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Roberts Creek Study Forest: Harvesting, windthrow and conifer regeneration within alternative silvicultural systems in Douglas-fir dominated forests on the Sunshine Coast

by

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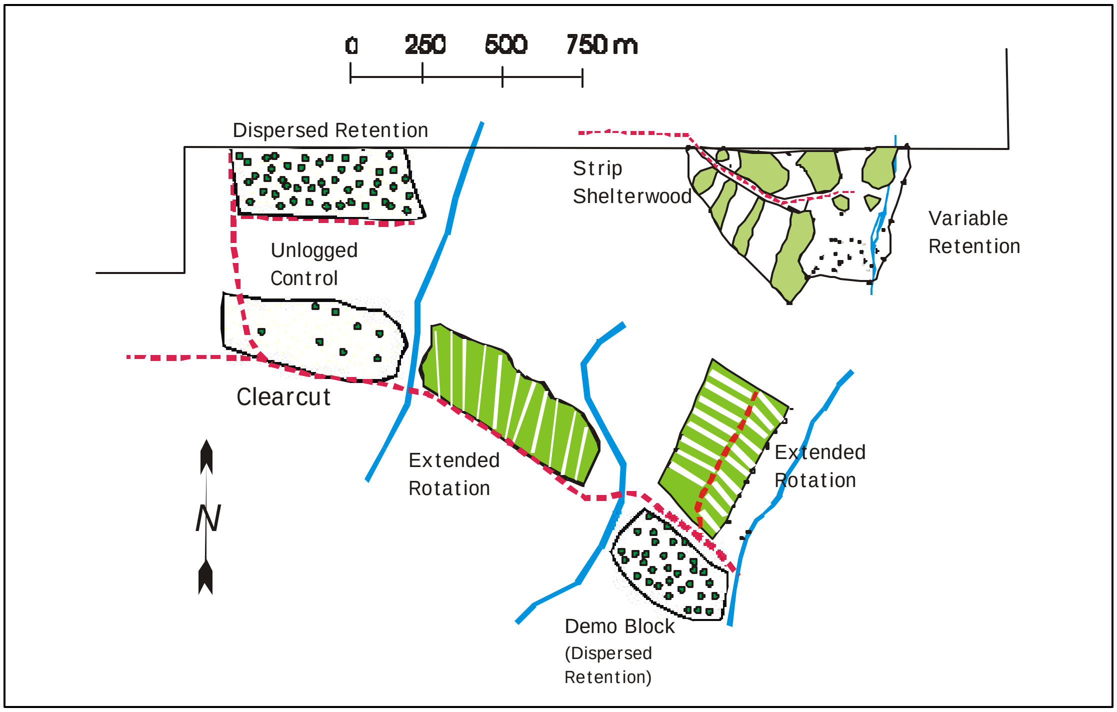

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Cover photo: Site diagram of Roberts Creek Study Forest, showing the silvicultural systems established as of January 2000.

TABLE OF CONTENTS

Tables:

Figures:

SUMMARY

Throughout British Columbia (BC), social, legislative, and stewardship issues are driving forest managers to evaluate alternatives to clearcutting for harvesting and managing forests. The BC Ministry of Forests established the Roberts Creek Study Forest (RCSF) to demonstrate and evaluate different harvest treatments in mature, mixed-conifer forests along the lower slopes of the Sunshine Coast, just north of Vancouver, BC . Selected treatments were designed to meet a variety of biological, social, and economic objectives and had management objectives in common, including: regenerate with Douglas-fir (primary species) and western redcedar (secondary species) for sawlog production, and employ cable yarding systems to minimize soil disturbance.

The RCSF evolved into a collection of adaptive management case studies. By 2001, seven blocks ranging between 8 and 19 ha were harvested, demonstrating clearcut with reserves, two dispersed retention treatments (57 and 95 predominantly Douglas-fir stems per ha), variable retention, strip shelterwood and two prescriptions of extended stand rotation. Monitoring within harvested treatments included post-harvest soil substrate, windthrow, overstory seed fall, and regeneration development (planted and natural).

Soil disturbance due to cable-yarding was considered low, with less than 3% of any block having thin humus displaced, exposing mineral soil. Windthrow occurred during the first fall / winter storms following harvesting in all treatments, both among dispersed trees and along windward boundaries. Trees immediately beside creeks and in wetter soils were especially susceptible to blowdown. Narrow yarding corridors oriented at right angles to dominant winds within an extended rotation treatment have been effective in limiting windthrow; windthrow was greater where corridors were more parallel to dominant winds. Crown pruning, among dispersed trees and along susceptible boundaries, is recommended for reducing windthrow to meet post-harvest stand structure objectives.

Dispersed retention enhanced natural regeneration (dominated by western hemlock) and reduced planted Douglas-fir and western redcedar seedling growth compared with that in the clearcut, suggesting pre-commercial thinning is required to meet species composition and density objectives. An increasing percentage of Douglas-fir seedlings beneath dispersed retention developed stem galls. Accepting a higher hemlock component beneath dispersed retention has potentially negative longer-term implications to stand development. Natural regeneration in the clearcut was similar to the composition of surrounding forest, and in combination with planting comes closer than dispersed retention to achieving the desired species composition of regenerating plantations.

In this report, early stand development in initial harvest treatments is contrasted with the structure and speculated development of the surrounding mature forests. Modifications to both dispersed retention and clearcut with reserves prescriptions are suggested to provide desired forest structure while maintaining Douglas-fir dominance.

KEY WORDS

forestry, forest management, harvest planning, harvesting, silvicultural systems, dispersed retention, shelterwood, windthrow, stand structure, regeneration, seedfall, Douglas-fir, western hemlock, western redcedar, Vancouver Forest Region, British Columbia.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

Clearcutting has historically been the dominant silviculture system in the Vancouver Forest Region (VFR) of the BC Ministry of Forests (MoF). However, interest in alternatives to clearcutting is gaining momentum among BC forest managers, in response to society's higher expectations of resource stewardship while attempting to provide a greater array of forest-related values. The Forest Practices Code (FPC), introduced in 1995, requires that non-timber values and the ecological complexity of the forest be addressed in forest management plans. Therefore shelterwood, small patch, single tree and group selection harvesting systems, as well as extended rotation systems, are being considered as alternatives to clearcutting.

In the early 1990s, seeking to provide forest managers with more information about alternatives to clearcutting, the South Coast Silviculture Systems Research Co-operative[1] identified priority areas within the VFR for demonstrating and studying alternative silviculture systems. The silviculture research component of the Forest Sciences Section (VFR) initiated research in old-growth, mixed hemlock (*Tsuga heterophylla*)/sitka spruce (*Picea sitchensis*)/ redcedar (*Thuja plicata*) forests on the Queen Charlotte Islands (Pendl 1994; D'Anjou 2001), and in the mature Douglas-fir forests of the coast-interior transition zone near Boston Bar (D'Anjou 1998). A third area, near Roberts Creek on the Sunshine Coast just north of Vancouver (Figure 1), administered by the Sunshine Coast Forest District Small Business Forest Enterprise Program, was considered a priority study area. In this area, the leading species is Douglas-fir *(Pseudotsuga menziesii)*, and there are management issues related to proximity to urban centres and visually sensitive areas.

