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

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Operational Summary

During 1992, alternative silvicultural systems were established in two areas of steep-sloped, old-growth forests on the west coast of the Queen Charlotte Islands. These systems consisted of single-tree selection (25% basal area removal), two levels of group selection (25% and 50% area removed in rectangular groups, < 0.3 ha in size), and clearcutting. An unlogged control area was applied at each site. Both forests, at Hangover and Gregory Creek, were within the CWHvh2 biogeoclimatic zone and composed of western hemlock, Sitka spruce and western redcedar. A Sikorsky S-64E Skycrane helicopter yarded all treated sites, causing little disturbance to ground surfaces.

Harvesting within the group selection treatments came closer than single-tree selection to meeting prescriptions. Single-tree selection tended to cut greater volume than prescribed. Residual tree damage attributed to harvesting was highest with the single-tree treatment (24.8% of trees damaged) and lowest in the 50% and 25% group selection treatments, with 15 % and 9.5 % of trees damaged respectively.

Natural regeneration composition was similar in all harvested treatments, with western hemlock representing from 74% to 90% of total regeneration and stocking exceeding maximum stocking based on current guidelines. Sitka spruce natural regeneration density was widely distributed but redcedar was the least reliable species to regenerate naturally. Natural regeneration density was lowest in the clearcut at both locations.

Planted Sitka spruce survival exceed 69% in all harvested treatments and early height growth exceeded that of natural regeneration. For planted redcedar with browsing protection, survival averaged 62% in harvested treatments; survival for Vexar®-protected redcedar was between 20 and 50% higher than for unprotected seedlings while also improving growth. Sitka spruce and western redcedar growth was greatest in the clearcut, followed by that in the 50% and 25% group selection gaps, with lowest growth in the unlogged control.

Long-term effect of cutting pattern on slope stability, stem rot development, and mistletoe development remain relevant indicators of suitability of group and single-tree selection for harvesting and management on these steep-sloped sites. Additional monitoring of these blocks is recommended.

Acknowledgements

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Introduction

The Queen Charlotte Islands are a group of more than 150 islands on the edge of the continental slope of the Pacific Ocean, approximately 90 kilometres west of British Columbia's northwest coast. The Islands are principally mountainous, with two main islands, Graham to the north, Moresby to the south, and a myriad of small ones, for a total area of 1,018,000 hectares (Figure 1). Three biogeoclimatic zones occur on the Islands. The Coastal Western Hemlock zone dominates, with smaller areas in the Mountain Hemlock and Alpine Tundra zones at higher elevations. Forested ecosystems are dominated by western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Sitka spruce (*Picea sitchensis*) (Banner et al 1984). On the wetter windward edge of the Islands, yellow-cedar (*Chamaecyparis nootkatensis*), and lodgepole pine (*Pinus contorta*) are found among the redcedar, hemlock, and spruce. The majority of the land base considered suitable for timber harvesting has been classified as having stands greater than 150 years of age, with significant portions of old growth exceeding 250 years of age.

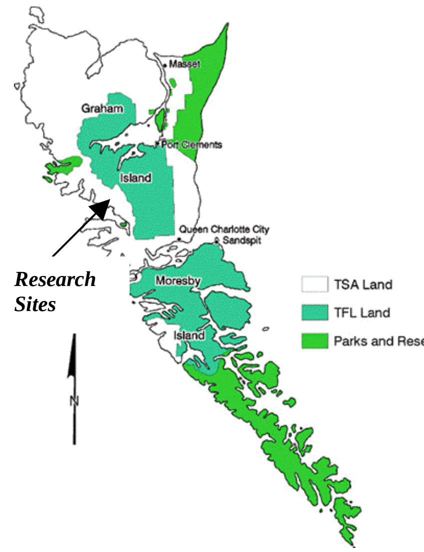


Figure 1. Research site location on Graham Island of the Queen Charlotte Islands (Scale 1:3,300,000)

Timber harvesting on the steep slopes had traditionally been done by clearcutting using cable yarding. Reforestation by a combination of natural and planted regeneration generally met stocking requirements, but intense browsing by the introduced Sitka black-tailed deer (*Odocoileus hemionus sitensis* Merriam) on redcedar and yellow-cedar threatened to deplete or eliminate the presence of these species in regenerating stands (Sullivan et al 1990). During the 1980s, concerns arose over the potential of forestry activities to accelerate mass wasting frequency (Sauder et al 1987) and thus threaten fish habitat (Tripp et al 1986). Finely textured soils, frequent seismic activity, shallow-rooting tree species, and high winds predispose the area to a high natural level of mass wasting (Sanders and Wilford 1986). The Fish-Forestry Interaction Program (FFIP) was initiated to find ways to reduce impact of forestry-related mass wasting on fish habitat. Recommendations for testing alternatives to clearcutting in an attempt to maintain slope stability (Sanders and Wilford 1986) were followed by an FFIP initiative to harvest two study areas along the west coast of Graham Island.

In 1992, in co-operation with the Forest Engineering Research Institute of Canada (FERIC), a range of silvicultural systems including group selection, single-tree selection and clearcutting were established on two steep-sloped sites on the west coast of Graham Island. These were considered environmentally sensitive sites and were considered typical of the ecosystems in this area. Harvesting, productivity costs, site and stand impacts of the helicopter logging were monitored and reported by FERIC (Krag 1998). Due to lack of information on the effects of the different silvicultural systems on meeting regeneration commitments, Experimental Project (EP) 862.34 was established to evaluate the implications of the various silvicultural systems on stand re-establishment. The South Moresby Forest Replacement Account funded the re-measurement of both planted (western redcedar and Sitka spruce) and natural regeneration in all treatments at both sites seven years after the completion of harvesting. This report summarizes the results of the recent and past measurements.

Objective

The objective of EP 862.34 was to describe and compare 1) natural regeneration density, composition and growth, and 2) planted Sitka spruce and redcedar survival and growth amongst a range of silvicultural systems. An additional objective was to evaluate the effectiveness of Vexar® tubing to reduce deer browsing intensity on planted western redcedar. This is the final report to the SMRFA.

Study Site Descriptions

Site Characteristics

Two steep-sloped sites perceived to be sensitive to conventional harvesting were chosen by the British Columbia Ministry of Forests District and Research staff and FERIC researchers. Located about 5 km apart, the Hangover and Gregory Creek sites (Figure 2) are within the Very Wet Hypermaritime subzone of the Coastal Western Hemlock biogeoclimatic zone (CWH vh2) (Green and Klinka 1994), characterised by mild temperatures and heavy rainfall. The majority of Gregory Creek was classified in the western hemlock–Sitka spruce–lanky moss ecosystem (04 site series) (Appendix 1), while Hangover Creek also contained areas within the wetter western redcedar–Sitka spruce–sword fern (site series 05) and western redcedar–Sitka spruce–Foamflower (site series 06) ecosystems (Sinomar 1991). Both locations contained sizeable areas of stable (Classes I-III) and unstable (Classes IV and V) terrain. The blocks differed in aspect, as Gregory Creek had a southerly aspect and Hangover Creek was primarily easterly facing (Table 1).

Table 1. Site descriptions

	Gregory Cr.	Hangover Cr.
Aspect	Southerly	Easterly
Elevation Range	60–310 m asl	200–500 m asl
Slope-Range	20 –120%	20 –100%
Slope Average	55%	65%
Soils	Podzols	Folisols
Soil Texture	Silty Loams	Silty Loams
Parent Material	Shale / Conglomerate	Shale / Conglomerate/ Limestones

Pre-harvest stand structure

Pre-harvest stand volume was greater and stand density was lower at Hangover Creek (Table 2). Diameter distributions at both locations were typical of uneven-aged stand structures. Western hemlock dominated within most diameter classes at Gregory Creek (Figure 3). Hangover Creek had a more equal mixture of western hemlock and Sitka spruce, reflecting greater areas within the wetter ecosystems. Yellow-cedar was found at both sites in the understory but at low densities: 5.8 sph at Hangover and < 1 sph at Gregory Creek. At both locations, Sitka spruce was the tallest species, followed by western hemlock, redcedar and yellow-cedar. Hemlock had the highest rate of defects, including forks/crooks and frost cracks, at both locations (Appendix 2), with hemlock dwarf mistletoe (*Arceuthobium tsugense* (Rosend.) G.N. Jones) observed more frequently at Gregory Creek. Western hemlock represented over 98% of the understory saplings and ploes (trees below 17.5 cm dbh but greater than 1.3 meter in height) at both locations, although their density was higher at Hangover Creek (1039 sph) than at Gregory Creek (756 sph).

Table 2. Pre-harvest stand structure by location

	Gregory Creek	Hangover Creek
Total volume (net – live)	763.8 m^3	898.3 m^3
Total volume by species		
• Western hemlock	625.4 m^3	414.5 m^3
• Sitka spruce	83.6 m^3	422.7 m^3
• Western redcedar	54.2 m^3	46.7 m^3
• Yellow-cedar	< 1 m^3	5.3 m^3
Stems per ha	339.9 sph	308.9 sph
Average dominant tree height (m)		
• Western hemlock	39.5	38.5
• Sitka spruce	46.8	43.5
• Western redcedar	36.3	34.0
• Yellow-cedar	16.6	22.3

Figure 2. Location of Gregory and Hangover Creek research sites (Scale 1:250,000)

