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Vol. 3 No. 19 May 2002

Contents

Helicopter logging in British Columbia: clearcut harvesting with the Sikorsky S-64E and S-64F Skycrane helicopters

Abstract

The Forest Engineering Research Institute of Canada (FERIC) studied a heavy-lift helicopter logging operation performed in coastal British Columbia. Sikorsky S-64E and S-64F Skycranes were used to harvest small clearcuts on steep mountain slopes that could not be easily developed for conventional cable yarding. The report presents harvesting productivity and cost, and describes factors affecting the operation.

Keywords

Helicopter logging, Sikorsky S-64E Skycrane, Sikorsky S-64F Skycrane, Aerial logging, Coastal British Columbia, Clearcut, Productivity, Costs.

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Introduction

Helicopter logging was first introduced into coastal British Columbia in the early 1970s, and by the late 1970s several firms were providing services to the coastal forest industry. Early trials demonstrated that helicopter logging was technically feasible but very expensive, and initially it was used only for harvesting high-value timber on sites that could not be harvested by conventional means. By the mid 1980s however, helicopter logging began to increase on the B.C. coast in response to increasing environmental and fibre-supply pressures. The introduction of the B.C. Forest Practices Code in 1995, coupled with favourable market conditions, triggered dramatic growth and innovation in helicopter logging in all regions of the province during the 1990s.

Today, many B.C. forest companies routinely include helicopter logging in their annual harvest plans, especially for harvesting environmentally sensitive and inaccessible sites. One unofficial estimate suggests helicopter logging now accounts for between 5 and 7% (3.5–4 million m^3) of the annual provincial harvest, and this could increase to as much as 15% in the future.

Used both as a stand-alone system and as a complement to conventional harvesting operations, helicopter logging is effective in a variety of silvicultural prescriptions, from clearcuts to partial cuts and single-stem selection cuts. Its advantages, compared to conventional cable yarding systems, include expanding the operable forest-land base; eliminating roads and reducing harvesting disturbance on environmentally sensitive sites; providing planners with greater flexibility in designing and harvesting cutblocks to address non-timber management objectives (e.g., visual quality); reducing the time required to respond to short-term market opportunities, and to develop and harvest difficult or remote sites that are inaccessible to conventional harvesting systems; improving recovery of high-value specialty products such as poles from areas scheduled for conventional harvesting; and allowing rapid salvage of timber damaged by windthrow, fire, and insects.

Forest engineers and planners recognize that helicopter logging is a highly specialized system with its own unique requirements for safe, cost-effective harvesting operations. However, information about the capabilities and performances of different helicopters in typical B.C. harvesting situations is scarce, as is information about site, stand, organizational, and operational factors that influence helicopter logging productivity and cost. To fill this need, FERIC has established an ongoing project to study helicopter logging operations in B.C.

This report presents the results of a study of a heavy-lift helicopter logging operation performed on southern Vancouver Island. Sikorsky S-64E and S-64F Skycranes were used to harvest small clearcuts on steep mountain slopes that could not be easily developed for conventional cable yarding. FERIC, TimberWest Forest Corp., and Canadian Air-Crane Limited cooperated in this case study.

Objectives

The goal of FERIC's project is to provide forest engineers with factual information on the capabilities, productivities, and costs of helicopters currently used for logging in British Columbia through an ongoing series of short-term case studies. The objectives of this case study were to:

- Describe the harvesting operation.
- Determine productivities and costs for the falling, yarding and loading phases.
- Compare productivities and costs of yarding with the Sikorsky S-64E and S-64F Skycranes.
- Identify features of the site, stand, harvest plan, and harvest system organization that may influence harvesting productivity and cost.

Site and stand descriptions

The study site consisted of two cutblocks on private land approximately 40 km southwest of Mesachie Lake in the Duncan Forest District, southern Vancouver Island (Table 1 and Figure 1). The two cutblocks were approximately 1 000 m apart on the same side of a predominantly south-facing slope. Elevations ranged between 500 m and 1 000 m above sea level. The terrain was steep and broken with slopes between 45 and 85%, and soils were generally shallow silt loams over bedrock. The site was in the moist mesic subzone of the Coastal Western Hemlock (CWHmm) biogeoclimatic zone (Green and Klinka 1994). Forest cover consisted of Douglas-fir (*Pseudotsuga menziesii*) with secondary components of western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*), and minor amounts of amabilis fir (*Abies amabilis*) and yellow cedar (*Chamaecyparis nootkatensis*). Merchantable volumes averaged 815 and 1 083 m^3/ha for the two cutblocks.

Harvesting prescription and plan

Harvesting with heavy-lift helicopters was prescribed for this area because conventional road construction and cable yarding were not feasible due to the scattered distribution of the merchantable stands, the steep unstable slopes, and broken rocky terrain. The large tree sizes, high log values, and the need to minimize damage to residual trees in leave areas and along gullies also favoured heavy-lift helicopters. Because the harvesting operation was on private land and therefore not subject to statutory utilization standards, TimberWest stipulated that low-quality logs