Subsequently, the Forest Sciences Section of VFR proposed the Roberts Creek Study Forest (RCSF) to demonstrate, evaluate

[1]The Co-operative, composed of representatives from academia, government, and other interested organizations, was established in 1990 to assess potential for co-operation in silvicultural systems research, to identify priority biogeoclimatic subzones and potential research sites, and to highlight potential research topics and methodology. The Co-operative is no longer active.

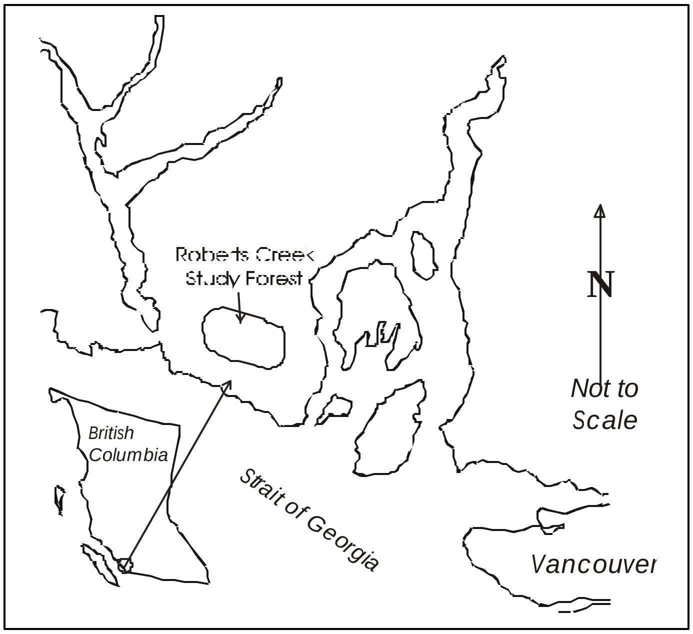


Figure 1. Location of Roberts Creek Study Forest.

and develop silvicultural systems that could potentially be applied to meet a variety of biological, social, and economic objectives. Harvesting in the RCSF began in 1993 with the "Demo Block", where 57 trees per ha (sph) of dominant Douglas-fir and redcedar were retained dispersed throughout the block, gaining both operational and research experience associated with partial cutting (D'Anjou 2001). Original plans were to establish three replications of three harvest treatments, including clearcut with reserves, dispersed retention (95 sph), and an extended rotation prescription, plus unlogged control. One replicate of each of these harvest treatments was completed (Phase 1) before a decision by government to curtail clearcutting in local forests administered by MoF prevented replication. The design of subsequent harvest treatments was primarily driven by hydrology research requirements (variable retention, strip shelterwood)

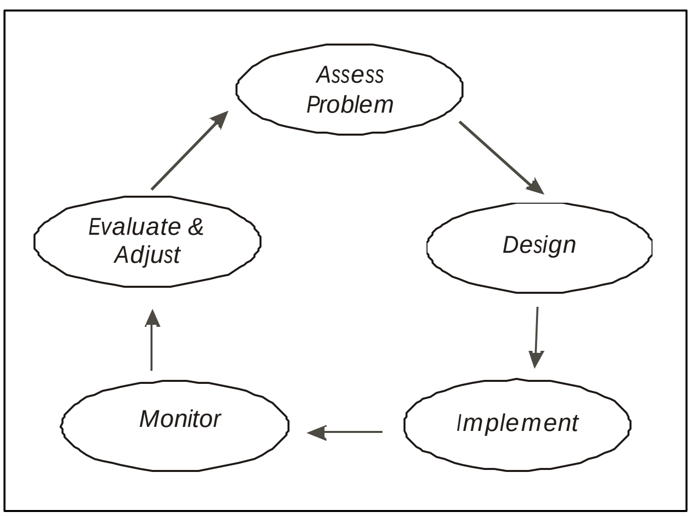


Figure 2. Adaptive management process (from Taylor 1996).

plus an additional extended rotation prescription (Phase 2).

The RCSF is considered a collection of adaptive management case studies where alternatives are designed, implemented, monitored for specific attributes of interest, evaluated by comparing actual outcomes with forecasts, and finally, adjusted as future treatment developments are suggested (Figure 2). Regeneration development and windthrow were attributes of interest and monitored in all harvest treatments. Regeneration development has implications for meeting reforestation goals specified for each harvest treatment, and for meeting long-term target stand structure goals. Research in other ecosystems has shown that the retention of overstory trees affects the growth and development of the regenerating understory which could deviate from or assist in meeting regeneration species composition, target densities and directing future stand development (D'Anjou 2000; D'Anjou 1998). Similarly windthrow has impact on meeting target stand goals. Significant windthrow has been measured (D'Anjou unpub.) or observed (D'Anjou 2000) in other silvicultural systems trials. The objective of regeneration monitoring is to the document the effects of alternative harvest treatments on meeting reforestation goals. The objective of windthrow monitoring is to quantify and characterise blowdown within and along treatment boundaries and assess opportunities for reducing its incidence.

This technical report will provide background to the RCSF, including ecosystem description and a summary of harvest treatments established to 2000 and depicted on the report cover. Results of windthrow monitoring in all harvested blocks, and regeneration monitoring and seedfall collection in Phase 1 treatments and initial demo dispersed retention, will be described and compared with other treatments and with stated objectives. Finally, the success of the dispersed retention, clearcut and extended rotation treatments on meeting long-term stand management goals will be considered and adjustments, if any, suggested for meeting outcomes more effectively.

2.0 STUDY AREA

The Roberts Creek Study Forest, approximately 40 km northwest of Vancouver, BC, lies within the Pacific Ranges Drier Maritime variant of the Coastal Western Hemlock Zone (CWHdm) (Green and Klinka 1994). The climate is characterized by warm, relatively dry summers and moist, mild winters with little snowfall. The blocks encompassing Phase 1 of the RCSF range from 350 to 500 meters above sea level. with gentle slope gradient (average 15%) and southerly aspect. The soils are predominantly classified as Humo-ferric Podzols with loamy sand or sandy loam texture and a thin Humimor forest floor (5 cm depth) (Inselberg 1993). The dominant soils tend to be nutrient poor to medium, and submesic to mesic in moisture, with an average rooting depth of 80 cm before reaching compacted basal till. Wetter (moist to wet) and richer (rich) nutrient conditions were confined to sites associated with ephemeral streams.

Charcoal on standing and fallen snags seen throughout the study area indicates that the current forests initiated following wildfires. Douglas-fir dominates the overstory, although western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) are also found among the tallest trees (Blackwell 1992). Shade-tolerant western hemlock and western redcedar form the understory diameter classes. The sparse understory vegetation is dominated by salal (*Gaultheria shallon*), with a secondary component of western redcedar and western hemlock. The very open herb/dwarf shrub layer is dominated by sword fern (*Polystichum munitum*) and bracken fern (*Pteridium aquilinum*), while the moderately sparse moss/lichen mat is dominated by *Hylocomium splendens* and *Kindbergia oregana* (Inselberg 1991). The site index for Douglas-fir (at 50 years breast height) was estimated at 32 meters (Province of BC 1997).

Initial logging during the 1870s was confined to the harvest of fallen and standing western redcedar for shingle bolts (Hodgins 1933). A shingle bolt camp (McNair's) operated at Roberts Creek in the 1920s (Dawe 1990). Mules, flumes, and later crawler tractors were utilized for cedar extraction. Subsequent harvesting used a network of roads, most of which are still evident. Some

Table 1. Summary of harvest treatments utilized at the Roberts Creek Study Forest.