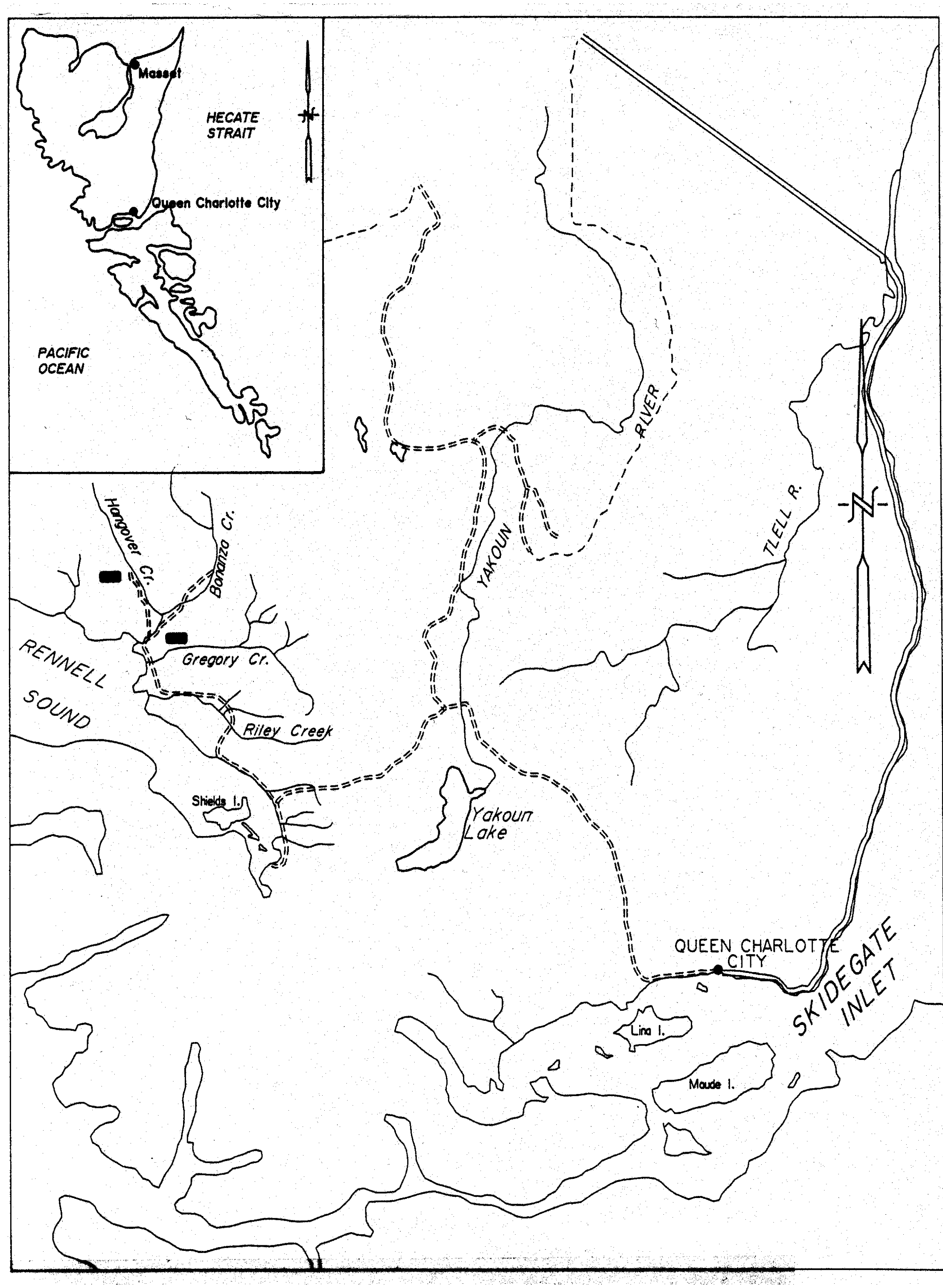
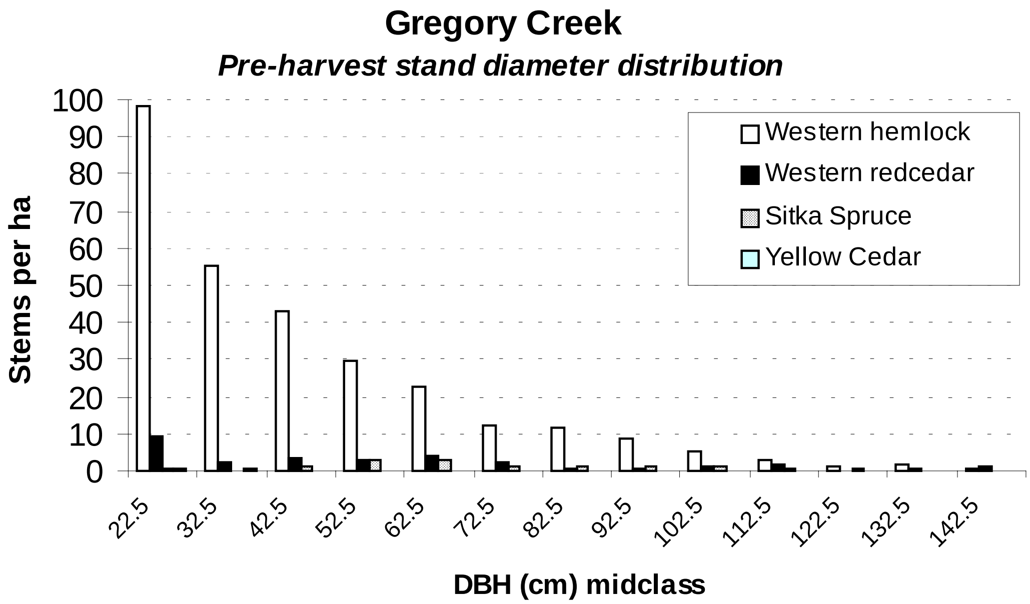
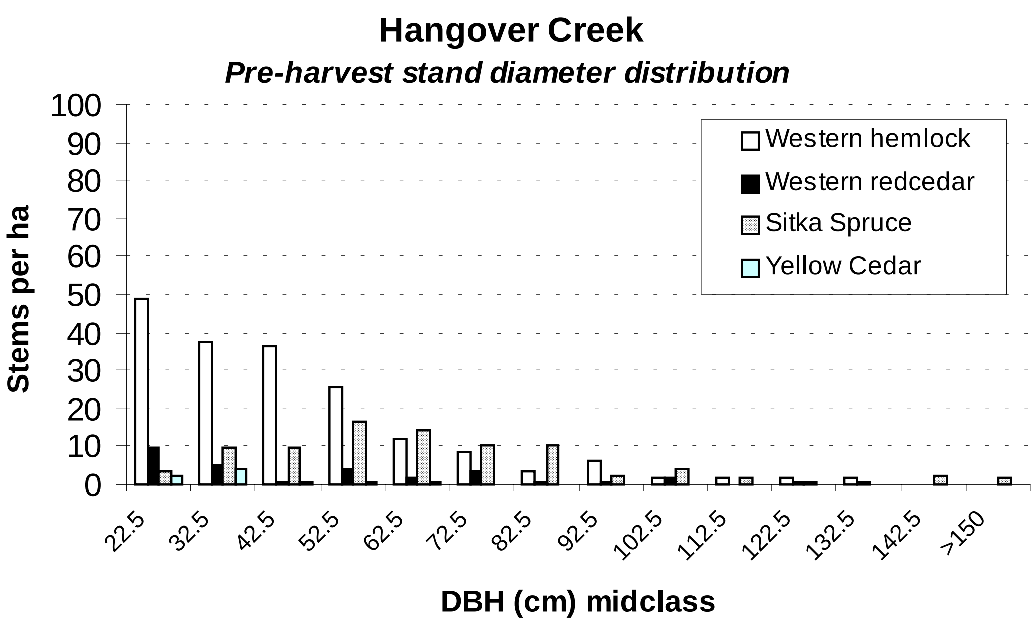


Figure 3. Pre-harvest stand diameter distribution by location and species





Study design

Treatments and experimental design

Four harvesting treatments were selected as representing a diverse range of treatments suitable for investigation. They included:

- **Single-tree selection -** prescribed removal of 25% ±5% of the pre-harvest stand basal area with proportional representation of all species and diameter classes.

- **25% and 50% group selection** - prescribed removal of 25 % and 50 % of the total area (also volume and basal area) in openings between 0.2 and 0.3 hectare in size uniformly distributed throughout the treatment units. Rectangular-shaped openings, approximately 60-70 m by 30-35 m, oriented with the long edge parallel to the contour line, were proposed to increase falling safety and to avoid damage to adjacent areas. Groups were pre-marked by painting trees around the boundaries.

- **Clearcut** - prescribed complete removal of all standing live and dead tress.

The group and single-tree selection prescriptions proposed one or two additional entries, with the first of these no earlier than 25 years after the initial entry, to allow the removal of trees left after the first pass.

A randomized block experimental design was employed to study the effect of the four silvicultural systems plus unlogged control on soil substrate, natural and planted regeneration development, and stand structure at the two sites. The Hangover and Gregory Creek sites were considered replications, and both selected sites were divided into five similarly-sized areas (Figure 4). The Hangover treatment units ranged from 8 to 11 hectares in size; at Gregory Creek treatments units ranged from 9.1 to 9.8 hectares. Each of the four silvicultural systems were assigned randomly to one of the areas within each site. The two control areas (unlogged treatment) were chosen to be at the edge of the rest of the experimental areas so that loaded helicopters would not have to fly over unlogged areas, increasing the efficiency of the yarding phase. Trees in all partial cutting treatments were marked to cut prior to falling

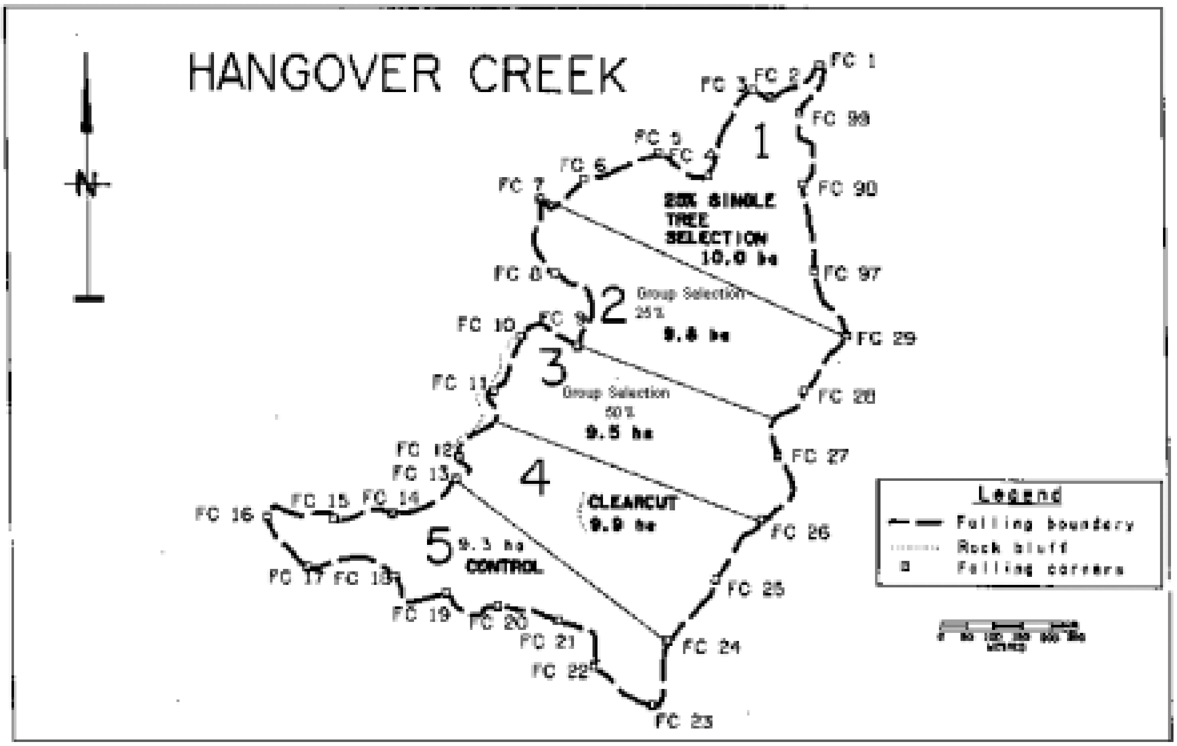
Measurements

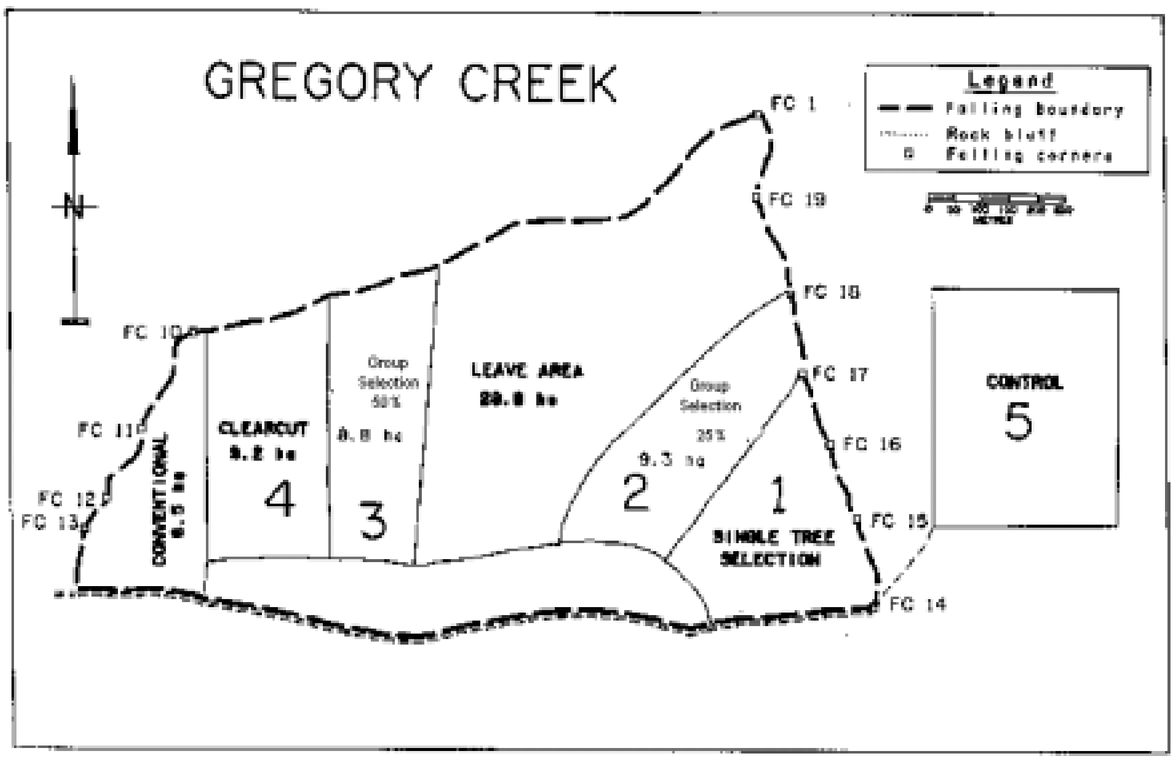
Within each treatment unit prior to harvesting, 50 grid points, spaced approximately 30 m apart and at least 15 m from area boundaries, were located and identified with numbered aluminum stakes. Measurements associated with soils substrate, natural regeneration, and planted regeneration were located using these grid points.

Stand structure

Pre-harvest stand structure measurements were centred on the 50 grid points. Within a 50m^2 circular area (3.99 m radius), all merchantable trees (> 17.5 cm dbh and > 1.3 meter in height) within the plot were identified, marked, and had the following data collected: species, dbh, and crown position (dominant, co-dominant, intermediate or overtopped). Within each treatment unit, the heights of 25 to 30 trees of each species within the dominant, co-dominant, and intermediate crown classes were measured. Post-harvest stand structure measurements in the first fall after harvesting followed similar methodology, with the additional measurement of stump height of cut trees.