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ISSN 1493-3381

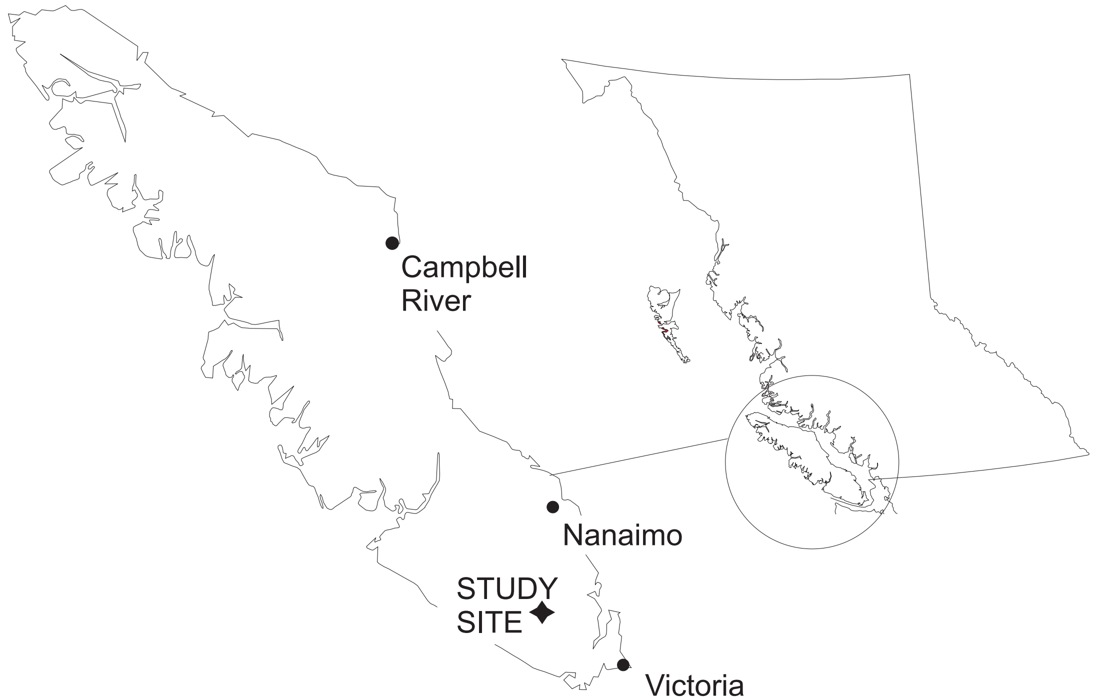

Figure 1. Location of study site.

Table 1. Site and stand descriptions

	Cutblock 1	Cutblock 2
Cutblock area (ha)	23.0	7.9
Site characteristics		
Terrain description	broken, rolling, rocky knobs	broken, rocky knobs
Slope - average (%)	65	80
Soil characteristics		
Texture	silt loam	silt loam
Depth (cm)	>35, variable	35, variable
Mass wasting hazard	high	high
Stand characteristics		
Species composition (%)		
Douglas-fir	55	60
western hemlock	22	26
western red cedar	11	14
amabilis fir	8	0
yellow cedar	4	0
Gross volume (m^3/ha)	815	1 083
Forest health concerns	none	minor incidence of dwarf mistletoe

were to be left on site.[1] Harvesting operations were scheduled for mid to late summer to take advantage of stable summer weather and long daylight hours. The study site was cruised and engineered by TimberWest and bids were solicited for the harvesting units,

[1] This practice is generally not permitted on provincially owned lands. More recent requirements for coarse woody debris to meet biodiversity goals have permitted the leaving of fibre on some sites.

stipulating the need for a heavy-lift helicopter to carry out yarding. Canadian Air-Crane was the successful bidder and proposed using the Sikorsky S-64 Skycrane.

The study area consisted of two harvesting units with irregularly shaped openings containing an estimated 25 000 m^3 of merchantable timber (Figure 2). Cutblock 1, 23.0 ha in total, consisted of four small clearcuts ranging from 1.1 to 16.8 ha. Cutblock 2 was 7.9 ha in total, made up of two small clearcuts of 1.3 and 6.6 ha. Two landings, or drop zones, were prepared on spur roads on gentler terrain below the study units. Landing 1 served only Cutblock 1; it was located 1 050 m slope distance from the center of Cutblock 1, at an average slope of 48%. Landing 2, about 3 km east-southeast of Landing 1, served both cutblocks; it was 1 140 m at 40% slope from the center of Cutblock 1, and 900 m slope distance at 44% from the center of Cutblock 2. Landing 2 included a main landing (A) and an overflow landing (B). A service landing used for helicopter refuelling and maintenance was situated about 2 km from the cutblocks.

Helicopter specifications

The Sikorsky S-64 Skycrane is a twin-turbine, heavy-lift helicopter, or "flying crane," designed for transporting large external loads. The Skycrane is available in two models, the S-64E and the S-64F, which are, respectively, the commercial versions of the CH-54A and CH-54B Tarhe military helicopters originally designed and manufactured in the 1960s by Sikorsky Aircraft Corporation for the U.S. Army. The S-64E Skycrane was first certified for commercial use in the United States in the late 1960s, and several units were manufactured between 1968 and 1970. The S-64F was certified in the early 1970s but no commercial units were built. No new units of either model have been built since the 1970s, so currently operating S-64E and F Skycranes are either original civilian S-64E units that have been remanufactured, or surplus military CH-54A and B helicopters that have been sufficiently upgraded to be certified for commercial use.

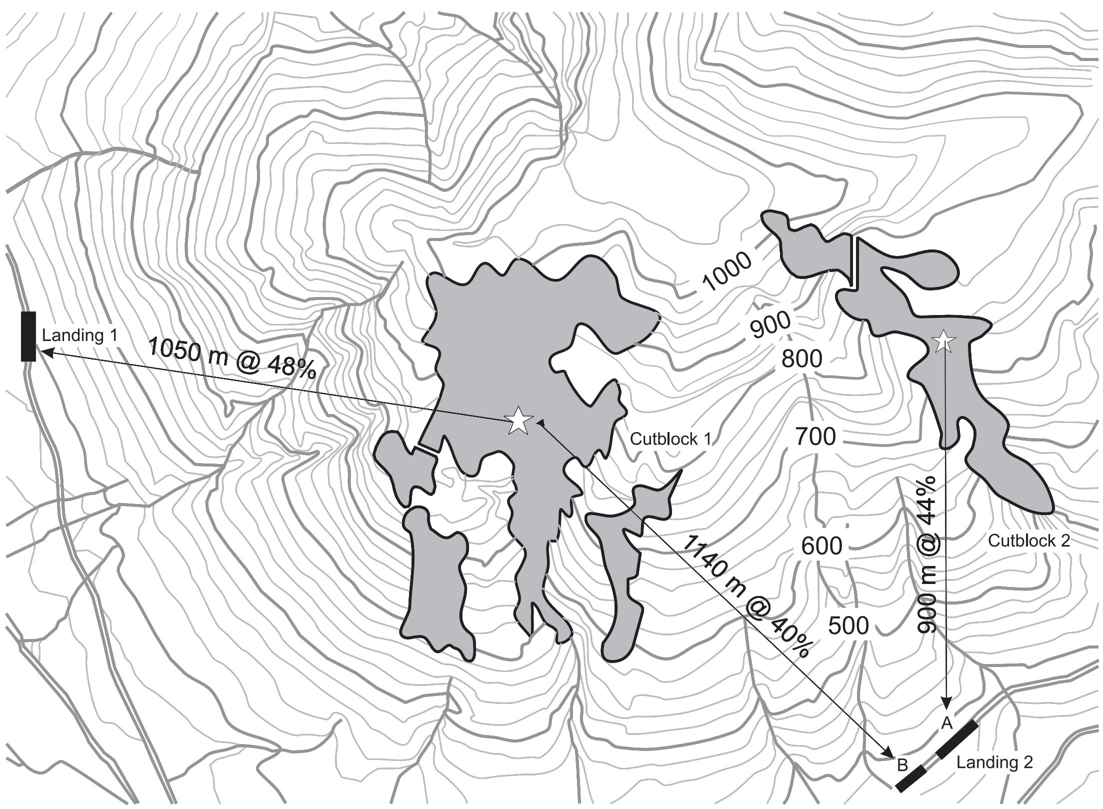

Figure 2. Harvest plan map.