Demo Block Cypress 6280B swing yarder rigged with a running skyline.

Prescription: *Dispersed Retention* **Block Size:** 7.7 ha
Two harvest entries. First entry retained dominant Douglas-fir and redcedar dispersed throughout the block; second entry reduced stand density to approx. 30 sph.

Site description: Gently sloping (average 11%) with a southwest aspect. Elevation averages 365 m. Humo-ferric Podzols, assessed as fresh to slightly dry in moisture and poor in nutrient status. Soils had a thin humus layer (<5 cm) that averaged 75 cm in depth before an impermeable layer was reached.

Harvest history: Three harvest entries completed. First entry late September 1993, completed in 7 weeks, retained dominant Douglas-fir and redcedar dispersed throughout the block at 57 stems per ha (sph). Windthrow, approximately 11.3 sph, removed by helicopter (1994). Second and final entry retained 24 sph (1997).

Phase 1 Washington SLH78 mobile swing yarder and Berger mechanical slack pulling carriage.

Prescription: *Dispersed Retention* **Block Size:** 11.4 ha
Two harvest entries. First entry retains dispersed Douglas-fir and redcedar between 75-95 sph. Second entry three to seven years after first entry, to retain permanently between 20-30 sph.

Site description: Block relatively flat with elevation ranging 410-460 m. Predominantly 01 site unit (Hw flatmoss). Minor portion of block classed as site unit 03 (FdHw –salal).

Harvest history: Three harvest entries. First entry (Jan 10 - April 21, 1997) retained dominant Douglas-fir and redcedar dispersed throughout block (95 sph). Windthrow (approx. 19 sph) removed by helicopter twice (1999 and 2000).

Prescription: *Clearcut with Reserves* **Block Size:** 10.1 ha
Single harvest entry. Retain a maximum of 1 sph overstory (Douglas-fir or redcedar preferred).

Site description: Block with gentle slope (< 10%) and southerly aspect. Elevation range from 360 m to 400 m. Site contains equal area of site unit 01 (Hw-flatmoss) and site unit 03 (FdHw –salal). Remaining 1.5 ha area is wetter site unit 07 (Cw-Foamflower).

Harvest history: Single harvest entry. Harvested between April 2 and December 9, 1996 (operations suspended April 4 to July 21). Retained 15 dominant Douglas-fir and a single white pine, dispersed throughout the block. Four trees, including the pine, blew down soon after harvest.

Prescription: ***Extended Rotation*** **Block Size:** 11.0 ha

Multi-entry prescription. Three harvest entries (thinnings) remove 10-20% of standing volume over 30-year period; final entry 50 years after first entry will retain dispersed overstory. Accelerate development of old growth characteristics (e.g. large diameter trees, enhanced understory) by extending final harvest.

Site description: Block with gentle slope (< 10%) and southwest aspect. Elevation ranges from 340 m to 380 m. Site classified within the 01 site unit (Hw-flatmoss). No evidence of root rot. Coarse textured glacial tills, thin forest floor, root depth of 75 cm.

Harvest history: First entry between March 4th and 29th, 1996, removed 11% of stand volume in 11 corridors, each 4-5m wide, roughly parallel and oriented in the north-south direction.

Phase 2 Washington SLH78 mobile swing yarder and Berger mechanical slack pulling carriage.

Prescription: ***Strip Shelterwood*** **Block Size:** 19.1 ha

Two harvest entries prescribed. First entry removes 50% of overstory cover in series of strips, 50-100 m wide. Second entry 3 to 7 years after first harvest to retain 10-20 reserve trees per ha.

Site description: Elevation ranges from 490 to 585 m, with 75% of the area described as site unit 01(05) [4-C(D)], the rest as 05(07). Slope is 5-15%, averaging 10%, rooting depth is 75 cm Humo-ferric Podzol with well developed Ae. Southwest to south aspect.

Harvest history: Single harvest entry. Trees removed in strips ranging 50-120 m wide, oriented roughly northeast-southwest. Remaining timber in strips ranging 50-100 m wide. Harvesting began in fall of 1998, completed by June 1999.

Prescription: ***Variable Retention*** **Block Size:** 12.9 ha

Single harvest entry. Retain forest structure in groups and dispersed singly.

Site description: Elevation ranges from 490 to 590 m, with 79% of the area described as site unit 01(05) [4-C(D)], 21% as 07. Humo-ferric Podzol with well developed Ae. Southwest to south aspect. Humus 5-10 cm depth. Slope 5-15%, averaging 10%.

Harvest history: Single harvest entry. Approximately 20 dispersed Douglas-fir trees plus two small groups of trees in the northern portion of the block. Harvesting began in fall of 1998, completed by June 1999.

Prescription: ***Extended Rotation*** **Block Size:** 17 ha.

Multi-entry prescription. Three harvest entries (thinnings) removing 10-20% of standing volume.; final entry 50 years after first. Accelerate development of old growth characteristics (e.g. large diameter trees, enhanced understory) by extending final harvest.

Site description: Entire area classified as 01 (05) ecosystem {4 B-C). Slope range 5-15%, average 10%. Humo-ferric Podzol with well developed Ae. Rooting depth average 75 cm. Upper Flume Creek (classified as S5 stream) located outside the eastern boundary of the block.

Harvest history: Single harvest entry. First entry (Spring 1997) removed 18% of stand volume in a series of 18 corridors 6-8 m wide, roughly oriented in the northwest-southeast direction. Retained 20m RMA on stream.

western redcedar has been harvested in the last 20 years.

3.0 METHODOLOGY

3.1 SILVICULTURE PRESCRIPTIONS AND STAND MANAGEMENT OBJECTIVES

The silvicultural systems (harvest treatments) were selected to provide a range of overstory conditions after the first harvest entry and to permit evaluation of the effects of harvesting intensity on various ecosystem components. The harvest treatment descriptions, harvesting details, and post-harvest aerial photos are included in Table 1.

All harvesting was conducted under the Small Business Forest Enterprise Program (SBFEP), as administered by the BC Ministry of Forests. Pre-harvest Silviculture Prescriptions (PHSP) were developed and approved for each block prior to harvesting, and had several stand management objectives in common, including:

- Regenerate with Douglas-fir (primary species) and western redcedar (secondary species) for sawlog production, over a 90 to 120 year rotation. Based on prevailing site characteristics (Inselberg 1993), Douglas-fir was the recommended primary species, with western redcedar and western hemlock (which was expected to regenerate naturally in all treatments) as secondary species (Green and Klinka 1994). This species composition is similar to that of current stands.
- Maintain water quality by preserving the integrity of streams and other water courses associated with the block. The only exception to this rule was associated with Phase 2 blocks where hydrology research required logging to stream edges.
- Employ cable yarding systems to minimize soil disturbance. Soils and slope conditions in the blocks currently within the RCSF are considered suitable for ground-based yarding.

3.2 SITE DESCRIPTION

Complete ecological description of all study blocks followed the biogeoclimatic system (Pojar et al. 1987). Numbered stakes established in a grid pattern (25 meter by 50 meter) throughout each block prior to harvest were utilized during ecological description to record position.