Figure 4. Treatment allocation to harvest unit – Gregory and Hangover Creeks





Natural regeneration

Pre-harvest measurements of understory regeneration assessed only saplings greater than 1.3 meter in height. A maximum of six saplings were ribboned within the $20m^2$ circular area (2.52 m radius) centred on the 50 grid points. Species, dbh class (0-5cm, 6-10 cm, 11-15 cm and >15 cm), height, and condition were recorded. In the year following harvesting, the condition of previously sampled regeneration (dead, missing, cut, or buried) and height of surviving saplings were assessed. Seventh-year assessment within the clearcut, single-tree and control units were made within 30 of the 50 plots established prior to harvest. In the group selection treatments, a total of 30 plots were established, both within gaps and beneath intact forest patches through the establishment of new plots. Seventh-year assessments of natural regeneration density included assessment in each of the four quadrants of a $10m^2$ (1.78 m radius) circular sampling area. Height, root collar diameter, and condition on a maximum of three dominant seedlings of each species (western hemlock, western redcedar and Sitka spruce) per plot were recorded. Inadequate marking of saplings during earlier measurements rarely allowed seventh-year measurements to be associated with previously measured saplings.

Soil surface substrate conditions

The soil surface substrate was visually estimated as percent cover in $10m^2$ (1.78 m radius) circular areas around 50 plot centres in each treatment, two years prior to harvest and one year following harvest, to quantify soil disturbance directly due to harvesting. The soil surface substrates types included:

- Rock
- Organic material (forest floor)
- Woody material (fresh and decaying wood)
- Mineral soil

Planted regeneration

Western redcedar (with and without Vexar® protection) and Sitka spruce container stock (Table 3) were planted beside 40 grid points chosen at random from the 50 grid points per treatment. The three species / Vexar® combinations were planted in parallel rows of three trees. Vexar®-protected redcedar were not planted in the Hangover Creek control treatment due to supply limitations. Measurements starting in the first fall after planting included: total height; foliar, stem, and leader condition; and damaging agent if any (e.g. deer browsing). Measurements were repeated after the second, fifth and seventh growing seasons after planting. Stem diameter (at root collar) measurements began in the fifth year. Seedlings were planted without regard for the presence or absence of gaps within the group treatments.

Table 3. Description of planted stock

	Sitka Spruce	Western redcedar
Stocktype	1+0 PSB 415B	1+0 PSB 313B
Seedlot	6574	6768
Provenance	Lyell Island	Port McNeill

Harvesting

Krag (1998) summarized costs, productivity, site and stand impact of harvesting process at both locations. Equipment consisted of one logging helicopter (a Sikorsky S-64E Skycrane), one support helicopter (a Bell 206 Jet Ranger), and two log loaders. The Skycrane typically yarded 20 to 30 turns in a 55- to 60-minute flying cycle, with 5- to 10-minute visual inspection and refuelling breaks between cycles. Falling, yarding, and loading operations were performed on the trial sites between June and November of 1992. Falling began on Gregory Creek in mid-June and on Hangover Creek in early July. Falling was completed on most of the Gregory helicopter yarding units by late September. Helicopter yarding operations on the two study sites were continuous except for a period of three days in early October, when a small blowdown patch was logged nearby. Original group openings were too small for landing a helicopter to discharge or pick up crews in case of emergencies, so were enlarged for safety.

Data Analysis

Forest stand structure (including species, stand density, and volume), soil surface substrate, natural regeneration (density, total height, and stem caliper), and planted regeneration (survival, height, and caliper growth and condition) were summarized by treatment for each location. Within the group selection treatments, measurements from harvested gaps were summarized and analyzed separately from measurements beneath areas with retained overstory. Measurements from retained groups of trees within the two group selection treatments were combined into a treatment labeled 'Group Islands'. In the analysis of variance (ANOVA), Gregory and Hangover Creek locations were treated as replicates (blocks) (Table 4). For the ANOVA of planted seedling height and diameter growth, there was no control since lack of Vexar®-protected seedlings at Hangover created an unbalanced design. The ANOVA of planted seedling survival used an arcsine transformation of the square root of survival to normalize the distribution of this variable. Contrasts were performed to compare treatments or species of interest. An α value of 0.05 was chosen as the level of significance for all tested variables.

The basic model has the following form:

$Y_{ijk} = \mu + a_i + b_j + ab_{ij} + c_{(ij)k}$ where

Y_{ijk} is the measured variable for treatment i, block j, and plot k;
μ is the overall mean;
a_i is the fixed effect of treatment i;
b_j is the random effect of block j;
ab_{ij} is the random interaction effect due to treatment $\times$ area;
$c_{(ij)k}$ is the random effect (error) due to variability between plots.

Table 4. The ANOVA table

Source		Degrees of freedom	F-test
Block	B	2-1=1	---
Treatment	A	5-1=4	MS_A/MS_{AB}
Treat. × Block	A * B	(2-1)(5-1)=4	---
Plots	P(AB)	(30-1)(2×5) = 290	
Total		2×5×30-1 = 299	

Results

Post-Harvest stand structure.

Post-harvest stand structure within the group selection treatments was closer to meeting specifications than singe-tree selection treatments (Table 5). Overcutting in the group selection treatments resulted when safety issues, including access to helicopters, resulted in increased gap sizes. The largest discrepancy between the prescriptions and the actual volume cut was at Gregory Creek, where cutting within the single-tree selection area removed twice as much volume as prescribed.

Table 5. Pre- and post-harvest stand volume, by location and treatment. Figures highlighted with a * are more than 5% over prescription

Treatment	Location	Period	Volume (m3)				
			Hw	Cw	Ss	Yc	Total
50% Group Selection	Hangover	Pre-harvest	6069	124	332	.	6525
		Post-harvest	2819	157	336	.	3312
		% Cut	**54%**	**0%**	**0%**	**.**	**49%**
	Gregory	Pre-harvest	3586	370	6777	145	10878
		Post-harvest	1504	116	4144	93	5857
		% Cut	**58%**	**69%**	**39%**	**36%**	**46%**
25% Group Selection	Hangover	Pre-harvest	4239	1645	854	30	6768
		Post-harvest	2474	1159	653	26	4312
		% Cut	**42%***	**30%**	**24%**	**13%**	**36%***
	Gregory	Pre-harvest	2446	445	2240	.	5131
		Post-harvest	1628	301	1625	.	3554
		% Cut	**33%***	**32%***	**27%**	**.**	**31%***
25% Single-tree Selection	Hangover	Pre-harvest	6768	43	1164	.	7975
		Post-harvest	4240	0	442	.	4682
		% Cut	**37%***	**100%***	**62%***	**.**	**41%***
	Gregory	Pre-harvest	7572	1197	3319	.	12088
		Post-harvest	4433	1038	574	.	6045
		% Cut	**41%***	**13%***	**83%***	**.**	**50%***

Residual tree damage

Krag (1998) summarized frequency of logging-related wounds on residual live trees within the group and single-tree selection treatment units at both locations (Table 6). Fresh wounds were easily distinguished from older pre-logging damage during post-harvest surveys. Scarring levels for corresponding treatment units were consistent between the Hangover and Gregory Creek sites; the highest level of wounding was associated with single-tree treatment, followed by 50% group selection, with the lowest levels in the 25% group selection system. Snag falling was considered to be responsible for most of the scarring within the interiors of the leave areas in the group selection units, and therefore was probably responsible for some of the scarring within the single-tree selection units as well. Most logging-related scars were relatively small, with median sizes ranging from about 140 to 170 cm^2.

Table 6. Frequency of harvesting-related scarring of residual trees (>17.5 cm dbh) in group selection and single-tree treatments (modified from Krag (1998).

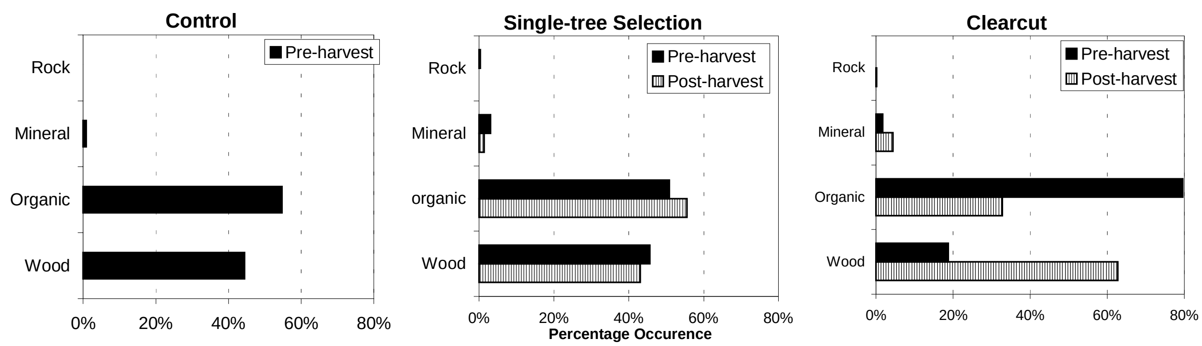
		Trees Surveyed	Trees With Scars	
			Number	%
50% Group Selection	Hangover	279	49	17.6
	Gregory	208	24	11.5
	Combined	**487**	**73**	**15.0**
25% Group Selection	Hangover	223	22	9.9
	Gregory	178	16	9.0
	Combined	**401**	**38**	**9.5**
25% Single-tree Selection	Hangover	330	78	23.6
	Gregory	276	72	26.1
	Combined	**606**	**150**	**24.8**

Soil surface substrate

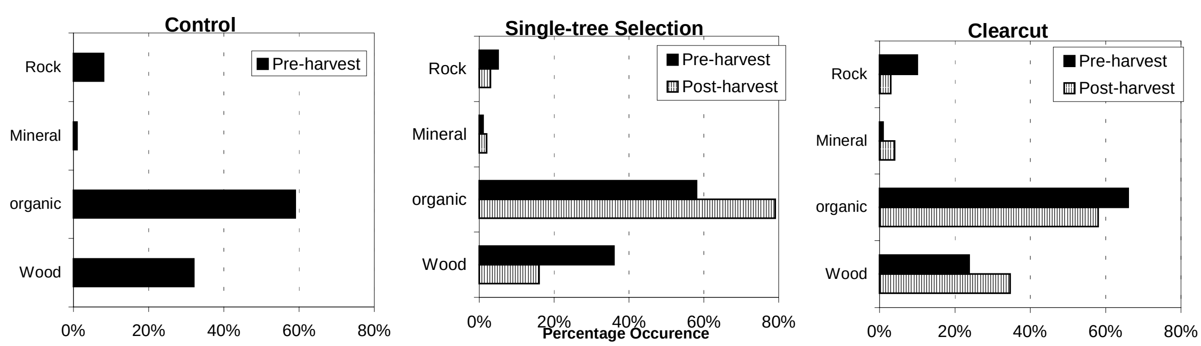
Organic and woody material were the most common soil substrates prior to and following harvesting (Figure 5 and Appendix 3). The woody material substrate tended to increase after harvesting, presumably due to material introduced through logging. Mineral soil exposure remained below 5% in most treatments, showing little soil disturbance due to falling and yarding.

Figure 5. Soil surface substrate by location and treatment, pre- and post-harvest

A) Gregory Creek



B) Hangover Creek



Planted regeneration

Survival and condition

The ANOVA indicated that seventh-year survival of planted seedlings differed between species but not between harvesting treatments (Appendix 4). Sitka spruce survival was significantly greater than that of Vexar®-protected redcedar (Table 7). Vexar®-protected redcedar survival was significantly greater than that of unprotected redcedar, with totals from 20 to 50% higher than unprotected seedlings. Seedling survival in harvested gaps was similar to that in the clearcut and was generally higher than under intact overstory. Vexar®-protected cedar survival tended to be greater than spruce under an intact overstory, but the trend reversed under open growing conditions. Browsing of side branches and stem leader were the most common defects noted on surviving planted regeneration (Appendix 5). ANOVA indicated that frequency of browsed leaders did not differ between treatments (Appendix 6).

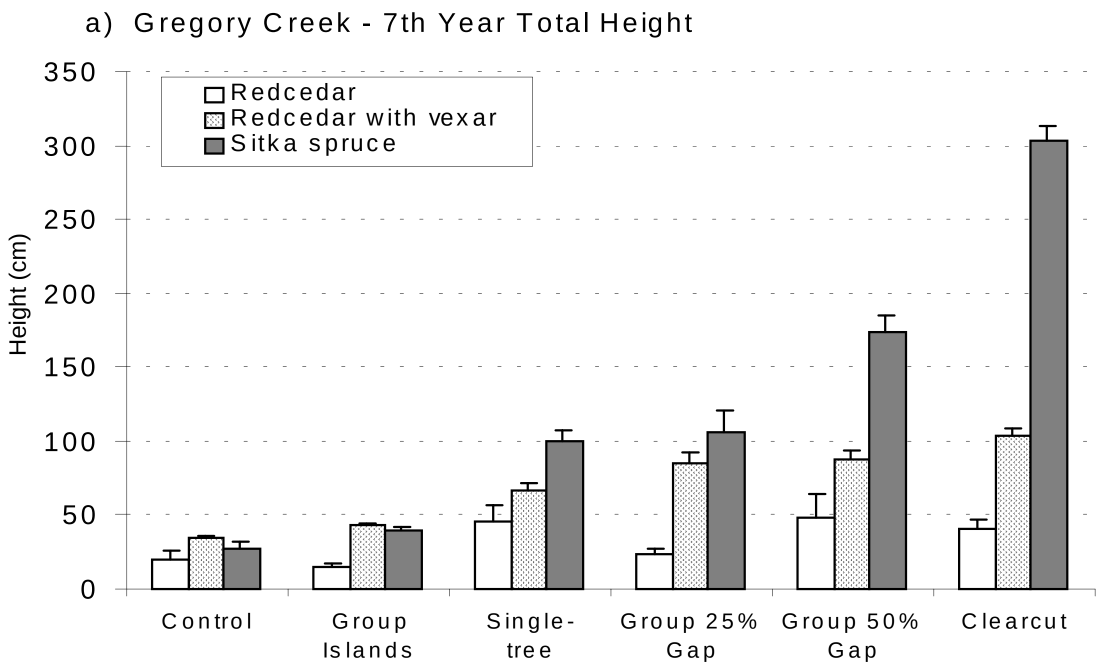
Table 7. Seventh-year survival of planted regeneration – by species and location. Treatments with shading have intact overstory. Total seedlings sampled in brackets.