In 1992, Erickson Air-Crane Inc. of Central Point, Oregon acquired the type certificate to the E and F Skycranes. Since 1993 the company has remanufactured nine S-64E and eight S-64F Skycranes (Helicopter Association International 2001). At present approximately twenty S-64E and eight S-64F Skycranes are certified for commercial use worldwide (Helicopter Association International 2001).

Table 2. Specifications for the Sikorsky S-64E and S-64F Skycrane Helicopters [a]

	Sikorsky S-64E	Sikorsky S-64F
Maximum permitted static load [b] (kg)	9 072	11 340
Engines (no.)	2	2
Engine power at takeoff (kW) (each)	3 356	3 579
Dimensions of main rotor (m)	22	22
Dimensions of tail rotor (m)	5	5
Service ceiling (m)	2 475	2 475
Standard fuel capacity (l)	5 116	5 116

[a] Source: Jane's Pocket Book of Helicopters.
[b] From Transport Canada type certificates for the Sikorsky (Erickson Air-Crane) S-64E and F helicopters.

Table 2 lists specifications for the E and F models, and Figure 3 shows the S-64E model. With rated payloads of 9 072 and 11 340 kg respectively, the S-64E and S-64F Skycranes are two of the largest helicopters routinely used for logging in British Columbia (Appendix I). Compared to the S-64E, the S-64F achieves its larger payload through the use of larger engines, modifications to the gearbox and rotor system, and general structural strengthening.

Figure 3. Sikorsky S-64E Skycrane.

Study methods

A FERIC researcher was on-site for most of the harvesting operation and collected shift-level information from TimberWest and Canadian Air-Crane for the falling, yarding, and loading phases. Shift-level data included shift production reports, data summaries for the helicopter cycles, and daily operating reports. During yarding, FERIC frequently discussed the progress of the harvesting operation with TimberWest and Canadian Air-Crane personnel to identify site, stand, layout, and organizational factors that influenced the helicopter's productivity.

Harvesting productivities were calculated from shift-level time and volume data provided by the cooperators, and harvesting costs for the helicopter system were estimated using several sources. Costs for the Sikorsky S-64 Skycranes and the support helicopter were estimated using a modified version of the costing methodology in Guimier and Wellburn (1984), plus information from The Official Helicopter Blue Book (HeliValue$ Inc. and Helibooks Ltd.1999) (Appendix II). Hourly costs for the other machinery 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 using 2000 rates. FERIC's cost estimates do not include stumpage or profit. It is stressed that the costs presented in this report are FERIC's estimates only and are not the actual costs incurred by either the licensee or the helicopter contractor.

Results and discussion

Description of the operation

TimberWest used its own crews and equipment for falling, processing logs at the landing, and loading trucks. The company also assigned two scalers to supervise log quality during yarding, and supplied a water truck and two operators for dust control at the landings. At the time of the study, TimberWest's crews had only limited experience with helicopter logging.

Falling was completed on both cutblocks before yarding began. Fallers were ferried to and from the felling sites daily by helicopter (a Bell 206B Jet Ranger). As falling progressed, the fallers built helipads throughout the cutblocks for their own use as well as for the rigging crews. Trees were felled cross-slope but no tree-jacking was done. In areas of extremely steep terrain, fallers intentionally left high stumps (i.e., >30 cm) to hold logs on the sidehill and prevent them from rolling downhill.

Bucking specifications were geared to the S-64E Skycrane. Generally, large logs were bucked to preferred lengths to meet helicopter payload restrictions, while smaller logs were left tree-length. Felled trees were limbed on three sides, and shape defects and broken ends were trimmed to reduce the amount of unmerchantable wood yarded to the landings.

Canadian Air-Crane's crews and equipment were used for the yarding phase, and were scheduled to work a 12-hour shift based on the daylight available at that time of year. Originally only an S-64E Skycrane was scheduled for this operation, but it was replaced for a short period by an S-64F Skycrane due to mechanical problems with the S-64E. Both helicopters used a 60-m longline for the yarding phase. The S-64E used a 545-kg helicopter grapple for the first production shift, before the rigging crews arrived, but the two helicopters used a 360-kg double hook for the rest of the yarding phase.

The yarding phase employed separate crews for the flight, helicopter maintenance, rigging, and landing tasks, plus one on-site woods foreman, for a total of 24 to 27 members (Table 3). The flight crew consisted of the Skycrane pilot and copilot and the support helicopter pilot; the maintenance crew consisted of three engineers for the S-64E and four for the S-64F. Eleven members were in the rigging crew, and the landing crew consisted of six to eight members (Figure 4). The flight, rigging, and landing crews did not vary in number with helicopter model.

The rigging crew was divided into five teams. Three two-person teams and one three-person team worked in Cutblock 1, and one two-person team worked in Cutblock 2. Teams were evenly spaced across the cutblocks to ensure crew members did not work beneath the Skycrane's flight path. The two cutblocks were yarded concurrently, starting at the top and working progressively downhill.

The Skycrane yarded about 20 turns[2] per 50- to 60-minute yarding cycle.[3] At the start of each cycle, it returned one load of chokers from the landing to a pre-arranged drop-off point in Cutblock 1. The support helicopter then delivered the chokers to the rigging crews in both cutblocks. The S-64 usually followed a fixed rotation, visiting each team twice per yarding cycle and yarding 2 or 3 turns consecutively from one rigging team before moving to the next team and repeating the process. At the end of each cycle, the Skycrane returned to the service landing for about ten minutes, the pilot and copilot changed positions, and a "hot" refuelling was performed. At the landings the chasers removed the chokers from the logs as soon as the Skycrane released the turn, and the front-end loaders then cleared the logs from the drop zone and placed them in decks for subsequent handling by TimberWest crews.