3.3 PRE-HARVEST STAND STRUCTURE

Pre-harvest operational cruises in all proposed blocks assisted prescription development and allowed the comparison of pre-harvest stand conditions between treatments (Table 2). Douglas-fir represented the highest stand volume, while hemlock volume and density tended to exceed redcedar in most of the blocks. Forest health surveys found minimal root rot within all blocks. No other disease or insect issues were evident.

3.4 HARVESTING

Harvesting rights were awarded through a bidding process. Tree falling and bucking was with chainsaws, and logs were removed with cable-yarding systems. Detailed summaries of the harvesting activities were reported by Hedin (1994) and Bowden-Dunham (1998) for the Demo and Phase 1 blocks respectively. Safety regulations did not allow for the retention of snags, except in the extended rotation treatments when operational conditions allowed their retention.

Table 2. Pre-harvest stand volume (m^3/ha) and density (stems per ha) by harvest treatment and species.

Treatment Block		Attribute	Total	Douglas-fir	Western redcedar	Western hemlock
Demo Block		Volume (m^3)	1165	79 %	4 %	16 %
		Stems/ha	*671*	*58 %*	*18 %*	*24 %*
		Basal area (m^2/ha)	85	79 %	6 %	15 %
Phase 1	Control	Volume (m^3)	721	68 %	11 %	20 %
		Stems/ha	*896*	*55 %*	*17%*	*27 %*
	Extended Rotation	Volume (m^3)	906	77 %	5 %	16 %
		Stems/ha	*880*	*51 %*	*19 %*	*30 %*
	Clearcut	Volume (m^3)	826	81 %	7 %	10 %
		Stems/ha	*1238*	*46 %*	*34 %*	*21 %*
	Dispersed retention	Volume (m^3)	852	73 %	7 %	18 %
		Stems/ha	*755*	*54 %*	*14 %*	*32 %*
Phase 2	Extended Rotation	Volume (m^3)	938	73 %	2 %	24 %
		Stems/ha	*630*	*59 %*	*9 %*	*32 %*
	Clearcut	Volume (m^3)	1106	60 %	5 %	35 %
		Stems/ha	*500*	*35 %*	*10 %*	*55 %*
	Strip Shelter	Volume (m^3)	1060	55 %	13 %	32 %
		Stems/ha	*716*	*21 %*	*41 %*	*48 %*

3.5 MEASUREMENTS

Measurements associated with the regeneration and windthrow component of the RCSF are summarized in Table 3. Not all measurements were made in all blocks, and methodology was adjusted as funding and staffing resources varied considerably as the project progressed. All measurements were randomly located in each treatment block, utilizing the numbered stakes as reference points. Post-harvest stand structure in the initial Demo dispersed retention block was determined using prizm plots established throughout the block. In Phase 1 treatment, two 0.5ha growth and yield plots were located centrally in each harvest treatment and unlogged control.

4.0 RESULTS

4.1 POST-HARVEST STAND STRUCTURE

Pre- and post-harvest stand structure assessments in the Demo dispersed retention and Phase 1 treatments are summarized in Table 4. A block-wide post-harvest assessment in the Phase 1 dispersed retention treatment revealed 95 sph remaining, lower than the 117 sph found in growth and yield plots. Basal area (12%) and volume removal (11%) were within the range of volume removal prescribed for the Phase 1 extended rotation treatment.

4.2 POST-HARVEST SOIL SURFACE SUBSTRATE

Post-harvest soil surface substrate assessment verifies whether soil disturbance during harvesting complies with limits specified in the silviculture prescriptions. It also has implications for subsequent natural regeneration development, as both Douglas-fir and redcedar germination are affected by substrate type (Curtis et al 1998; Burns and Honkala 1990).

Table 3. Measurements associated with regeneration monitoring plus windthrow..

Measurement	Blocks	Methods
Soil substrate	All harvested blocks	Point samples throughout all harvested blocks. Descriptors of soil substrate included undisturbed forest floor, disturbed forest floor, mineral soil, decayed wood, and slash
Douglas-fir cone crop assessments	• Dispersed Retention: Demo and Phase 1 • Unlogged Control (Phase1) and buffers	Cone crop of dominant Douglas-fir cone production visually estimated utilizing binoculars annually in late fall. Cone crop rated by tree according to five classes: none, few, several, many, or loaded. Yearly crop rating summarized according to seven-class rating in Eremko *et al.* (1989): Class 1: No cones. Class 2: Very Light, few cones on < 25% of trees. Class 3: Light, few cones on > 25% of trees. Class 4: Light, many cones on < 25% of trees. Class 5: Medium, many cones on 25% to 50% of trees. Class 6: Heavy, many cones on > 50% of trees. Class 7: Very Heavy, many cones on almost all trees
Seedfall	Dispersed Retention (Demo and Phase 1), Phase 1 Control	Seedfall sampled in the unlogged control (phase 1), demo block and Phase1 dispersed retention. Thirty circular seed traps (.25m^2) placed beside randomly selected grid points. Seeds removed in late fall and following spring) and counted by species. Initial sample of Douglas-fir seed tested for germination
Planted regeneration	All harvested blocks	Douglas-fir and redcedar planted beside randomly selected grid points and ribboned to separate from operationally planted seedlings. Measurements included height, stem caliper, condition defects, and level of surrounding vegetation overtopping. Douglas-fir — Demo: 1+1 PBR 415B, Height: 59 cm, Caliper 10 mm; Phase 1: 1+0 PSB 415B, Height: 32.5 cm, Caliper: 3.7mm; Phase 2: 1+0 PSB 415B, Height: 29.5 cm, Caliper: 3.2 mm Western redcedar — Demo: 1+1 PBR 415B, Height: 56 cm, Caliper 8 mm; Phase 1: 1+0 PSB 415B, Height: 44.6 cm, Caliper: 3.3 mm; Phase 2: 1+0 PSB 410B, Height: 30.5 cm, Caliper: 2.3 mm
Natural regeneration	All harvested blocks	Circular plots, ranging from 1 m^2 to 50 m^2, established randomly throughout each block. Total natural regeneration by species counted during each assessment period. Seedlings subsampled by species to evaluate survival, growth, and germination substrate.
Vegetation cover	All harvested blocks	In Phase 1 (Year 3) and Phase 2 (Year 2) blocks. Species cover estimated within 5 m^2 circular plots, randomly throughout each treatment. Cover visually estimated for each of four quadrants placed in the circular sampling area. The number of plots varied by treatment: control: 30 plots; dispersed retention: 52; extended rotation: 70; and clearcut: 63.
Windthrow	All harvested blocks plus Phase 1 control	100% sampling within dispersed retention block (Phase 1 and Demo), Phase1 control and Phase 1 extended rotation. In Phase 1clearcut, 100%sampling along the north boundary and subsampling along the western boundary. In Phase 2 strip shelterwood, two 25m wide plots established in each of the two most eastern unlogged strips at right angles to windward edges. In Phase 2 extended rotation, 100% sampling within four plots with boundaries following yarding corridors. Data collection include species, dbh, subsample of total height and description of failure (root or stem failure).

Table 4. Pre- and post-harvest stand density, basal area and total volume: Phase 1 treatments and Demo dispersed retention.