		Gregory Creek			Hangover Creek		
Treatment		Redcedar	Redcedar with Vexar	Sitka spruce	Redcedar	Redcedar with Vexar	Sitka spruce
Control		2.2 % (91)	50.0 % (90)	7.9 % (89)	11.1 % (90)	.	21.1 % (90)
Single-tree		33.3 % (90)	64.4 % (90)	88.9 % (90)	28.0 % (93)	74.4 % (90)	62.2 % (90)
Group 25%	Understory	9.5 % (63)	58.7 % (63)	34.9 % (63)	3.3 % (30)	70.0 % (30)	73.3 % (30)
	Gap	40.0 % (30)	96.7 % (30)	90.0 % (30)	21.1 % (57)	73.7 % (57)	80.7 % (57)
Group 50%	Understory	14.6 % (48)	62.5 % (48)	33.3 % (48)	16.7 % (48)	68.8 % (48)	45.8 % (48)
	Gap	25.8 % (66)	62.1 % (66)	78.8 % (66)	28.6 % (42)	69.0 % (42)	69.0 % (42)
Clearcut		32.2 % (90)	62.2 % (90)	88.8 % (89)	31.1 % (90)	77.8 % (90)	93.3 % (90)
Overstory Condition		Redcedar	Redcedar with Vexar	Sitka spruce	Redcedar	Redcedar with Vexar	Sitka spruce
Open		31.2 % (186)	67.7 % (186).	85.4 % (185)	27.5 % (189)	74.6 % (189)	84.1 % (189)
Closed		11.7 % (111)	60.4 % (111)	34.2 % (111)	11.5 % (78)	69.2 % (78)	56.4 % (78)

Total and incremental height and stem diameter growth

Treatment ranking based on height of planted Sitka spruce and western redcedar seedlings followed a similar pattern at both locations, with both species showing preference for open growing conditions (Figure 6 & Appendix 7). The ANOVA conducted on seventh-year total height and stem diameter (at root collar) indicated a significant treatment * species interaction (Appendix 8). Analysis by species indicated growth of both Sitka spruce and Vexar®-protected redcedar was greater in the clearcut than either in the gaps or in the single-tree treatment (Appendix 9). Planted Sitka spruce growth exceeded redcedar growth at both locations and in all treatments except under closed overstory conditions, where growth was most limited. Sitka spruce growth was more sensitive to treatment than redcedar. Vexar® protection of planted redcedar improved cedar growth. Neither Sitka spruce nor redcedar with Vexar® have reached mean free-growing height criteria (4.0 m for spruce; 2.0 m for redcedar) in any treatment. During the latest two-year period, Sitka spruce showed substantially greater height growth (Figure 7) and diameter growth (Appendix 10) than redcedar (both protected and unprotected) within all treatments except in the uncut portions of the group selection and control units (Appendix 11). Growth differences between species beneath an intact overstory are minimal as deer browsing resulted in negative height and caliper growth of both species. Growth of Sitka spruce (height and stem diameter) and vexared-redcedar (stem diameter) was greater in the clearcut than in the gaps of the group selection treatments (Appendix 12).

Figure 6. Planted regeneration 7th year total height, by location. Error bars are 1 Standard error (SE)



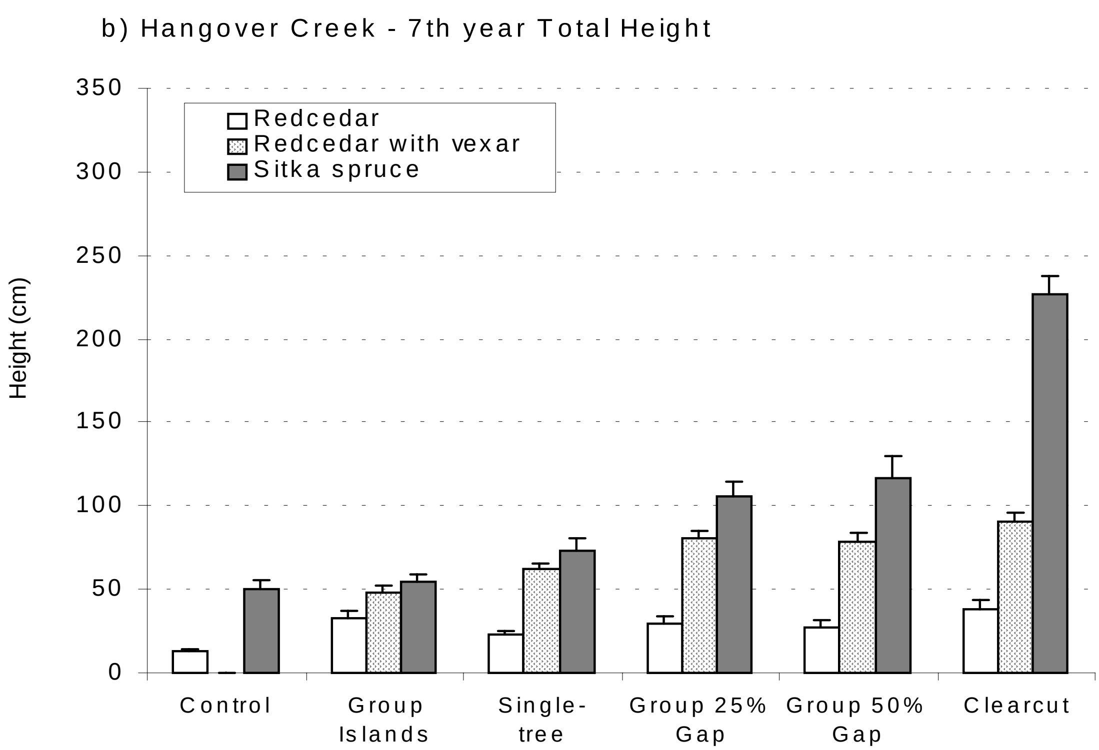
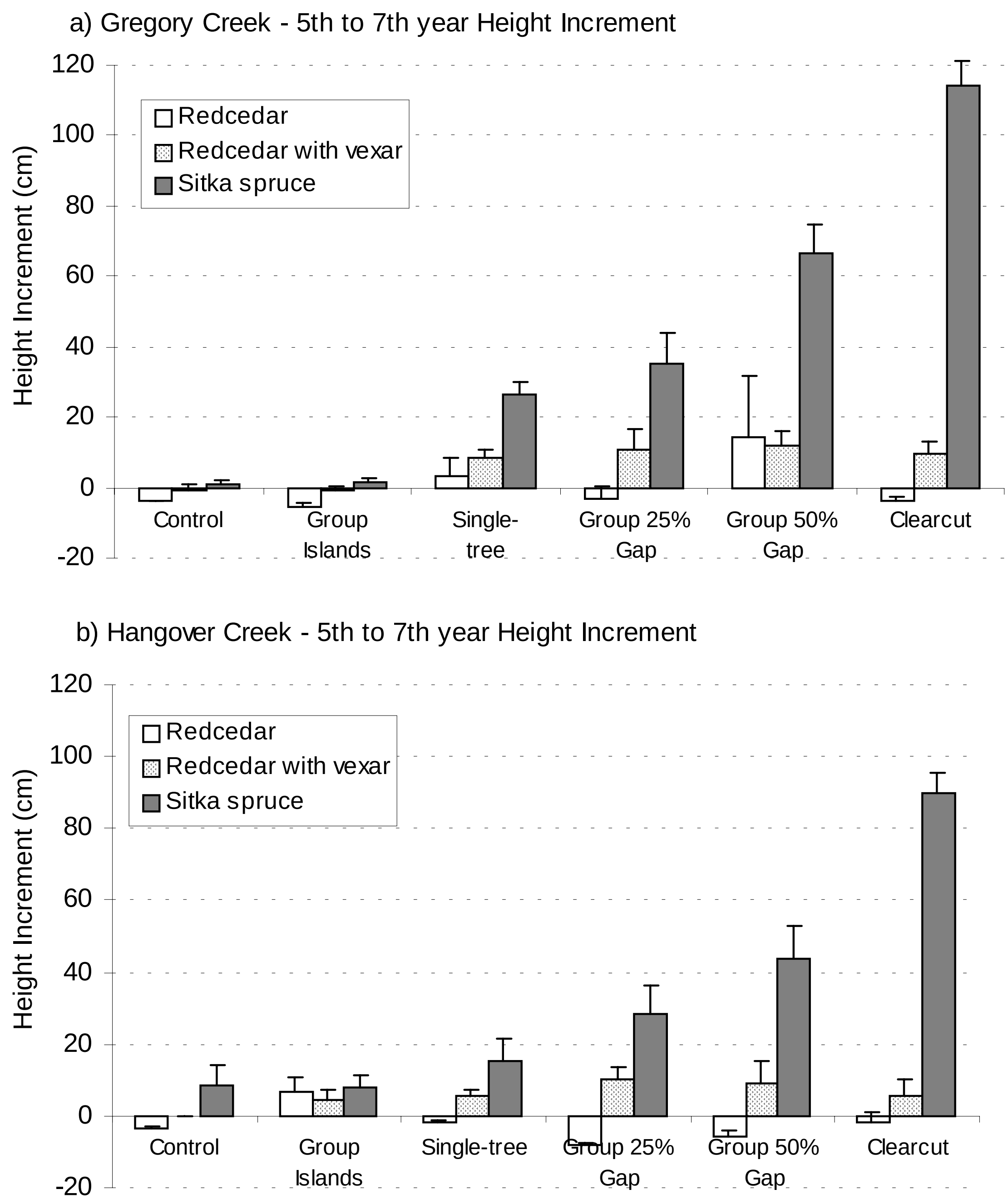


Figure 7. Planted regeneration height increment (Year 5 to 7), by location. Error bars are 1 SE



Natural regeneration

Pre-harvest natural regeneration

Pre-harvest density of saplings exceeding 1.3 meters in height was statistically similar between treatments at each location (Figure 8 and Appendix 13). Total density of advanced regeneration at Hangover Creek (1039 sph) was greater than at Gregory Creek (756 sph). Western hemlock dominated the understory, representing over 98% of all sampled trees, widely distributed in both locations (Appendix 14). Sitka spruce was found in less than 5% of sample plots and at low densities (< 30 stems per ha). Western redcedar was absent in most treatments at both locations. Post-harvest assessments revealed that advanced regeneration mortality due to harvesting (cutting, burying etc.) was highest within the clearcut (> 90%). Mortality within gaps of the 25% and 50% group selection treatments was lower, at 75% and 62% mortality respectively (Figure 9). Hemlock mortality was observed within unharvested areas although the damaging agent was not recorded.