The helicopter engineers had an on-site service trailer, two standard highway fuel tanks, an aircraft refuelling system and a standard highway truck to assist with routine on-site maintenance and refuelling of the Skycranes. The maintenance time for the Skycrane depended upon the number of

2 A yarding turn is defined as the sequence of activities required to transport one load of logs from the stump to the landing. A turn consists of the following elements: flying from the landing to the hook-up site (fly empty); securing the load of logs (hook-up); flying from the hook-up site to the landing with the load of logs (flying loaded); and placing and releasing the logs on the landing (unhook).

3 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 3. Crew complement for the yarding phase using both Landings 1 and 2, or Landing 2 only

Cutblock or landing (no.)	Crew description	Crew position	Landings 1 and 2 crew members (no.)	Landing 2 only crew members (no.)
	Flight crew	Skycrane pilot	1	1
		Skycrane copilot	1	1
		Bell 206 pilot	1	1
Cutblock 1	Rigging crew	hooktender	4	4
		second hooktender	4	4
		chokersetter	1	1
Cutblock 2	Rigging crew	hooktender	1	1
		second hooktender	1	1
Landing 1	Landing crew	chaser	2	n.a.
		wheeled loader operator	1	
		landing bucker	1	
Landing 2	Landing crew	chaser	2	4
		wheeled loader operator	1	1
		landing bucker	1	1
Service landing	Maintenance crew	flight engineer	3 or 4	3
	Supervision	woods foreman	1	1
	Canandian Air-Crane crew		26 or 27	24
	Other	hydraulic loader operator	2	1
		scaler	2	1
		water truck operator	2	2
	TimberWest crew		6	4
	Total crew		32 or 33	28

flight hours flown each shift. Usually two engineers performed 4–6 hours of pre- and post-flight maintenance each shift, and two engineers were on-site during the yarding operation to perform refuelling and maintenance checks. Following every third yarding cycle, the Skycrane was shut down and the maintenance crew performed a mandatory mechanical inspection, which took 30–60 minutes. Engineers rotated their work schedules between pre-yarding, yarding, and post-yarding shifts.

The yarding phase was supported by a Bell 206B Jet Ranger II helicopter, whose primary tasks were ferrying rigging crews to and from their work sites and distributing chokers from the drop-off point in Cutblock 1

Figure 4. Rigging crew hooking up a turn in Cutblock 1.

to the rigging crews during the latter half of each yarding cycle (Figure 5). Typically, the support helicopter began flying rigging crews to their work sites about one-half to one hour before the Skycrane lifted off, to allow the crews to pre-set their turns for the first yarding cycle.

Figure 5. Bell 206B Jet Ranger II support helicopter.

The loading phase was performed by TimberWest crews and equipment on a scheduled 12-hour shift (actual shift lengths varied from 8 to 15 hours). The hydraulic loaders spread the decked logs for processing by the landing buckers and loaded the manufactured logs onto the trucks for hauling to TimberWest's sortyard. Both landings were active initially, but as yarding progressed downhill, the slope of the flight path into Landing 1 became progressively steeper. After Day 6 only Landing 2 was used because it had a gentler approach slope (Figure 6).

Figure 6. Front-end loader working at Landing 2.

Harvesting productivity and cost

A total net volume of 22 650 m^3 was harvested from the two cutblocks. Table 4 summarizes shift-level productivities for the falling, yarding, and loading phases. Detailed results for the two helicopters are presented in the section, Performance of the S-64E and S-64F Skycranes.

Falling

Falling operations began in April and continued steadily until the sites were completed in July. In 55 scheduled falling days during this period, a crew of 1 to 7 fallers worked a total of 245 faller-shifts to fall timber and build heli-pads, and the Bell 206B Jet Ranger helicopter recorded 59 flight-hours of support. Four faller-shifts are included to remove snags in stands adjacent to the openings. In addition, 12 scheduled falling days were cancelled during the April-July period because fog and low cloud prevented the support helicopter from ferrying the fallers to the cutblocks. Because the decision to cancel a scheduled falling shift was made before the support helicopter was requested, no helicopter cost was incurred for the cancelled shifts.

Based on the net volume, each faller produced an average of 94 m^3/6.5-hour production shift. Falling productivity was reduced because the steep and broken terrain made cross-slope directional falling and bucking difficult, and thorough in-woods bucking and delimbing were emphasized.[4] Actual falling productivity was higher than the 94 m^3/faller-shift calculated from the final scaled volume because low-quality timber had to be felled even though it was not yarded. TimberWest conservatively estimated that each faller averaged about 100 m^3/shift when the low-quality volume was included.[5] Overall, Canadian Air-Crane's yarding crews were pleased with the quality of falling and bucking on the study sites.

The practice of leaving high stumps to prevent the logs from rolling worked well on this site. However, it is not an accepted falling practice and requires B.C. Ministry of Forests approval on provincially owned lands.

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4 Stringent log processing is emphasized in helicopter logging operations to minimize the amount of unmerchantable wood yarded by the helicopter.

5 Rick Jaccard, TimberWest Forest Corp., personal communciation, December 1999.

Table 4. Shift-level productivities for the falling, yarding, and loading phases

	Cutblocks 1 and 2
Falling	
Scheduled shifts worked (no.)	55
Non-productive shifts (no.)	12
Average fallers per shift (no.)	4.5
Total faller shifts worked (no.)	245
Production falling shifts (no.)	241
Snag falling shifts (no.)	4
Production per 6.5-h falling shift (m^3)	94
Yarding	
Logging helicopter - total shifts worked (no.)	25
Scheduled shifts with production (no.)	22
Scheduled shifts lost to weather (no.)	2
Scheduled shifts lost to mechanical problems (no.)	1
Average flight hours per productive yarding shift (no.)	6.3
Production per productive yarding shift (m^3)	1 030
Loading	
Total shifts worked (no.)	44
Average loaders per shift (no.)	1.3
Total loader shifts worked (no.)	56
Production per 11.8-h loading shift (m^3)	405

Yarding

The yarding phase operated seven days per week. Helicopter yarding began in early August and required 22 productive shifts to complete, 17 by the S-64E and 5 by the S-64F. Additionally, two shifts were lost to weather and one shift was lost to mechanical problems. Yarding operations were also shut down for a three-week period in August because of extreme fire hazard. During this period the Skycrane moved to another job.