	Treatment	Measure-ment Period	Stems / ha	Basal area (m^2/ha)	Total Volume (m^3/ha)
Demo (Dispersed Retention)		Pre-	671	85	1165
		Post-	57	17	249
Phase 1	Clearcut	Pre-	654	85.2	1218
		Post-	1	1 (est.)	5 (est.)
	Dispersed Retention	Pre-	978	83.8	1033
		Post-	117	24.4	321
	Extended Rotation	Pre-	775	76.7	965
		Post-	664	67.5	859

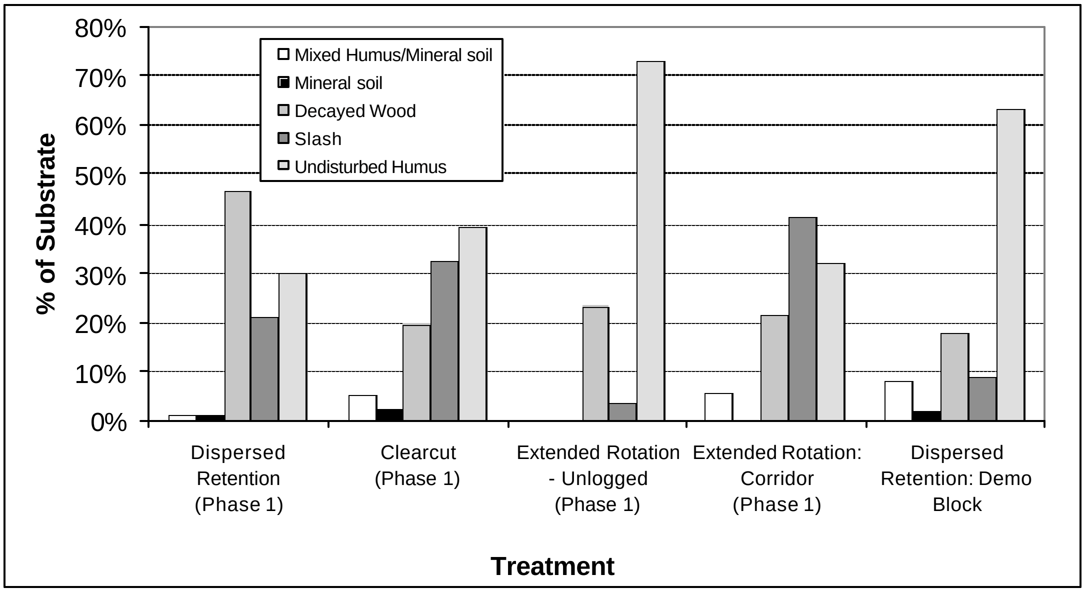


Figure 3. Frequency of post-harvest soil substrate types in Phase 1 harvest treatment and Demo dispersed retention.

Manual falling and cable yarding caused little direct soil disturbance (Figure 3), and disturbance was below maximum levels specified in the pre-harvest plans for each individual block. The dominant substrates in all harvested blocks included an undisturbed humus layer, well-decayed wood, and logging slash (< 25 cm diameter). Mineral soil preferred by both Douglas-fir and redcedar regeneration occurred on less than 3% of any site; disturbed forest floor occurred on less than 5%. Ground disturbance was slightly higher in the Phase 1 clearcut than in the dispersed retention treatment.

4.3 WINDTHROW

A pre-harvest assessment of windthrow potential (Form FS 712-2[2]), based on average site attributes (topographic exposure, soil factors) suggested that a moderate hazard existed. However, the use of forest stand attributes (uniform structure, tree height >30 m, and height/diameter ratio >90) would have predicted a high hazard.

Windthrow occurred in all harvested blocks at rates higher than in the Phase 1 unlogged control block, where it was less than one tree per ha per year during a four-year assessment period (1997-2000) (Figure 4). Maximum windthrow was in the Phase 2 strip shelterwood treatment, where windthrow occurred along the windward edges of remaining timber. Similarly, windthrow

[2] Windthrow Field Cards, Forest Practices Branch, BCMOF (HFP 98/05).

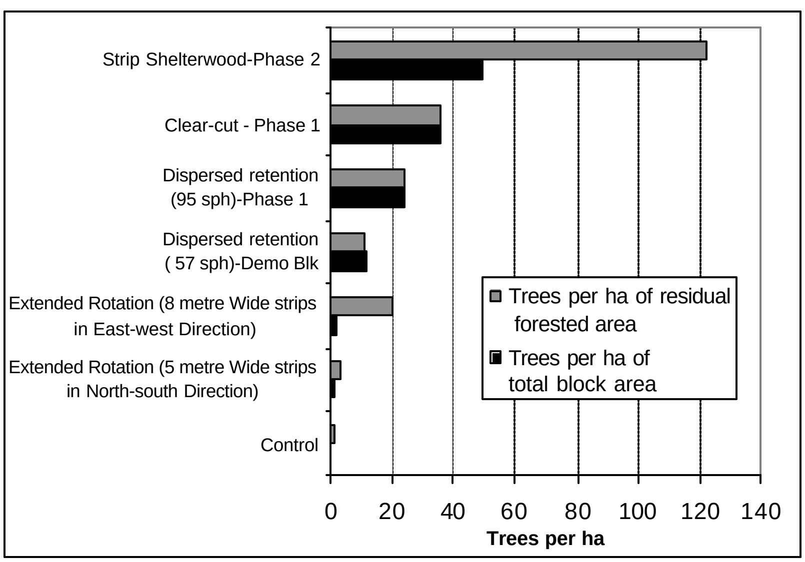


Figure 4. Density of windthrow (based on residual forested area and total block size), by harvest treatment. Measurement periods are as follows: Demo dispersed retention: 8 years; Phase 1 blocks: 4 years; Phase 2 blocks: 1 year.

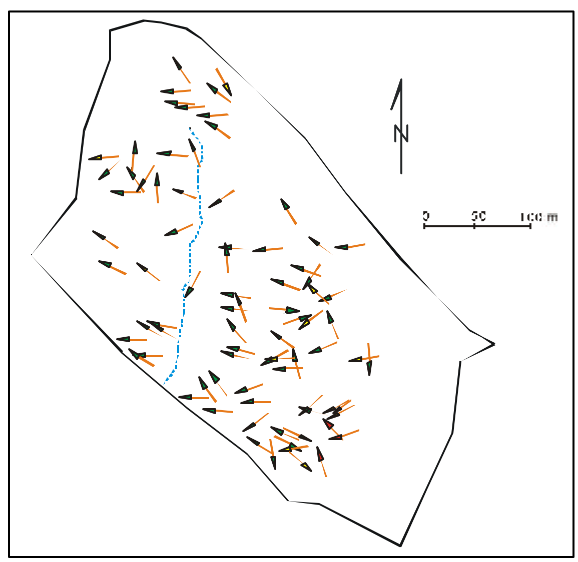


Figure 5 Distribution of windthrow in the Demo dispersed retention block.

occurred along the clearcut's western boundary, where moist to very moist soils presumably increased blowdown up to 100 meters into the boundary. Windthrow was less severe along the clearcut's northern boundary, while four out of twelve reserve trees within the block blew down. In the two dispersed retention treatments, 19.8% (Demo block) and 22% (Phase 1 block) of the post-harvest stand density blew down, a percentage exceeding that in other provincial silviculture system studies (Huggard et al 1999; Coates 1997).