Figure 8. Pre-harvest understory regeneration density (>1.3 meter in height, < 17.5 cm dbh), by location and treatment

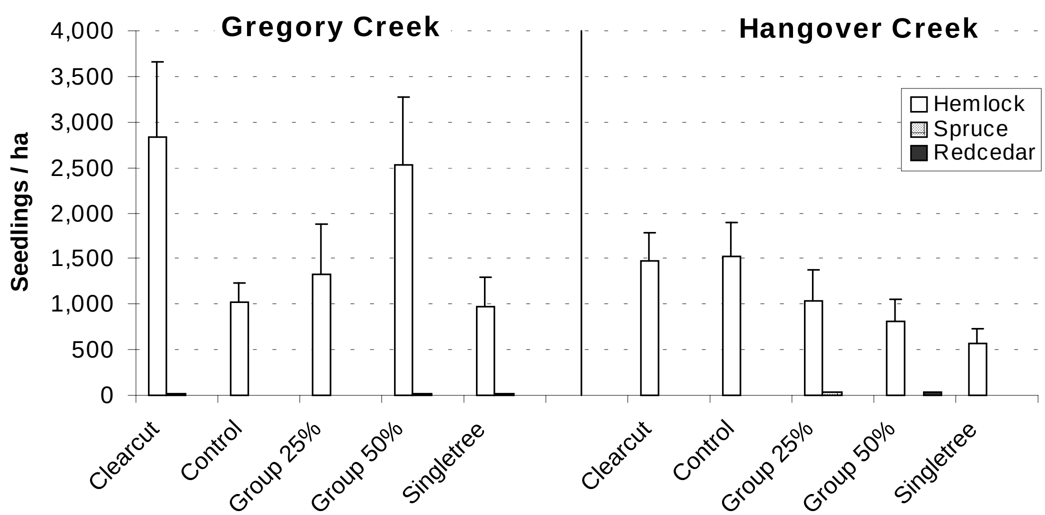
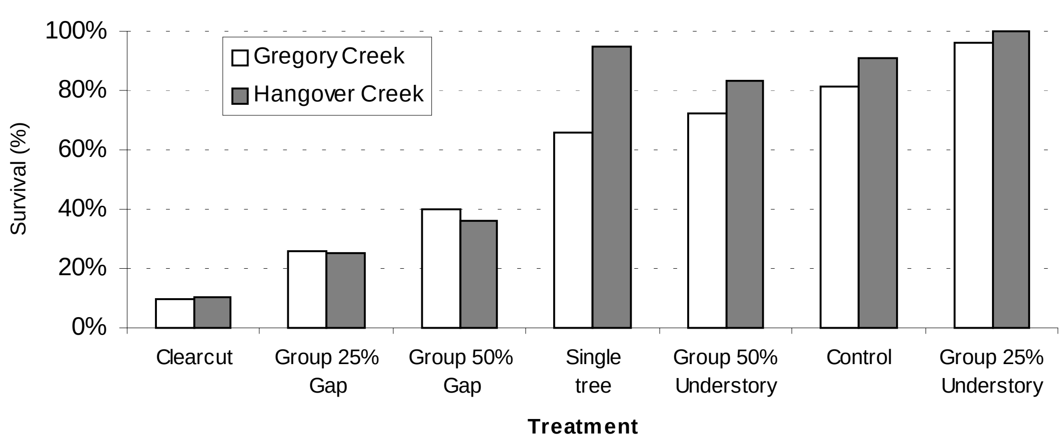


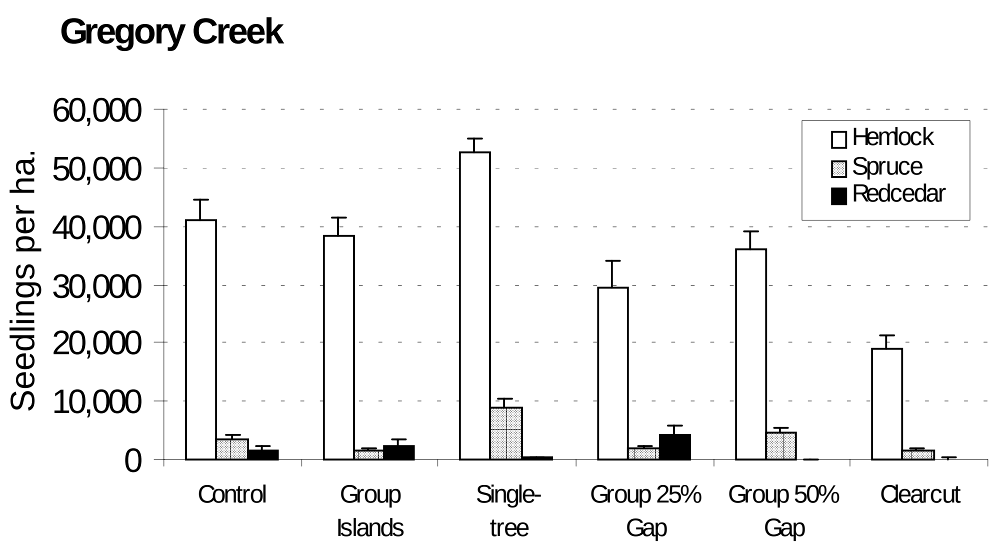
Figure 9. Post-harvest survival (%) of advanced hemlock regeneration



Post-harvest natural regeneration

Western hemlock dominated natural regeneration composition seven years after harvesting, representing over 74% and 82 % of total density at Gregory and Hangover Creek respectively (Figure 10). Both total regeneration density and hemlock regeneration density were significantly different between treatments (Appendix 13). Redcedar failed to regenerate at Hangover Creek despite greater density of redcedar within the stand compared with Gregory Creek. Lowest natural regeneration densities were within clearcuts in both locations. Distribution of natural regeneration within treatment units followed a similar pattern regardless of treatment (Appendix 14). Western hemlock was the most widely distributed of the three species, represented in over 90% of assessment plots. Sitka spruce, far less abundant than hemlock, was sampled in over 50% of plots, more widely distributed than cedar in most treatment units. Mean height of naturally-regenerated hemlock was greater than of natural spruce, planted redcedar with Vexar® and planted spruce in all treatments but the clearcut, where planted Sitka spruce exceeded the height of other regeneration (Figure 11).

Figure 10. Seventh-year natural regeneration density by treatment and species



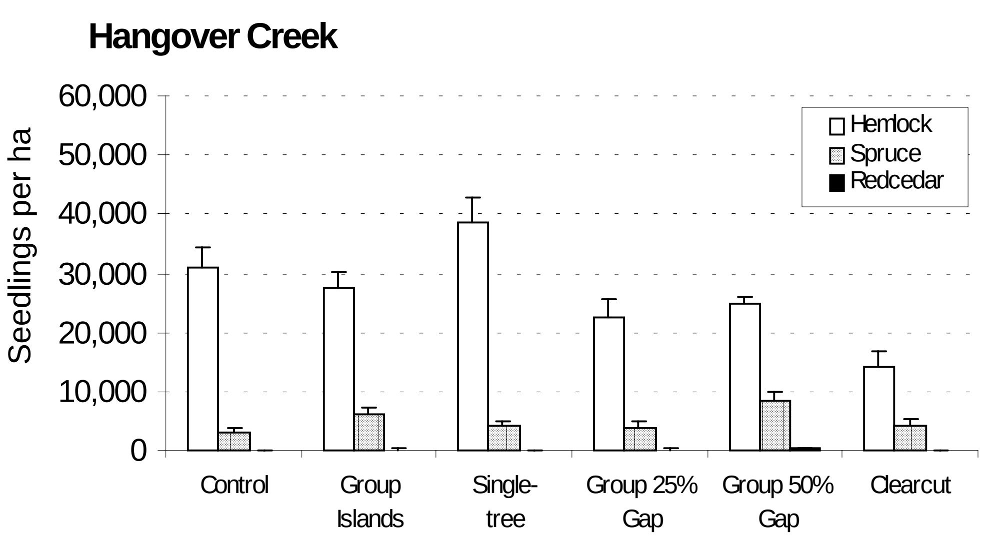
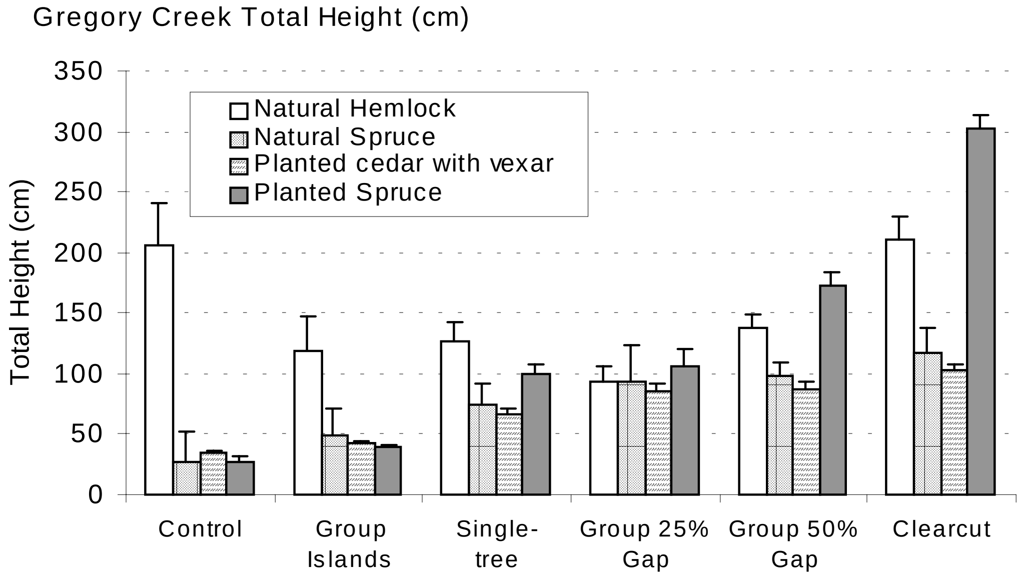
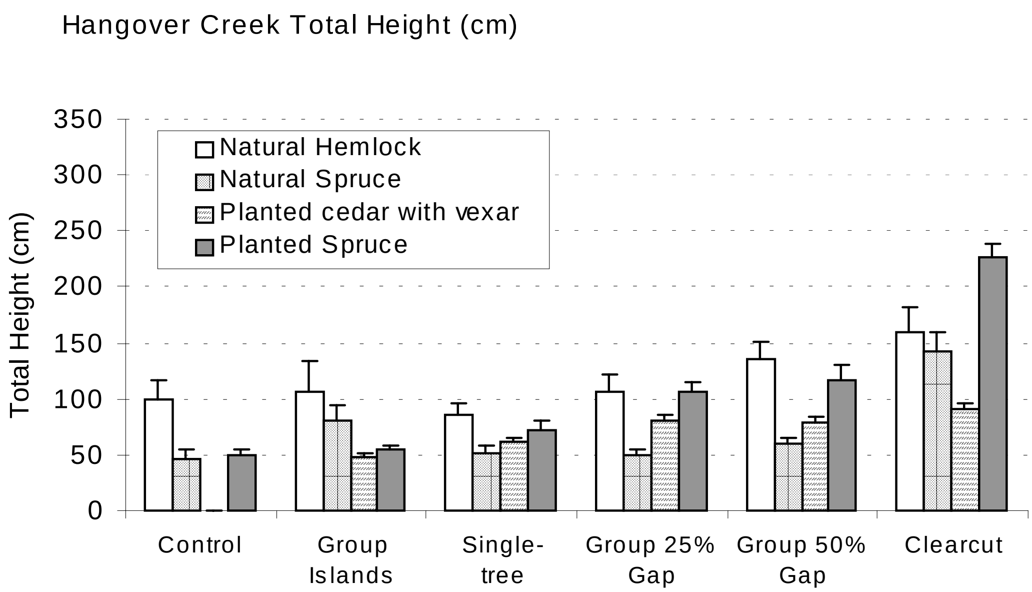


Figure 11. Seventh-year total height of dominant natural regeneration and average planted regeneration by species, treatment and location.





Summary and conclusions

This trial evaluated the potential of group and single-tree selection for harvesting and regenerating forest stands on steep-sloped sites considered sensitive to traditional harvesting practices. The results identify some early consequences of these alternatives to meeting regeneration objectives.

Hand falling and helicopter yarding proved capable of creating small gaps (less than 0.3 ha) and of removing single trees with little disturbance to forest floor. Smaller gaps, down to 700 m^2 (30 meter radius) have been created in old growth hemlock / spruce forests of southwest Alaska, although falling and yarding difficulties were encountered (Anon 1999). Gaps between 2800 m^2 and 6400 m^2 were considered more operationally efficient. Pendl (1994) suggested that due to safety issues, including providing suitable helicopter landing pads for emergency purposes on sites with limited access, openings should not be smaller than 1 ha, and should be placed on terraces or gently sloping terrain. Along with safety issues, forest type, specific site conditions including slope, and yarding methods (ground based, cable yarding or helicopter) will affect the practical and minimum gap size.

Harvesting within the group selection treatment units came closer than single-tree selection to meeting post-harvest stand structural goals while resulting in less damage to the residual stand. In the single-tree selection units, greater volumes were cut than were prescribed. Single tree selection is an operational challenge in closed-canopy old growth stands, and when misapplied, can significantly change species composition due to the removal of few large-diameter trees. Successful application of single-tree selection requires high levels of communication with all members of the logging crew, including clearly describing the prescription. The species present on these sites are rated as highly susceptible to decay according to the Tree Wounding and Decay Guidebook (BCMOF 1997). This combined with a retention period of at least 25 years till the next entry makes the potential for harvesting-induced tree decay a relevant issue when assessing the long-term success of these systems. Subsequent stand inventories in both locations should make special note of disease indicators reflecting changes in disease incidence. Dwarf mistletoe infection of regenerating hemlock within gaps and single-tree selection units is another longer-term issue. Research suggests ‘selective harvesting’ increases mistletoe infections (Buckland and Marples 1952: Shea 1966; Stewart 1976), while clearcutting can reduce parasite incidence (Shaw 1982; Shaw and Hennon 1991). Continued monitoring of natural regeneration within the different treatment units in this study will provide more knowledge of the long-term behaviour of mistletoe within both clearcut and partially-cut stands.