Canadian Air-Crane planned to begin yarding operations at 7:00 a.m. each morning. However, the cutblocks were frequently obscured by early morning fog and low cloud and the support helicopter was not usually able to deploy the rigging crew on schedule. To minimize waiting time, Canadian Air-Crane's on-site foreman decided the next day's starting time in the previous evening, based on the current day's weather and the next day's forecast. Scheduled starting and quitting times for the loading crews were not affected. As a result, yarding operations usually started between 8:00 and 9:00 a.m. The average yarding shift was reduced from 12 to 10.5 hours because time lost for fog in the morning could not be made up in the evening due to shortening day lengths by mid-September.

The support helicopter worked a total of 82.4 flight hours during the yarding phase (3.7 flight-hours/productive yarding shift) to transport the rigging crews to and from their work sites and to distribute chokers. A typical shift for the support helicopter consisted of 0.7–1 hours to ferry rigging crews and 2.7–3.0 hours to disperse chokers.

In total, the Skycranes required 137.7 flight-hours to extract a total payload of 20 159 000 kg,[6] yielding an average weight-to-volume conversion ratio of 890 kg/m^3 based on 22 650 m^3 net scaled volume. On average, the logging helicopters flew 6.3 hours or 6 yarding cycles per shift, and produced approximately 1 030 m^3/productive shift and 165 m^3/flight-hour. Based on field observations and discussions with the cooperators, the principal factors affecting yarding productivity were long average flight distances, steep flight path slopes, and the requirement to leave uneconomic logs on site.

Flight distance: Average flight distances ranged from 900 to 1 150 m, resulting in average turn times of 3.0 minutes and 20.3 turns/flight-hour. According to Canadian Air-Crane, average flight distances of 600 to 800 m produce a 2-minute average turn time which is optimal for Skycrane helicopters.

Flight path slope: The slope of the flight path to Landing 1 became steeper (over 30%) as yarding progressed, and the pilots reduced descent speed to maintain safe helicopter flight, increasing turn times. Canadian Air-Crane opted to land turns at Landing 2 to decrease the flight path slope. Even though the flight distance increased, the gentler flight path slope enabled the pilots to maintain a higher flight speed which offset the longer flight distance. As a general rule, Canadian Air-Crane prefers to operate the Skycrane on flight path slopes of 35% or less.

Fibre recovery standards: Target logs were often tangled or covered with low-quality logs which were not yarded. The Skycrane occasionally had difficulty breaking turns free and turn times increased. The rigging crews would reduce turn payloads if difficult breakouts were anticipated. Additionally, leaving low-grade logs on the harvest site presented a potential hazard for the rigging crews working downslope as yarding progressed.

Although the flight distance and flight path options encountered during this study were not optimal, these features were dictated by the terrain and locations of the stands to be harvested, and could not be significantly altered. Fibre recovery standards were controllable by the forest company, and leaving low quality logs on the hill undoubtedly improved the profitability of the harvesting operation for TimberWest. However, Canadian Air-Crane's yarding productivity was adversely affected by making turn breakout more difficult, thereby increasing turn time. Additionally, leaving these logs on the hillside added a potential safety risk to the hill crew and finally, some unacceptable wood was inevitably yarded and then discarded at the landing, resulting in increased cull logs yarded.

Coastal heavy-lift helicopter logging contractors typically budget for a cull factor of about 5% of total yarded volume (depending on site and stand). Because of the utilization standards used for this operation, Canadian Air-Crane expected the cull factor to be close to 9%.[7] Helicopter logging contractors in B.C. are typically paid according to the project's net scale volume rather than total weight flown. Therefore, minimizing the amount of cull yarded is very important to overall yarding productivity and cost.

Loading

Loading activities began at the same time as the yarding phase and were completed in late October. The loading crew worked 44 shifts to load and process logs at Landings 1 and 2. The hydraulic loaders worked a total of 56 loader-shifts and averaged 405 m^3/11.8-hour shift.

In general, the landings were large enough to permit continuous yarding without significantly affecting the Skycrane's productivity. TimberWest's loading crews and equipment did not work on Sundays or holidays, so on these days Canadian Air-Crane's front-end loaders stockpiled the logs around the perimeter of the drop zone. There was sufficient space to stockpile 1–2 days' yarding production, but longer breaks in loading

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6 In the helicopter logging industry, the logging helicopter's productivity per flight-hour is typically expressed in terms of weight rather than volume. Weight is measured directly whereas volume is derived from weight and the conversion varies from site to site due to differences in species composition, wood density, cull factors and waste allowance. Appendix IV presents average weight-to-volume ratios used by Canadian Air-Crane for the main commercial conifer species of the B.C. coast.

7 Because the operation was on private land, a waste and residue survey was not required. Therefore the actual amount of waste and residue left on-site is not known.

activity would have caused delays for the yarding phase.

The overflow landing could only be reached by driving through the center of the main landing. When only Landing 2 was active, a second hydraulic loader near the entrance of the main landing cleared access for log trucks passing through. The second loader would not have been needed if the road had bordered the landing rather than ran through its center.

Harvesting costs

Table 5 summarizes the main cost centers and stump-to-truck harvesting costs for this operation.[8] The per-unit stump-to-truck harvesting cost, including falling, yarding, loading, and processing, was estimated at $77.27/m^3. The volume estimate of 25 000 m^3, based on the timber cruise, over-estimated the actual net volume by about 2 350 m^3, resulting in fixed costs being amortized over a final net scale volume of only 22 650 m^3. The yarding phase comprised the largest portion of the harvesting cost (81%), followed by the falling phase (11%), and the loading and processing phase (8%).

Average falling and loading phase costs were estimated at $8.50/m^3 and $6.35/m^3, respectively. The falling cost reflects the productivity effects of the steep and broken terrain and the higher level of in-woods bucking and delimbing (compared to a typical cable yarding operation), while the loading cost reflects the need for a second hydraulic log loader at the entrance to Landing 2.

The average yarding cost for the two cutblocks, estimated at $62.42/m^3, reflects the effects of weather-related delays, long flight distances, steep flight path slopes, and log utilization standards on helicopter yarding productivity. The yarding helicopter alone accounted for 67% of the total yarding cost, and 54% of the total stump-to-truck cost.

[8] In order to more realistically reflect stump-to-truck costs of helicopter logging, cost estimates for this and other recent FERIC helicopter logging studies are derived using a methodology that departs from FERIC's conventional costing approach.