Dispersed smaller diameter western redcedar was more prone to windthrow than Douglas-fir. Douglas-fir trees exceeding 80 cm dbh were more resistant to windthrow than smaller diameter trees. Trees beside an ephemeral stream in the western portion of the Demo block blew down in the first storm, presumably due to shallow or unbalanced rooting (Figure 5). Windthrow occurred within the narrow, north–south oriented corridors of the Phase 1 extended rotation treatment, mainly among small redcedar poles (< 17.5 cm dbh) along corridor edges. Windthrow was higher amongst the wider, east-west corridors of the Phase 2 extended rotation treatment. Blown-down Douglas-fir in all treatments typically demonstrated root failure, with overturned trees falling in a westerly to northerly direction. Redcedar showed a greater frequency of stem breakage (20%) and stem leaning (15%).

Following the initial windthrow in Phase 2 blocks, pruning and/or topping of the remaining trees was completed among both dispersed and aggregated trees in the variable retention treatment, and throughout the strip shelterwood treatment. A first-year assessment suggested the pruning and topping treatments were effective in minimizing windthrow following subsequent winter storms, but additional monitoring is required to confirm this.

4.4 DOUGLAS-FIR CONE CROP AND CONIFER SEEDFALL

Dispersed, dominant healthy trees can release millions of seeds per hectare over a large distance. With suitable soil substrate and environmental conditions, this seedfall allows natural regeneration to establish itself, and can complement planting in meeting reforestation obligations. Cone crops among the dispersed Douglas-fir trees in the Demo block (Figure 6), and the resulting

Table 5. Yearly Douglas-fir cone crop rating in dispersed retention treatments (Demo and Phase 1) and surrounding unlogged stands. Cone crops considered collectable are shaded.

Year	Demo Dispersed retention	Phase 1 Dispersed retention	Unlogged Stands
1993	Light (pre-harvest)	-	Very light
1994	Light (Yr 1)	-	Medium
1995	Very Heavy (Yr 2)	-	Light
1996	Medium (Yr 3)	-	Light
1997	Very Light (Yr 4)	Light (Yr 1)	None
1998	None (Yr 5)	None (Yr 2)	Very Light
1999	Heavy (Yr 6)	Light (Yr 3)	Light
2000	Very Light (Yr 7)	-	-
2001	Heavy (Yr 8)	Medium (Yr 5)	Medium

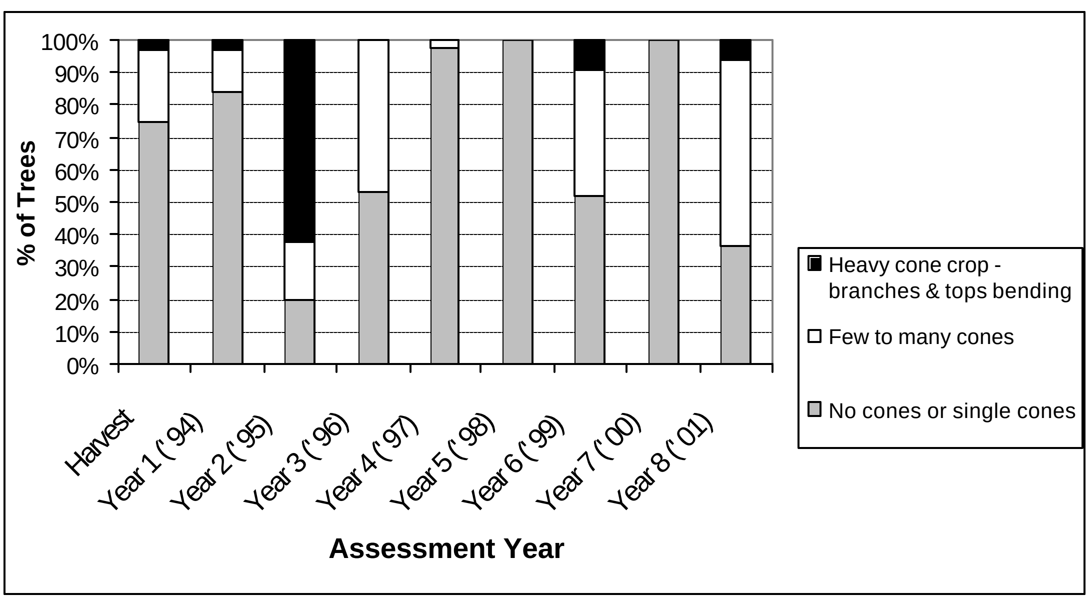


Figure 6. Yearly Douglas-fir cone crop of individual trees in Demo dispersed retention block: pre-harvest to 8th year after harvest.

cone crop rating (Table 5), exceeded those of the unlogged areas, suggesting a post-harvest cone and seed enhancement effect, as identifed by Williamson (1983). Douglas-fir cone crops in unlogged forest surrounding the harvested blocks were generally light during the 1993-2001 period. Visually estimating Douglas-fir cone crops was effective in differentiating heavy seedfall years (e.g. 1995) from years of light or no cone crops and subsequent low seedfall. The Douglas-fir cone crops in the Phase 1 dispersed retention treatment tended to be below that of the Demo block, with only one year's crop (medium in Year 5) considered collectable during the assessment period.

The yearly variation in redcedar seedfall was large, with over one million seeds produced per hectare despite fewer than 6 sph remaining in the Phase 1 dispersed retention treatment (Table 6), although seed from adjacent stands may be contributing to the total. Western hemlock demonstrates prodigious seed production, exceeding other species in the unlogged control during all measurement years. Hemlock seed traveled at least 100 m, based on seed collected in dispersed retention treatments, where the closest hemlock was along block boundaries.

4.5 NATURAL REGENERATION

The forests undergoing study within the RCSF would typically be classified as being in the stem exclusion stand development phase described by Oliver and Larson (1990), with closed overstory canopy and little understory vegetation or conifer regeneration. Hemlock dominated the understory regeneration, with lesser amounts of redcedar typically regenerating from rooted bent branches in a process termed layering. Few understory hemlock and redcedar saplings survived the harvesting phase.

4.5.1 NATURAL REGENERATION DENSITY

Fifth-year natural regeneration density and composition differed among Phase 1 treatments (Figure 7), with the dispersed retention (75 sph) treatment showing the highest fifth-year total density (37,400 germinants per ha) and highest density of individual species, including hemlock, whose density reached 18,000 seedlings per ha. Natural regeneration in the Demo dispersed reten-