From a silvicultural perspective, the natural regeneration within harvested gaps is similar in species composition to that within clearcuts. The similar proportion of hemlock to Sitka spruce in all treatments supports the results of studies in southwest Alaska that determined that pre-harvest stand composition in mixed Sitka spruce and western hemlock stands was more responsible for species mixture than cutting intensity (Duncan 1999). Total natural regeneration density exceeds the maximum allowable stocking based on current guidelines (BCMOF 1995) and group selection appears to enhance natural regeneration establishment over that in a clearcut. Hemlock domination has management implications in the wetter 05 and 06 site series where Sitka spruce and redcedar are recommended for regeneration. Planting will allow Sitka spruce to compete with the dense (but initially slower-growing) hemlock by increasing early height growth over natural regeneration. Planting and browsing protection is essential if redcedar is to remain a component of the forest stand. Sitka black-tailed deer, perhaps a factor for low natural regeneration redcedar development at Gregory and the almost complete absence of redcedar at Hangover, has also been recognised as a negative factor in the establishment of other vegetation species (Banner 1989). Neither group nor single-tree selection provided any practical reduction in deer browsing pressure in this study.

Conifer growth reductions in gaps compared with that in clearcuts have been documented by Coates (1998) in the Interior Cedar-Hemlock zone, a transitional zone between interior and coastal conditions in areas of northwest British Columbia. He found that within a range of gap sizes, growth of spruce and redcedar levelled off, reaching growth similar to that under clearcut conditions for gaps between 1000 m^2 and 5000 m^2 in size. Results at Hangover and Gregory Creek suggest that gaps greater than 3000 m^2 are required if growth rates comparable to clearcutting are required. Lower shade tolerance in the wetter climate of the Queen Charlotte Islands may in part explain the larger gap size requirements found in this study, although slope and aspect differences are also factors to consider in explaining the differences.

Designing alternatives to clearcutting to maintain structural components of natural stands have increasingly considered the natural disturbance processes of the ecosystem. Ecosystems typical of the Hangover and Gregory Creek areas are classified as “Natural Disturbance Type 1” with rare stand-initiating events (return period of 250 years). These stands regenerate following the death of individual trees or groups of trees from disease, insects and windthrow (BCMOF 1985a). Single-tree selection prescriptions include a cutting pattern that simulates this small gap natural stand initiation and maintains multi-aged stand structure in the harvested stand. The other and more conspicuous agents for stand re-initiation include landslides and larger-scale windthrow, which is the most widespread agent for large-scale natural disturbance in southeast Alaska (Nawicki and Kramer 1998). Group selection could be considered a means to simulate both landslides and smaller windthrow events. Slope stability and aesthetics objectives become limit controlling factors as opening sizes approach clearcutting. Application of either prescription must recognise that regeneration commitments can be met, although with additional stocking control in gaps, lengthening the time period to meet free-growing height requirements, and perhaps longer term reductions in plantation growth rates.

Monitoring of the Hangover and Gregory Creek sites provides experience with different approaches for harvesting these steep-sloped sites and provides some indication of regeneration dynamics within gaps and under single-tree selection. The long-term impact of harvesting on slope stability remains an issue as roots of cut stumps continue to deteriorate, reducing their stabilising influence. The long-term effect of the tested systems on windthrow and forest health remain to be documented. Monitoring of both sites over the next 10 to 20 years will provide direction data as to the suitability of prescriptions on these and similar sites.

References

Anon 1999. Science Findings Award – Submission Form – Silvicultural alternatives to clearcutting in the old-growth forests of Southwest Alaska.

Banner A., J Pojar, J. Schwab and R. Trowbridge. Vegetation and soils of the Queen Charlotte Islands: Recent Impacts of Development. Pp. 261-279. In: G.G.E. Scudder & N. Gessler (eds.), The Outer Shores: Based on the Proceedings of the Queen Charlotte Islands First International Scientific Symposium, University of British Columbia, August 1984 327 pp.

B.C. Ministry of Forests. (BCMOF). 1995. Forest Practices Code of British Columbia mapping and assessing terrain stability guidebook. B.C. Ministry of Forests and B.C. Ministry of Environment. Victoria.

B.C. Ministry of Forests. (BCMOF). 1995a. Biodiversity Guidebook. Forest Practices Code of British Columbia B.C. Ministry of Forests and B.C. Ministry of Environment. Victoria. 99p.

B.C. Ministry of Forests (BCMOF). 1995. Establishment to Free Growing Guidebook. . Forest Practices Code of British Columbia . April 1995. B.C. Ministry of Forests and B.C. Ministry of Environment. Victoria. 130p.

B.C. Ministry of Forests (BCMOF). 1997. Tree Wounding and Decay Guidebook. March 1997. B.C. Ministry of Forests and B.C. Ministry of Environment. Victoria. 19p.

Buckland, D.C. and Marples, E.G. 1952. Management of western hemlock infested with mistletoe. B.C. Lumberman, 36.

Duncan, S. 1999. (Editor). Alternatives to clearcutting of old growth in Southeast Alaska. Science findings. Pacific Northwest Research Station. Issue #19. October 1999.

Green, R.N. and K. Klinka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. B.C. Min. For., Victoria, B.C.

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 *In* Carnation Creek and Queen Charlotte Island. Fish/Forestry Workshop : applying 20 years of coast research to management solutions. Editors D.L. Hogan, P.J. Tschaplinski and S. Chatwin. B.C. Min. For., Res. Br., Victoria, B.C. Land Manage. Handbook ; 41

Nowacki, G.J. and M.G. Kramer. 1998. The effects of wind disturbance on temperate rain forest structure and dynamics of southeast Alaska. Gen. Tech. Rep. PNW-GTR-421. Portand Oregon U.S. Dept. Aric. For Serv., Pac Northwest Res Stat. 25p.

Pendl, F. 1994. Alternative Silvicultural Systems for Environmentally Sensitive Sites on Steep Slopes—An Operational Trial - Establishment Report – Unpublished. B.C. Min Forests.

Sanders, P.W. and D.J. Wilford. 1986. Silvicultural alternatives for the management of unstable sites in the Queen Charlotte Islands: A literature review and recommendations. . B.C. Min Forests Land Management Report Number 42. Victoria B.C.

Sauder E.A., R.K. Krag, and G.V. Wellburn. 1987. Logging and mass wasting in the Pacific Northwest with application to the Queen Charlotte Islands, B.C.: A Literature review. Land Management Report No. 53. B.C. Ministry of Forests and Lands and Forest Engineering Research Institute of Canada. Western Division, Vancouver, B.C..

Shaw, C.G., III. 1982. Development of dwarf mistletoe in western hemlock regeneration in southeast Alaska. Can J. For. Res. 12: 482-488.

Shaw, C.G. III and P.H. Hennon,. 1991. Spread, intensification, and upward advance of dwarf mistletoe in thinned young stands of western hemlock. Plant Dis. 75: 363-367.

Shea, K.R. 1966. Dwarf mistletoe of coastal western hemlock: principles and practices for control. For. Pap. No. 9. Forest Research Center, Weyerhaeuser Timber Co. Centralia Wash.

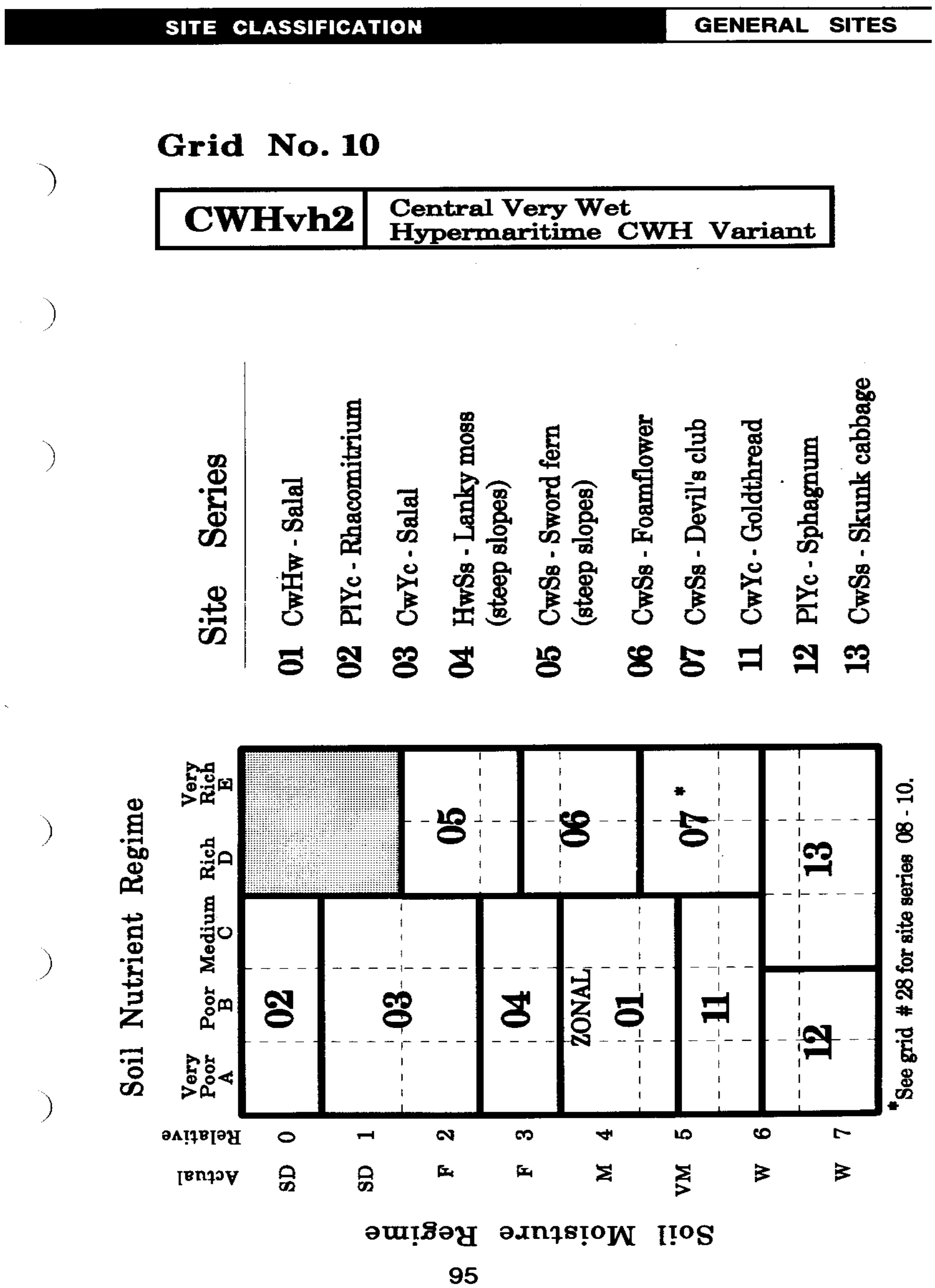
Sinomar K.B. 1991. Ecological site description of silvicultural systems research trials at Hangover and Gregory Creeks on the west coast of the Queen Charlotte Islands. Internal report for B.C. Ministry of Forests. Vancouver Forest region. October 1991.

Stewart, J.L. 1976. Dwarf mistletoe infection from residual western hemlock on cutover stands. USDA For Serv. Pac. Northwest For. Range Exp. Stn. Res. Note No. PNW-278

Sullivan, T.P., A.S. Harestad, and B.M. Wikeem. 1990. Control of mammal damage in Regenerating British Colmbia's Forests. 1990. Lavender D.P. et al Editors. UBC Press. Gov. of B.C.

Tripp, D.B. and V.A. Poulin. 1986. The effects of mass wasting on Juvenile Fish Habitats in streams on the Queen Charlotte Islands. Land Management Report No. 45. B.C. Ministry of Forests and Lands. Victoria, B.C.

