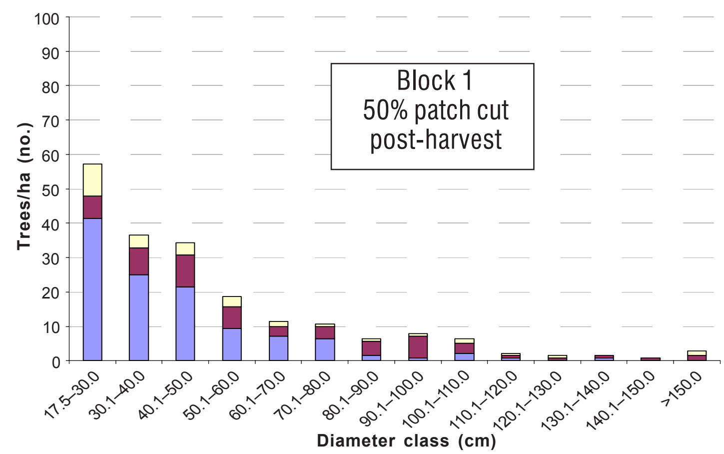


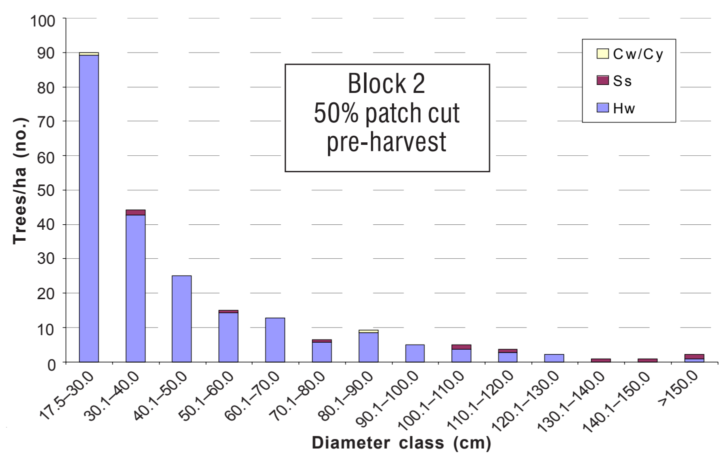


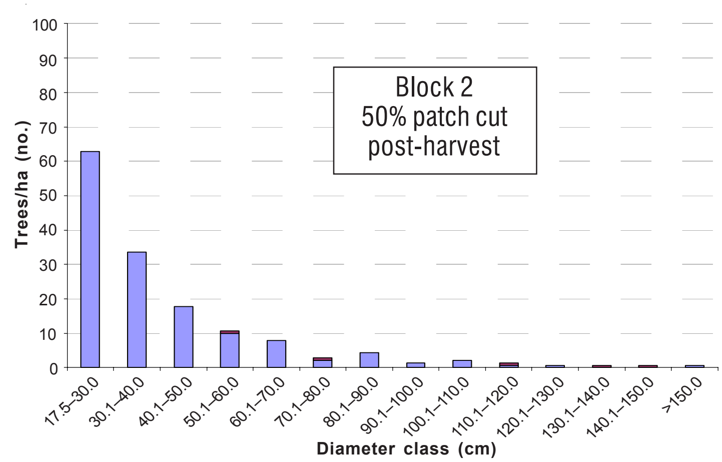

Block 2
25% patch cut
pre-harvest
Cw/Cy
Ss
Hw
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)

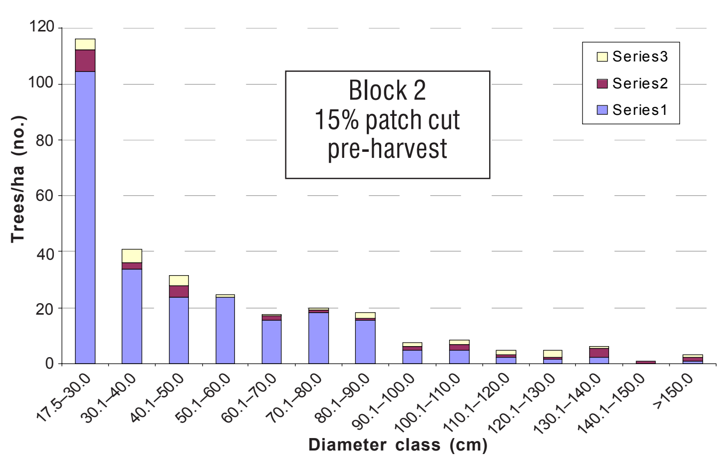

Block 2
25% patch cut
post-harvest
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)