Table 5. Cumulative falling, yarding, and loading phase costs

	Falling ($/m^3)	Yarding ($/m^3)	Loading and processing ($/m^3)	Total ($/m^3)
Prime costs				
Yarding helicopter	-	41.91	-	41.91
Support helicopter	1.46	2.04	-	3.50
Other equipment [a]	-	1.16	2.87	4.03
Chainsaws	0.62	0.12	0.14	0.88
Choker replacement	-	0.32	-	0.32
Labour	4.35	6.75	2.63	13.73
Subtotal	6.43	52.30	5.64	64.37
Other costs				
Mobilization	-	1.60	0.01	1.61
Crew transport	0.24	0.37	0.40	1.01
Supervision	1.43	0.57	-	2.00
Crew room and board	-	1.52	-	1.52
Overhead	0.40	3.93	0.30	4.63
Project costs	-	2.13	-	2.13
Subtotal	2.07	10.12	0.71	12.90
Total	8.50	62.42	6.35	77.27

[a] In this study "Other equipment" consisted of service landing equipment, wheeled loaders, and hydraulic loaders.

Yarding crew labour and overhead costs account for 11% and 6% of total yarding cost, respectively.

Performance of the Sikorsky S-64E and S-64F Skycranes

Three combinations of logging helicopters and rigging systems were used in this study: the S-64E using a grapple; the S-64E using chokers; and the S-64F using chokers. Table 6 summarizes shift-level time distributions for productive shifts, assuming a 12-hour shift, typical for heavy-lift operations in the summer months. Pre- and post-shift maintenance, the three shifts lost to weather and mechanical downtime, and the fire hazard shutdown are excluded. Canadian Air-Crane supplied the actual number of flight hours worked by each combination during the study, and FERIC estimated the distribution of non-flight hours from field notes and discussions with Canadian Air-Crane. While the period of observation was too short to provide reliable estimates of long-term time distribution, the results highlight some important considerations when planning and scheduling a heavy-lift helicopter logging operation.

In total, the three helicopter/rigging system combinations recorded 137.7 flight hours during the yarding phase, or 52% of the 264 hours potentially available for yarding during the 22 productive shifts. Routine in-shift maintenance and refuelling times, closely linked to flight time, were estimated as 30.7 hours, or 12% of total scheduled hours. Therefore, flight time and associated service activities accounted for 64% of the total time potentially available for yarding during the productive shifts.

Table 6. Shift-level time distributions for productive shifts

	S-64E with grapple	S-64E with chokers	S-64F with chokers
Productive shifts (no.)	1	16	5
Non-productive shifts (no.)			
Weather	0	2	0
Mechanical	0	1	0
Total shifts (no.)	1	19	5
Flight time (h) [a]			
Total flight-hours	8.3	96.4	33.0
Flight hours/productive shift	8.3	6.0	6.6
Non-flight time (h) [b]			
Maintenance	1.0	9.0	5.0
Refuelling	1.2	11.0	3.5
Weather	0.0	50.0	14.0
Other [c]	1.5	15.6	4.5
Total non-flight time	3.7	95.6	27.0
Total potential hours [d]	12.0	192.0	60.0
Ratio of flight hours to total potential hours (%)	69	50	55

[a] Information supplied by Canadian Air-Crane.
[b] Estimates by FERIC based on detailed timing, field observations and discussions with cooperators.
[c] Includes time waiting for rigging crew to be deployed, other in-shift organizational delays, and ending the shift early.
[d] Assumes a nominal 12-hour day.

Even though this operation was conducted in late summer when the weather would be expected to be most stable, an estimated 64 hours of available time were lost due to low cloud and fog. Occasionally shifts were extended into the early evening, but daylight in mid September was not adequate to fully compensate for time lost to morning fog. An additional 21.6 hours were unavailable for flying due to organizational reasons, i.e., downtime at the beginning and end of each shift while the rigging crews were deployed to, and then returned from, their hook-up sites. Also, potential flight time was occasionally sacrificed at the end of the day because of crew fatigue or because the time available did not warrant starting another yarding cycle.

Overall the harvesting operation averaged 6.3 flight-hours per productive shift. Both machines equipped with double-hook systems experienced significant weather-related downtime and as a result averaged 6.0 and 6.6 flight-hours per productive shift, respectively. The S-64E with grapple experienced no delays due to weather and achieved 8.3 flight hours in the one productive shift worked. The ratio of flight hours to total available hours ranged from 50–55% when using chokers to 69% when using the grapple. Although technically the Skycrane with grapple could have worked longer given the favourable weather, 8 flight hours is generally considered to be a full day for pilots engaged in ongoing helicopter logging operations, whether using chokers or grapples. For budgeting and scheduling purposes, therefore, 6–8 flight-hours per day is a reasonable estimate for heavy-lift helicopter logging operations in summer.

Table 7 compares yarding productivities for the three combinations. The S-64E averaged 119 m^3/flight-hour when using the grapple and 160 m^3/flight-hour when using chokers. The longer average turn time experienced with the grapple (3.3 minutes, compared to 2.9 minutes when using chokers) explains part of this difference. However, it was generally considered more difficult to optimize turn weight when using the grapple. The relatively large tree sizes and poor blend of piece sizes made it more difficult for the pilot to pick up several logs at once or to select an appropriate combination of logs. The S-64E averaged only 1.6 logs and 5 770 kg per turn (64% of rated lift capacity) with the grapple compared to 3.3 logs and 6 860 kg per turn (76% of rated lift capacity) when using chokers.

The S-64E and S-64F with chokers averaged 160 and 190 m^3/flight-hour, respectively. Both combinations achieved average load factors of 76%, close to the desired average of 80% set by Canadian Air-Crane for this operation. However, the S-64F was more productive because its average turn weight was 25% larger (8 590 kg/turn for the S-64F, compared to 6 860 kg/turn for the S-64E), even though its turn time was marginally longer.

Overall, Canadian Air-Crane's foreman considered the S-64F to be better suited to yarding the study site than the S-64E because its greater horsepower, torque, and payload capacity made it more effective at handling the long flight distances, the relatively large logs, and poor blend of piece sizes.