Appendix 1. Site classification grid – CWHvh2 (From Green and Klinka 1994)



Appendix 2. Defects of overstory trees by location and species: pre-harvest

	Gregory		Hangover	
	Hemlock	Redcedar	Hemlock	Redcedar
Scars	29%	33%	21%	37%
Fork/Crooks	32%	33%	25%	24%
Frost Crack	3%	2%	3%	-
Mistletoe	16%	-	2%	-
Conks	1%	-	1%	-

Appendix 3. Soil surface substrate: pre- and post-harvest

Substrate	Single-tree		Group 25%		Group 50%		Clearcut		Control	
Gregory Creek	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
• Wood	46%	43%	31%	37%	19%	21%	19%	63%	44%	21%
• Organic Material	51%	56%	68%	60%	80%	78%	80%	33%	55%	74%
• Mineral soil	3%	1%	0%	2%	1%	0%	2%	4%	1%	4%
• Rock	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hangover										
• Wood	36%	16%	31%	25%	28%	33%	24%	35%	32%	27%
• Organic Material	58%	79%	60%	64%	61%	50%	66%	58%	59%	64%
• Mineral soil	1%	2%	3%	7%	2%	10%	1%	4%	1%	2%
• Rock	5%	3%	6%	5%	8%	7%	10%	3%	8%	7%