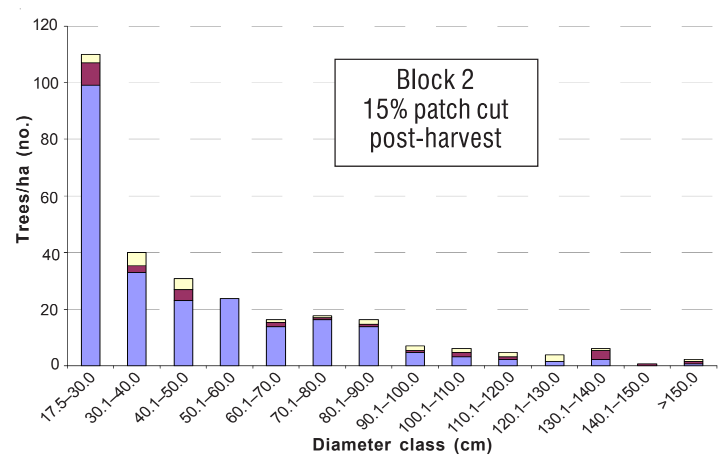

Block 1
50% patch cut
pre-harvest
Cw/Cy
Ss
Hw
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)


Block 1
50% patch cut
post-harvest
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)


Block 2
50% patch cut
pre-harvest
Cw/Cy
Ss
Hw
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)


Block 2
50% patch cut
post-harvest
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)


Block 2
15% patch cut
pre-harvest
Series3
Series2
Series1
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)


Block 2
15% patch cut
post-harvest
Trees/ha (no.)
17.5–30.0 30.1–40.0 40.1–50.0 50.1–60.0 60.1–70.0 70.1–80.0 80.1–90.0 90.1–100.0 100.1–110.0 110.1–120.0 120.1–130.0 130.1–140.0 140.1–150.0 >150.0
Diameter class (cm)

Appendix VI-b: Summary of total and harvested basal areas by treatment and species

	Block 1 - Hangover Creek			Block 2 - Gregory Creek			
	50% patch cut	25% patch cut	25% single-tree selection	50% patch cut	25% patch cut	25% single-tree selection	15% single-tree selection
Area summary							
Total area (ha)	10.36	9.11	9.30	7.09	10.96	10.59	8.32
Area harvested (ha)	3.94	2.90	n/a	2.76	1.55	n/a	n/a
Proportion harvested (%)	38.0	31.8	n/a	38.9	14.1	n/a	n/a
Basal area summary							
All species							
Total basal area (m^2)	89.49	59.62	68.01	71.40	76.3	80.83	84.02
Basal area harvested (m^2)	38.81	15.85	18.48	32.72	15.45	22.88	8.58
Proportion harvested (%)	43.4	26.6	27.2	45.8	20.2	28.3	10.2
Standard error (%)	7.4	5.6	3.2	10.4	8.0	3.1	3.2
95% confidence interval	28.2–58.5	15.0–88.1	20.6–33.8	24.0–67.6	3.6–36.9	21.9–34.7	3.6–15.8
Significance [a]	NS	NS	NS	NS	NS	NS	NS
Western hemlock							
Total basal area (m^2)	30.90	38.02	40.87	59.39	46.11	65.63	55.27
Basal area harvested (m^2)	11.98	11.17	10.8	25.74	10.45	20.12	4.15
Proportion harvested (%)	38.8	29.4	26.4	43.3	22.7	30.7	7.5
Standard error (%)	7.9	5.9	3.9	10.0	7.5	3.2	2.8
95% confidence interval	22.6–54.9	17.3–41.4	18.5–34.3	22.3–64.4	7.1–38.2	24.2–37.1	1.7–13.3
Significance [a]	NS	NS	NS	NS	NS	NS	NS
Sitka spruce							
Total basal area (m^2)	46.59	15.00	17.00	11.40	7.62	14.62	16.24
Basal area harvested (m^2)	24.93	3.89	6.11	6.37	1.70	2.76	3.77
Proportion harvested (%)	53.5	25.9	35.9	55.9	22.3	18.9	23.2
Standard error (%)	8.5	11.20	7.3	21.5	11.9	8.6	11.2
95% confidence interval	36.1–71.0	1.7–50.3	20.4–51.5	3.2–>100.0	<0.0–48.5	0.0–37.8	<0.0–47.1
Significance [a]	NS	NS	NS	NS	NS	NS	NS

[a] NS = ‘Proportion harvested’ is not significantly different from treatment removal target (25% or 50%) ($\alpha = 0.05$).