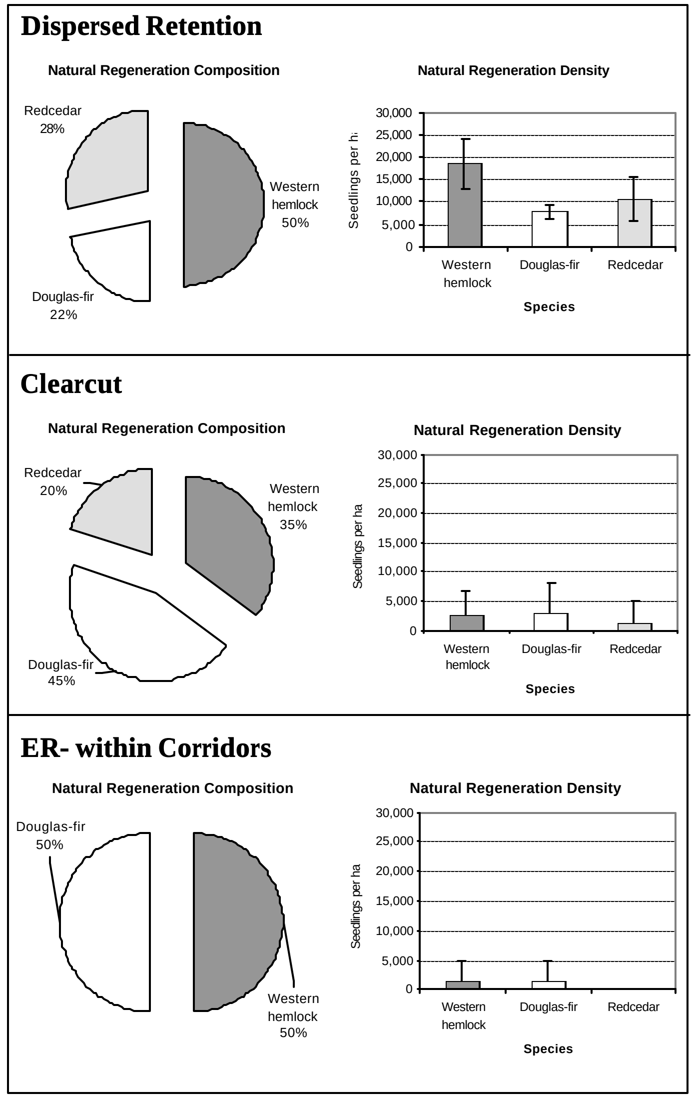
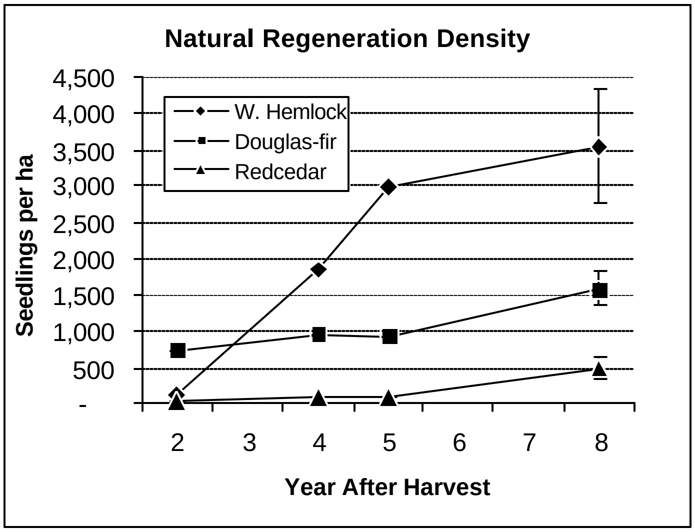


Figure 7. Fifth-year natural conifer regeneration density and composition by species in Phase 1 treatments. Error bars indicate 1 standard error (s.e.) above and below mean.

Table 6. Yearly seedfall by species in Phase 1 treatments (unlogged control and dispersed retention) and Demo dispersed retention block.

			1994	1995	1996	1997	1998	1999	Post-harvest 3-Year Total
		Species	Year 1	Year 2	Year 3	Year 4	Year 5		
Demo		Df	11,000	1,312,000	874,000	53,000	0	-	2,239,000
		Redcedar	27,000	536,000	1,760,000	213,000	11,000	-	2,520,000
		Hemlock	16,000	61,000	266,000	48,000	27,000	-	402,000
				Pre-treat	Harvest yr	Year 1	Year 2	Year 3	
Phase 1	Control	Df	-	709,000	717,000	168,000	0	90,000	258,000
		Redcedar	-	60,000	460,000	59,000	5,700	80,000	144,700
		Hemlock	-	2,163,000	13,968,000	1,184,000	31,000	1,380,000	2,595,000
	Dispersed retention	Df	-	1,032,000	-	9,000	0	80,000	89,000
		Redcedar	-	21,000	-	430	150	1,220,000	1,220,580
		Hemlock	-	1,108,000	-	17,000	571	40,000	57,571



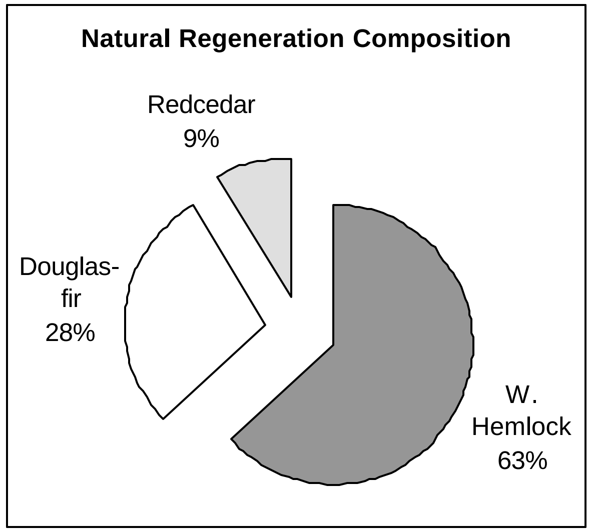


Figure 8. Eighth-year natural conifer regeneration density and composition by species in Demo dispersed retention block. Error bars indicate 1 s.e. above and below mean.

tion block (currently 25 trees per ha) was also dominated by hemlock, but the density of all species was lower compared with Phase 1 dispersed retention (Figure 8). Douglas-fir natural regeneration density in the Demo dispersed retention block, both in total and for well-spaced density (> 2 m inter-tree distance), increased in the first five years, but by Year 6 it declined to minimum stocking requirements (500 stems / ha).

The density of the three principal conifer species was more similar in the Phase 1 clearcut than in the dispersed retention treatments, with hemlock density declining due to germinant mortality and little new ingress, and both redcedar and Douglas-fir density increasing slightly since the previous assessment. Both hemlock and Douglas-fir regenerated within the narrow corridors of the extended rotation treatment, but Douglas-fir mortality and little subsequent ingress suggests that understory conditions were not suitable for germinant survival.

4.5.2 NATURAL REGENERATION AND SOIL SURFACE SUBSTRATE

The highest density of natural regeneration of the three main conifer species was on mineral soil (Figure 9), with lesser densities on humus (forest floor) and decayed wood.

4.5.3 NATURAL REGENERATION GROWTH

Early growth of natural Douglas-fir and western hemlock regeneration was unaffected by the presence of dispersed over-