Appendix 4. Results of Analysis of variance – planted regeneration 7th year survival

```
Source                  DF   Mean Square    Error Term                 F Value      P-value
BLOCK                   1    0.00123920      ---               ---       ---
TREAT                   3    0.28372982      BlOCK*TREAT                1.21         0.4391
BLOCK*TREAT             3    0.23413408      ---              ---       ---
SPECIES                 2    6.61663634      BLOCK*SPECIES              231.88       0.0043
BLOCK*SPECIES           2    0.02853458      ---               ---       ---
TREAT*SPECIES           6    0.16801081      BLOCK*TREAT*SPECIES        2.43         0.1516
BLOCK*TREAT*SPECIES     6    0.06901517      ---               ---       ---
OBS(BLOCK TREAT SPCS) 419    0.11245371

Contrast                       DF  Mean Square                            F Value      P-value
Redcedar vs Cedar with Vexar    1   6.97525260                           6.97525260    0.0001
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Appendix 5. Frequency of branch and leader browsing of planted regeneration by treatment, species and location.

		Gregory Creek			Hangover Creek		
Condition		Redcedar	Redcedar with vexar	Sitka spruce	Redcedar	Redcedar with vexar	Sitka spruce
a) Branch Browsing							
Control		100 %	42.2 %	14.3 %	80 %	.	5.3 %
Single-tree		80.0 %	56.9 %	73.8 %	57.7 %	23.8 %	34.5 %
Group 25%	Gap	83.3 %	27.8 %	25.9 %	91.6 %	38.1 %	45.7 %
	Understory	83.3 %	24.3 %	36.6 %	100 %	28.6 %	31.8 %
Group 50%	Gap	76.5 %	34.1 %	3.8 %	83.3 %	51.7 %	51.7 %
	Understory	85.7 %	16.6 %	25.0 %	37.5 %	18.8 %	36.4 %
Clearcut		82 %	62.5 %	87.1 %	89.2 %	78.6 %	79.8 %
b) Leader browsing							
Control		100 %	35.5 %	57.1 %	70 %	.	5.3 %
Single-tree		73.3 %	44.8 %	43.8 %	58.3 %	14.9 %	9.1 %
Group 25%	Gap	83.3 %	27.6 %	18.5 %	91.6 %	16.6 %	2.2 %
	Understory	100 %	37.8 %	50.0 %	100 %	0 %	0 %
Group 50%	Gap	76.5 %	14.6 %	5.8 %	34.5 %	34.4 %	13.8 %
	Understory	100 %	13.3 %	18.75 %	37.8 %	9.0 %	13.6 %
Clearcut		75.9 %	41.1 %	3.8 %	89.2 %	54.3 %	1.2 %

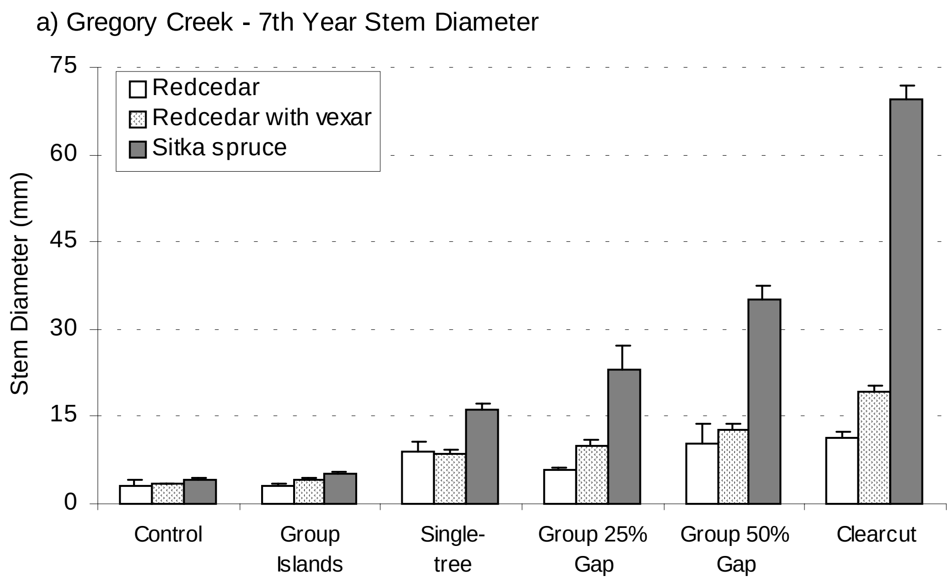
Appendix 6. Analysis of variance of leader browsing frequency

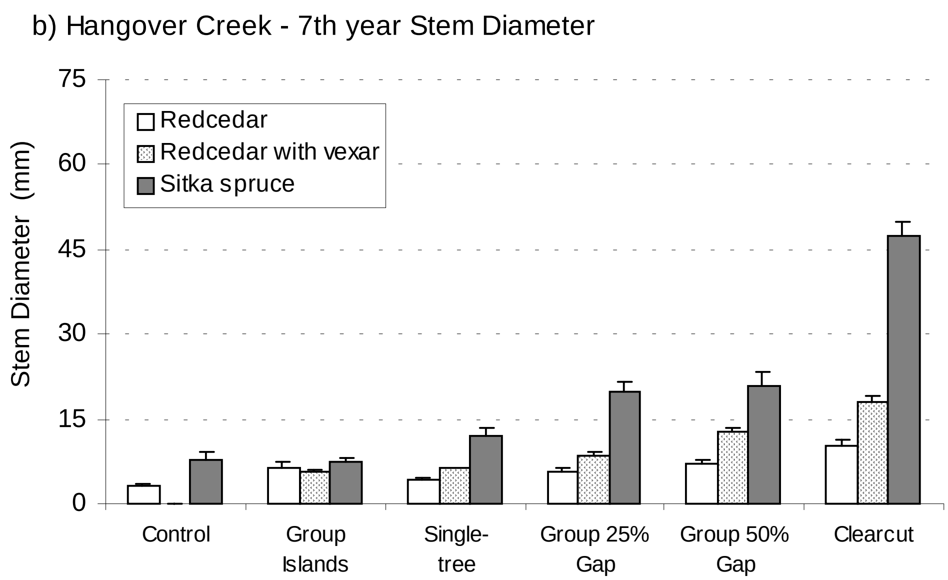
Source	DF	Mean Square	Error term	F Value	Pr > F
BLOCK	1	0.01107766		0.13	0.7145
TREAT	4	0.08502852	BLOCK*TREAT	0.25	0.8960
BLOCK*TREAT	4	0.34007723		4.11	0.0027
SPECIES	2	1.11181270	BLOCK*SPECIES	7.43	0.1186
BLOCK*SPECIES	2	0.14960383		1.81	0.1648
TREAT*SPECIES	8	0.22167248	BLOCK*TREAT*SPECIES	2.48	0.1242
BLOCK*TREAT*SPECIES	7	0.08935702		1.08	0.3744

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	0.06375410	0.77	0.3804

Appendix 7. Planted regeneration 7th-year stem diameter, by location.

(Error bars are 1 SE)





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Appendix 8. Results of analysis of variance – planted regeneration 7th year total height and 7th year stem diameter

Dependent variable: 7th year total height

Source	DF	Mean Square	Error term	F Value	P Value
BLOCK	1	24546.106358		12.64	0.0004
TREAT	3	138878.16960	BLOCK*TREAT	29.86	0.0098
BLOCK*TREAT	3	4651.6116056		2.40	0.0678
SPECIES	2	382403.50367	BLOCK*SPECIES	37.21	0.0262
BLOCK*SPECIES	2	10277.142361		5.29	0.0054
TREAT*SPECIES	6	85603.128826	BLOCK*TREAT*SPECIES	26.19	0.0005
BLOCK*TREAT*SPECIES	6	3268.107421		1.68	0.1236
OBS (BLOCK TREAT SPECIES)	419	1942.15			

Dependent variable: 7th year stem diameter

Source	DF	Mean Square	Error term	F Value	P Value
BLOCK	1	1492.011896		15.50	0.0001
TREAT	3	10271.65123	BLOCK*TREAT	40.06	0.0064
BLOCK*TREAT	3	256.4311871		2.66	0.0476
SPECIES	2	17585.88588	BLOCK*SPECIES	18.87	0.0503
BLOCK*SPECIES	2	931.7265118		9.68	0.0001
TREAT*SPECIES	6	4273.481556	BLOCK*TREAT*SPECIES	13.96	0.0027
BLOCK*TREAT*SPECIES	6	306.123142		3.18	0.0046
OBS (BLOCK TREAT SPECIES)	419	96.3			

Appendix 9. Analysis of variance: planted regeneration – 7th-year height and stem diameter by species

------------------------------- SPECIES = Redcedar-------------------------------------

Dependent variable: 7th year total height

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	391.78122358		0.58	0.4476
TREAT	3	590.29737006	BLOCK*TREAT	1.78	0.3241
BLOCK*TREAT	3	332.03227543		0.49	0.6882
Obs (BLOCK TREAT)	97	673.87005365			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	509.16050364	0.76	0.3869

Dependent variable: 7th Year stem diameter

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	37.29414494		1.61	0.2079
TREAT	3	166.65421492	BLOCK*TREAT	28.46	0.0105
BLOCK*TREAT	3	5.85674338		0.25	0.8594
OBS (BLOCK TREAT)	97	23.20001981			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	243.52322213	10.50	0.0016

--------------------------------- SPECIES = Redcedar with Vexar-----------------------

Dependent variable: total height – Year 7

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	2697.01897527		3.60	0.0595
TREAT	3	10013.25746049	BLOCK*TREAT	75.96	0.0025
BLOCK*TREAT	3	131.81963429		0.18	0.9124
Error	159	748.40255048			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	4627.56654881	6.18	0.0139

Dependent variable: stem diameter – Year 7

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	27.03642130		1.07	0.3020
TREAT	3	1112.09006528	BLOCK*TREAT	127.08	0.0012
BLOCK*TREAT	3	8.75097896		0.35	0.7913
Error	159	25.21414378			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	1205.85358978	47.82	0.0001

Appendix 9 (Con't)

-------------------------------- SPECIES= Sitka Spruce --------------------------------

Dependent variable: total height – Year 7

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	50485.00378342		13.07	0.0004
TREAT	3	344576.14433661	BLOCK*TREAT	27.89	0.0108
BLOCK*TREAT	3	12354.12529867		3.20	0.0249
Error	163	3861.34700998			

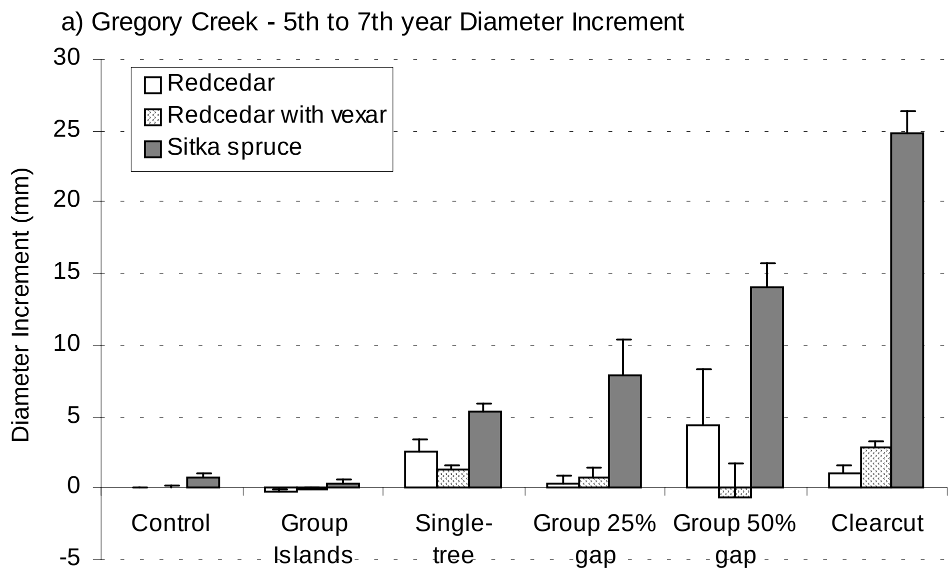
Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	603813.20243087	156.37	0.0001

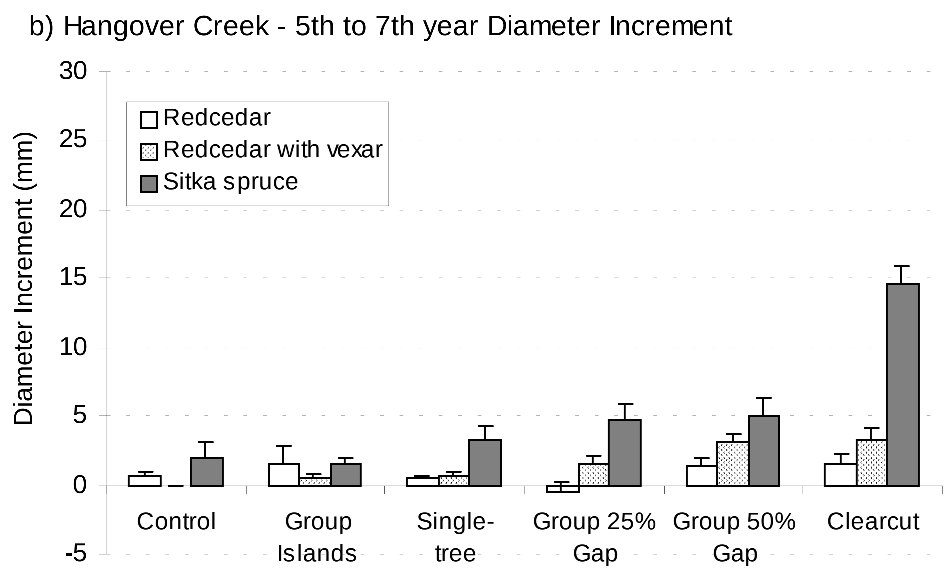
Dependent variable: stem diameter – Year 7

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	3769.35756600		18.03	0.0001
TREAT	3	20374.25225852	BLCOK*TREAT	21.11	0.0160
BLOCK*TREAT	3	960.17816064		4.59	0.0041
Error	163	209.05056572			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	34183.42724229	163.52	0.0001

Appendix 10. Planted regeneration 5th to 7th year stem diameter increment





Appendix 11. Analysis of variance: Planted regeneration- 5th to 7th Year height and stem diameter growth

Dependent Variable: 5th to 7th year height Increment

Source	DF	Mean Square	Error Term	F Value	Pr > F
BLOCK	1	4956.64008509		8.70	0.0034
TREAT	3	18008.77089557	Block*Treat	58.63	0.0037
BLOCK*TREAT	3	307.15226983		0.54	0.6555
SPECIES	2	99471.85509487	Block*Species	55.74	0.0176
BLOCK*SPECIES	2	1784.69613004		3.13	0.0446
TREAT*SPECIES	6	22816.62797934	Block*Treat*Species	63.39	0.0001
BLOCK*TREAT*SPECIES	6	359.91363845		0.63	0.7046
Obs (Block Treat Species)	413	569.4			

Contrast	DF	Mean Square	F Value	Pr > F
Redcedar vs vexared Cedar	1	6415.72778298	11.27	0.0009
Both Cedar vs spruce	1	198935.67725672	349.37	0.0001

Dependent Variable: 5th to 7th year stem diameter Increment

Source	DF	Mean Square	Error Term	F Value	Pr > F
BLOCK	1	296.67158673		8.56	0.0036
TREAT	3	898.82061672	BLOCK*TREAT	29.41	0.0100
BLOCK*TREAT	3	30.56040555		0.88	0.4505
SPECIES	2	3041.13967879	BLOCK*SPECIES	5.98	0.1432
BLOCK*SPECIES	2	508.33850808		14.67	0.0001
TREAT*SPECIES	6	608.80404655	BLOCK*TREAT*SPECIES	5.63	0.0271
BLOCK*TREAT*SPECIES	6	108.19394977		3.12	0.0053
Obs (Block Treat Species)	413	34.65990543			

Contrast	DF	Mean Square	F Value	Pr > F
Redcedar vs vexared Cedar	1	6.66194943	0.19	0.6613
Both Cedar vs spruce	1	5961.98136054	172.01	0.0001

Appendix 12. Analysis of variance, by species: Planted regeneration- 5th to 7th Year height and stem diameter growth

---------------------------- SPECIES= Sitka Spruce ------------------------------------

Dependent Variable: 5th to 7th year height growth

Source	DF	Mean Square	Error term	F Value	Pr > F
BLOCK	1	1373.99656935		22.05	0.0001
TREAT	3	71644.06629688	BLOCK*TREAT	84.24	0.0021
BLOCK*TREAT	3	220.58226587		3.54	0.0160
OBS (Block Treat)	163	1050.22			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs gaps	1	112596.24491298	107.21	0.0001

Dependent Variable: 5th to 7th year stem diameter growth

Source	DF	Mean Square		F Value	Pr > F
BLOCK	1	1373.99656935	BLOCK*TREAT	22.05	0.0001
TREAT	3	2407.77875090		10.92	0.0402
BLOCK*TREAT	3	220.58226587		3.54	0.0160
OBS (Block Treat)	163	62.32129366			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	3964.09468676	63.61	0.0001

------------------------ SPECIES = Redcedar with Vexar----------------------------

Dependent Variable: 5th to 7th year height growth

Source	DF	Mean Square	Error term	F Value	Pr > F
BLOCK	1	238.87405323		0.79	0.3760
TREAT	3	131.25215554	BLOCK*TREAT	2.07	0.2822
BLOCK*TREAT	3	63.27884379		0.21	0.8902
OBS (Block Treat)	163	303.08022835			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs gaps	1	273.32165924	0.90	0.3437

Dependent Variable: 5th to 7th year stem diameter growth

Source	DF	Mean Square	Error term	F-Value	Pr > F
BLOCK	1	44.86629299		2.32	0.1301
TREAT	3	47.91211534	BLOCK*TREAT	1.14	0.4593
BLOCK*TREAT	3	42.14431052		2.18	0.0931
OBS (Block Treat)	163	19.37438939			

Contrast	DF	Mean Square	F-Value	Pr > F
Clearcut vs Gaps	1	103.78031694	5.36	0.0219

Appendix 12 (con't)

---------------------------- SPECIES = Redcedar------------------------------------

Dependent Variable: 5^{th} to 7^{th} year height growth

Source	DF	Mean Square	Error Term	F Value	Pr > F
BLOCK	1	377.65750842		2.16	0.1452
TREAT	3	107.68451817	BLOCK*TREAT	0.47	0.7258
BLOCK*TREAT	3	230.35226122		1.32	0.2738
OBS (Block Treat)	163	174.94651761			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	57.34529505	0.33	0.5684

Dependent Variable: 5^{th} to 7^{th} year stem diameter growth

Source	DF	Mean Square	Error term	F Value	Pr > F
BLOCK	1	5.83147070		0.49	0.4857
TREAT	3	9.36533544	BLOCK*TREAT	1.18	0.4469
BLOCK*TREAT	3	7.92150606		0.67	0.5753
Obs (Block Treat)	92	11.90235383			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Gaps	1	4.26756909	0.36	0.5508

Appendix 13. Analysis of variance – total density of natural regeneration: pre-harvest and post-harvest

Dependent variable: natural regeneration density: pre-harvest

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	130.47847654	BLOCK*TREAT	3.06	0.1551
TREAT	4	52.06690348	BLOCK*TREAT	1.22	0.4254
BLOCK*TREAT	4	42.61873084		1.71	0.1494
Error	246	24.99373110			

Dependent variable: natural regeneration density: 7^{th}-year post-harvest

Source	DF	Mean Square	ERROR TERM	F Value	Pr > F
BLOCK	1	7521.27636902	BLOCK*TREAT	12.81	0.0232
TREAT	4	8697.55359852	BLOCK*TREAT	14.82	0.0115
BLOCK*TREAT	4	586.96490667		1.27	0.2808
Error	295	461.22235318			

Contrast	DF	Mean Square	F Value	Pr > F
Clearcut vs Control	1	12939.69515692	28.06	0.0001
Clearcut vs Gaps	1	8775.30124106	19.03	0.0001

Appendix 14. Distribution of natural regeneration by location and treatment.
Figures represent percentage of plots containing at least one sample of each of the three main species.

Location / Treatment		Sitka spruce		Western redcedar		Western hemlock	
Gregory Creek		Pre-Harvest	Post-Harvest	Pre-Harvest	Post-Harvest	Pre-Harvest	Post-Harvest
Control	.	0 %	45 %	0 %	22.6 %	71 %	93.5 %
Single tree	.	4 %	93 %	0 %	21.4 %	50 %	100 %
Group 25%	Gap	0 %	56 %	0 %	59.3 %	40.7 %	100 %
	Understory	0 %	57 %	0 %	42.9 %	60 %	100 %
Group 50%	Gap	0 %	93 %	0 %	2.6 %	41 %	100 %
	Understory	5 %	38 %	0 %	9.5 %	90.5 %	90.5 %
Clearcut	.	4 %	57 %	0 %	10 %	70 %	96.7 %
Hangover Creek							
Control	.	0 %	53 %	0 %	3.3 %	66.7 %	100 %
Single tree	.	0 %	60 %	0 %	10 %	40 %	96.7 %
Group 25%	Gap	7 %	83 %	0 %	3.3 %	36.7 %	90 %
	Understory	0 %	83 %	0 %	13.3 %	16.7 %	90 %
Group 50%	Gap	0 %	97 %	3 %	13.3 %	36.7 %	100 %
	Understory	0 %	70 %	3 %	3.3 %	30 %	100 %
Clearcut	.	0 %	70 %	0 %	0 %	56.7 %	93.3 %

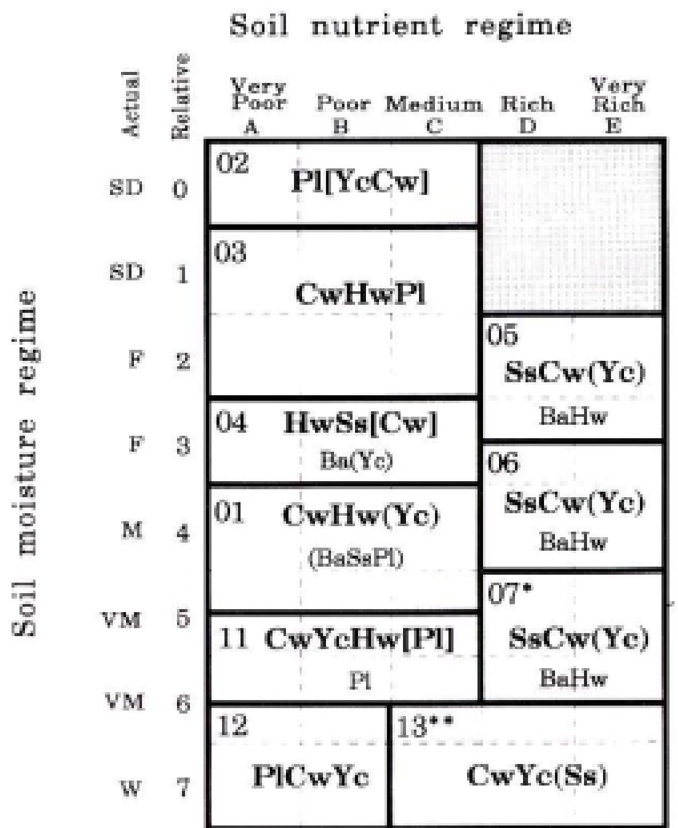
Appendix 15. Post-harvest natural regeneration density by location, treatment and species

				Group 25%		Group 50%		
		Control	Singletree	Understory	Gap	Understory	Gap	Clearcut
Gregory Creek	Western Hemlock	41,129	52,655	43,714	29,370	33,286	36,026	18,833
	Sitka Spruce	3,323	8,862	2,200	1,815	857	4,769	1,633
	Western Redcedar	1,484	310	4,629	4,444	95	26	167
	Total Density	45,935	61,828	50,543	35,630	34,238	40,821	20,633
	% Hemlock	**90%**	**85%**	**86%**	**82%**	**97%**	**88%**	**91%**
	% Spruce + redcedar	**7%**	**14%**	**4%**	**5%**	**3%**	**12%**	**8%**
Hangover Creek	Western Hemlock	31,067	38,700	26,167	22,433	28,700	24,933	14,167
	Sitka Spruce	3,133	4,067	6,833	3,967	5,567	8,433	4,033
	Western Redcedar	67	0	267	133	33	267	0
	Total Density	34,267	42,767	33,267	26,533	34,300	33,633	18,200
	% Hemlock	91%	90%	79%	85%	84%	74%	78%
	% Spruce + redcedar	**9%**	**10%**	**21%**	**15%**	**16%**	**25%**	**22%**

Appendix 16. Recommended tree species grid – CWHvh2
(from Green and Klinka 1994)

Grid No. 10

CWHvh2	Central Very Wet Hyperimaritime CWH Variant



See comments on facing page
* See grid # 28 for site series 08 - 10
** See grid # 33 for site series 14 - 18

Site series

01 CwHw - Salal
02 PlYc - Rhacomitrium
03 CwYc - Salal
04 HwSs - Lanky moss (steep slopes)
05 CwSs - Swordfern (steep slopes)
06 CwSs - Foamflower
07 CwSs - Devil's club
11 CwYc - Goldthread
12 PlYc - Sphagnum
13 CwSs - Skunk cabbage