Table 8 presents estimated yarding costs per cubic metre for the three combinations, based on productive shifts only. Differences in yarding productivity explain the observed differences in unit cost between the systems. The S-64F produced the lowest total yarding cost ($54.14/$m^3$) because the higher flight-hour productivity compensated for its higher hourly owning and operating cost (Appendix II). Likewise, the S-64E with chokers produced a slightly lower total yarding cost than the S-64E with grapple. The cost per cubic metre of the S-64E with grapple was higher than with chokers because a substantially lower productivity per flight-hour was realized by the S-64E with grapple.

Conclusions and implementation

A total of 22 650 m^3 was harvested from the two cutblocks in this study. The areas were felled over a four-month period with

Table 7. Shift-level productivities by helicopter and configuration [a]

	S-64E with grapple	S-64E with chokers	S-64F with chokers
Productive shifts (no.)	1	16	5
Cycles (no.)	10	78	34
Turns (no.)	152	1 996	651
Turn aborts (no.)	0	45	5
Logs (no.)	237	6 668	2 400
Total flight hours (h)	8.3	96.4	33.0
Total weight flown (kg)	876 500	13 693 000	5 589 000
Total volume flown (m^3) [b]	985	15 385	6 280
Average turn time (min)	3.3	2.9	3.0
Average turns/flight hour (no.)	18.3	20.7	19.7
Productivity by weight (kg)			
Per productive shift	876 500	855 800	1 117 100
Per flight hour	105 600	142 000	169 300
Per turn	5 770	6 860	8 590
Productivity by volume (m^3)			
Per productive shift	985	962	1 256
Per flight hour	119	160	190
Per turn	6.5	7.6	9.6
Load factor (%) [c]	64	76	76
Abort frequency (%) [d]	0.0	2.3	0.8
Weight-to-volume conversion factor (kg/m^3) [e]	890	890	890

[a] Differences due to rounding.
[b] Average for both cutblocks.
[c] Load factor = (average turn weight/max. permitted static load (from Table 2))•100.
[d] Abort frequency = (total no. of aborts/total no. of turns)•100.
[e] Common conversion factors by species are given in Appendix IV.

55 working days, including time required to fall snags in the adjacent stands and to build helipads for fallers and rigging crews. The falling team averaged 4.5 fallers/day worked and each faller averaged 94 m^3/6.5-hour shift. Sikorsky S-64E and S-64F Skycranes completed yarding in 22 working days and averaged 1 030 m^3/10.5-hour shift. One or occasionally two hydraulic loaders completed loading of trucks in 44 working days, averaging 405 m^3/11.8-hour loader shift.

FERIC estimated the total cost of falling, helicopter yarding, and loading at \$77.27/m^3. Falling accounted for \$8.50/m^3, or 11% of the total harvesting cost. The steep, broken terrain and thorough bucking and delimbing to minimize the amount of unmerchantable wood flown to the landings reduced productivity and increased costs compared to falling for conventional cable yarding operations. The use of a helicopter to transport the fallers to and from the cutblocks further added to falling costs.

Loading accounted for \$6.35/m^3, or 8% of the total harvesting cost. The location, size, and design of the landing areas necessitated a second loader on-site to ensure access to the log decks for the logging trucks, and to relieve drop zone congestion.

Table 8. Helicopter yarding phase costs by helicopter and configuration for productive shifts			
	S-64E with grapple	S-64E with chokers	S-64F with chokers
Prime costs ($/m³)			
Yarding helicopter	56.85	42.27	38.67
Support helicopter		2.28	1.75
Other equipment [a]	1.16	1.18	0.91
Chainsaws		0.13	0.10
Choker replacement		0.36	0.27
Labour		7.77	4.91
Subtotal	58.01	53.99	46.61
Other costs ($/m³)			
Mobilization	1.38	1.41	1.12
Crew transport		0.42	0.33
Supervision		0.72	0.55
Room and board	0.30	1.48	1.14
Overhead	4.11	4.21	3.22
Project cost	1.49	1.52	1.17
Subtotal	7.28	9.76	7.53
Total ($/m³)	65.29	63.75	54.14

[a] In this study "Other equipment" consisted of service landing equipment, wheeled loaders and hydraulic loaders.

Helicopter yarding accounted for $62.42/m³, or 81% of the harvesting cost with the cost of the logging helicopter alone at $41.91/m³, or 54%.

The yarding phase was performed by S-64E and S-64F Skycranes, primarily using a double-hook-and-choker system. Due to its larger payload capability, the S-64F was 19% more productive per flight-hour and its yarding cost per m³ was 15% less than the S-64E at comparable flight distances. The S-64E also performed one shift of yarding with a grapple. Achieving the desired turn weights was difficult with the grapple, and productivity per flight-hour was significantly less than with chokers, with cost slightly higher. Since this study was conducted, Canadian Air-Crane has switched to using a helicopter grapple system almost exclusively for economic and safety reasons. However, many helicopter-logging operations still use hill crews and chokers.

This study reflects some of the challenges associated with heavy-lift clearcut helicopter logging. Important considerations identified during this study include:

- Match the capabilities of the logging helicopter to piece size and flight distance. Overall yarding productivity may have been improved if the Sikorsky S-64F helicopter with chokers had yarded the entire study area. Canadian Air-Crane felt that the S-64F was more suited to handle the large diameter timber and long flight distances encountered at the study site because it had greater horsepower, torque, and payload capacity than the S-64E.
- Consider the effect of flight distance and path slope on yarding productivity. Average flight distances were longer and flight path slopes into the landings were steeper than desirable, and resulted in longer-than-optimal turn times.

However, terrain and the locations of the harvesting sites and landings controlled these variables. According to Canadian Air-Crane, average flight distances of 600–800 m produce average turn times of two minutes, which are optimal for the Skycrane. As a general rule Canadian Air-Crane prefers to operate the Skycrane on flight path slopes of 35% or less.

- Ensure landing design and size are adequate to accommodate the volume yarded each day. Loading cost may have been less if the road had bordered Landing 2 rather than run through the center of it. Truck access to the overflow landing would have improved and a second loader may not have been needed.
- Consider the effect of fibre recovery standards on yarding productivity, cull factor, and crew safety. Leaving low-grade wood on the site increased turn times by causing difficult breakouts and hang-ups, and reduced payload because the rigging crews built smaller turns to facilitate breakout. Low-grade logs left on site presented safety hazards for the crew and increased the amount of waste wood (cull) flown to the landing. Productivity and safety may have been improved if cutblock boundaries had been changed to eliminate areas with a high proportion of low value timber that was scheduled to be felled but not yarded.
- Consider seasonal weather conditions when scheduling time of harvest. When possible, schedule harvesting for the most favourable period to reduce downtime.

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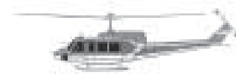
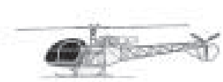
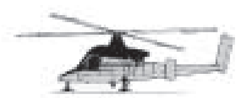
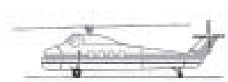
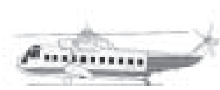
Acknowledgements

The author gratefully acknowledges the cooperation of George Jeffery and the rest of the crew from Canadian Air-Crane, as well as the crew from TimberWest. Special thanks to Rick Jaccard of TimberWest, Cowichan Woodlands for his invaluable assistance. The author would also like to thank FERIC employees Ray Krag and Ingrid Hedin for project advice and draft report review, and Shelley Ker for graphics and report layout.

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] Sikorsky [c]	S-64E S-64F	9072 11340	2 2	3356 (each) 3579 (each)	22 22	5 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 Sikorsky	S-61N S-61N Shortski	3629 4084	2 2	1044 (each) 1044 (each)	18.9 18.9	3.2 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	Sikorsky S-64F Skycrane	Bell 206B Jet Ranger
OWNERSHIP COSTS			
Total purchase price (P) $	19 800 000	21 800 000	475 000
Expected life (Y) y	10	10	10
Expected life (H) h*-	25 000	25 000	10 000
Scheduled hours/year (h) = (H/Y) h	2 500	2 500	1 000
Net flight hours/year (fh) h	2 000	2 000	800
Salvage value as % of P (s) %	40	40	50
Interest rate (Int) %	9.0	9.0	9.0
Insurance rate (Ins) %	12.0	12.0	12.0
Salvage value (S) = ((P • s)/100) $	7 920 000	8 720 000	237 500
Average investment (AVI) = ((P + S)/2) $	13 860 000	15 260 000	356 250
Loss in resale value ((P-S)/(fh • Y)) $/flight-hour	594.00	654.00	29.69
Interest ((Int • AVI)/fh) $/flight-hour	623.70	686.70	40.08
Insurance ((Ins • AVI)/fh) $/flight hour	831.60	915.60	53.43
Total ownership costs (OW) $/flight-hour	2 049.30	2 256.30	123.20
OPERATING COSTS			
No. of pilots required for the operation (pil)	5	5	1
Annual pilot base salary (PS) $/y	50 000	50 000	35 000
Annual flight hours/pilot (pilh) h/y	800	800	800
Flight hour rate (pil$) $/h	125	125	52
Annual pilot flight pay (PF) = (pilh • pil$) $/y	100 000	100 000	28 000
Wage benefit loading (WB) %	45	45	45
No. of engineers (eng)	5	6	0
Engineer salary (ES) $/y	112 500	112 500	-
Fuel consumption (F) L/flight-hour	2 080	2 080	98
Fuel (fc) $/L	0.85	0.85	0.85
Oil as % of fuel (fp) %	1.5	1.5	1.5
Annual parts inventory (Inv) = % of P $/y	2.5	2.5	2.5
Wages for the operation, including fringe benefits			
Pilot (((PS • pil) + ((pil$ • pilh • pil))/fh) • (1 + (WB/100)) $/flight-hour	543.75	543.75	110.25
Engineer (75% • (PS + PF) • (1 + (WB/100))/fh $/flight-hour	407.81	489.38	0.00
Total wages (W) $/flight-hour	951.56	1 033.13	110.25
Fuel (F • fc) $/flight-hour	1 768.00	1 768.00	83.30
Oil ((fp/100) • (F • fc)) $/flight-hour	26.52	26.52	1.25
Maintenance $/flight-hour	1 700.00	2 000.00	225.00
Parts inventory ((Inv/100) • P/fh $/flight-hour	247.50	272.50	14.84
Helicopter registration fees $/flight-hour	1.61	1.63	2.38
Total operating costs (OP) $/flight-hour	4 695.19	5 101.78	437.02
TOTAL OWNERSHIP AND OPERATING COSTS (OW + OP) $/flight-hour	6 744.49	7 358.08	560.22

[a] These costs are estimated using FERIC's standard costing methodology for determining machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company studied.

Appendix III

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

	Wheeled log loader 21-t class	Hydraulic log loader 46-t class
OWNERSHIP COSTS		
Total purchase price (P) $	400 000	550 000
Expected life (Y) y	8	10
Expected life (H) h	14 400	14 400
Scheduled hours/year (h) = (H/Y) h	1 800	1 440
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	9.0	9.0
Insurance rate (Ins) %	3.0	3.0
Salvage value (S) = ((P • s)/100) $	120 000	165 000
Average investment (AVI) = ((P + S)/2) $	260 000	357 500
Loss in resale value ((P-S)/H) $/h	19.44	26.74
Interest ((Int • AVI)/h) $/h	13.00	22.34
Insurance ((Ins • AVI)/h) $/h	4.33	7.45
Total ownership costs (OW) $/SMH	36.77	56.53
OPERATING COSTS		
Fuel consumption (F) L/h	28.0	25.0
Fuel (fc) $/L	0.40	0.40
Lube & oil as % of fuel (fp) %	15	15
Annual operating supplies (Oc) $	1 500	2 500
Annual repair & maintenance (Rp) $	41 500	41 300
Fuel (F • fc) $/h	11.20	10.00
Lube & oil ((fp/100) • (F • fc)) $/h	1.68	1.50
Operating supplies (Oc/h) $/h	0.83	1.74
Repair & maintenance (Rp/h) $/h	23.06	28.68
Total operating costs (OP) $/SMH	36.77	41.92
TOTAL OWNERSHIP AND OPERATING COSTS (OW + OP) $/SMH	73.54	98.45

[a] These costs are estimated using FERIC's standard costing methodology for determining machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company studied.

Appendix IV

Common conversion ratios for typical B.C. coastal coniferous commercial tree species [a]

Tree species	Conversion ratio [b] (kg/m^3)
Western red cedar	682
Amabilis fir	746
Yellow cedar	773
Douglas-fir	841
Western hemlock	909

[a] Weight per m^3 is the green log weight and includes bark and a minor portion of limbs and tops.
[b] John Smith, Canadian Air-Crane Limited, personal communication.