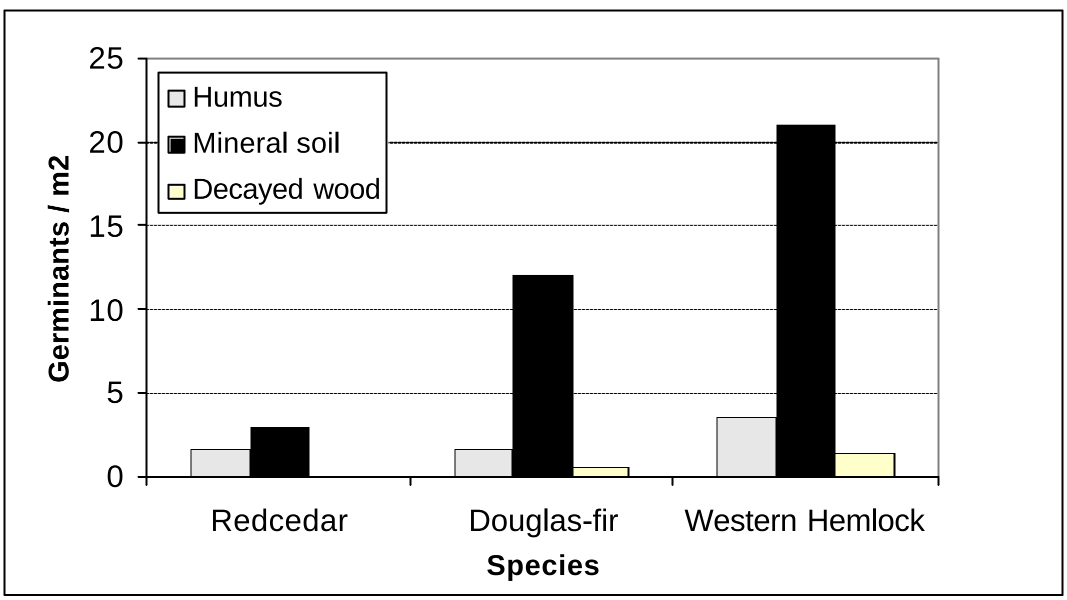


Figure 9. Natural regeneration density (germinants / m^2) by surface substrate and species in Phase 1 dispersed retention treatment.

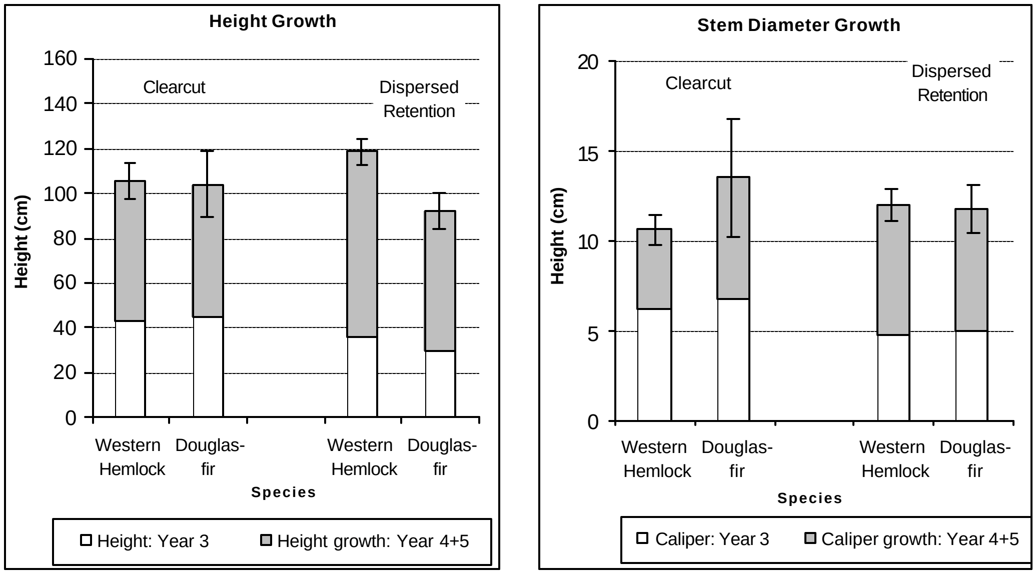


Figure 10. Third- and fifth-year total height and stem diameter of naturally regenerated western hemlock and Douglas-fir: Phase 1 dispersed retention and clearcut. Error bars indicate 1 s.e. above and below mean.

story, as third-year height and stem diameter were similar to the clearcut (Figure 10). Douglas-fir germinants reached an initial height similar to that of planted styroblock seedlings by Year 3 in both blocks. By Year 5, Douglas-fir in the clearcut demonstrates similar height growth but greater stem diameter growth than western hemlock; beneath the dispersed overstory, growth advantage shifts to western hemlock with similar stem diameter growth but greater height growth than Douglas-fir. Natural Douglas-fir regeneration growth in the Demo dispersed retention block was similar to that of Phase 1 dispersed retention during the five years after harvest.

4.6 PLANTED REGENERATION

Phase 1 blocks were spring planted with one-year-old Douglas-fir and western redcedar styroblock (plug) container stock, while larger two-year-old styroblock transplant (1+1) stock was planted in the Demo dispersed retention block. Seedlings planted within the eastern end of the clearcut (2-3/B) were excluded from treatment comparisons since site conditions were significantly drier than in the other treatment blocks (3-4/B). In the drier portion of the clearcut, Douglas-fir total height and stem diameter were approximately 25% smaller than in the other portions of the block; redcedar measurements were over 30% smaller in the drier portions of the block.

4.6.1 PLANTED REGENERATION SURVIVAL

Operationally planted Douglas-fir and redcedar seedlings typically demonstrated high survival in clearcuts, a result of moderate growing season climate, low deer browsing pressure, and moderate levels of competing vegetation. In Phase 1 blocks,

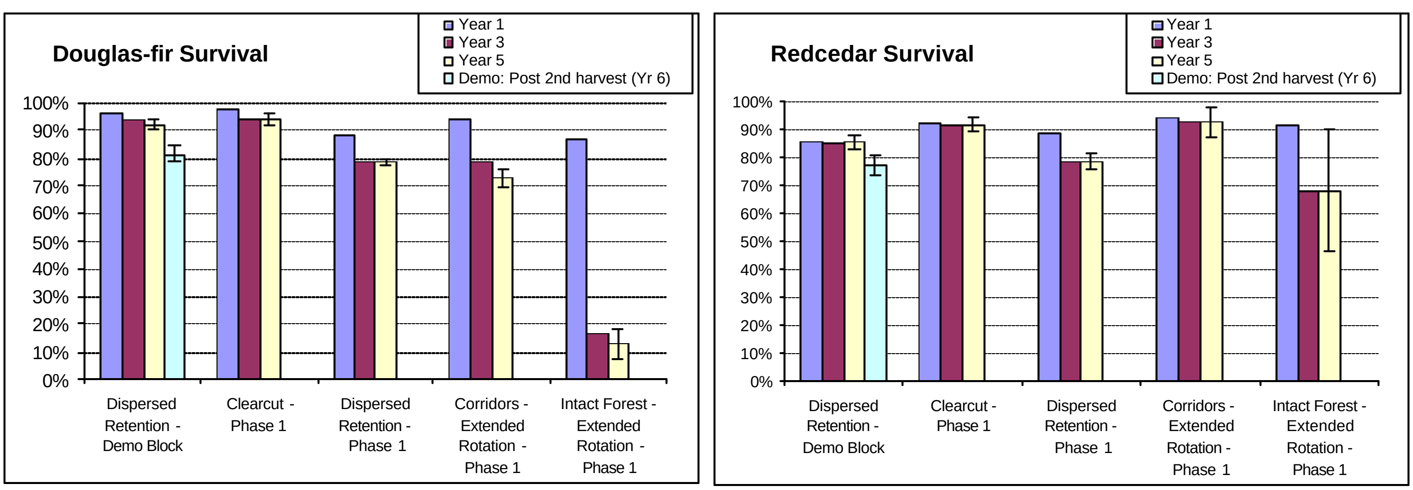


Figure 11. Planted redcedar and Douglas-fir survival by treatment: 1, 3, and 5 growing seasons after harvest, and following second harvest entry within Demo dispersed retention block. Error bars indicate 1 s.e. above and below mean.

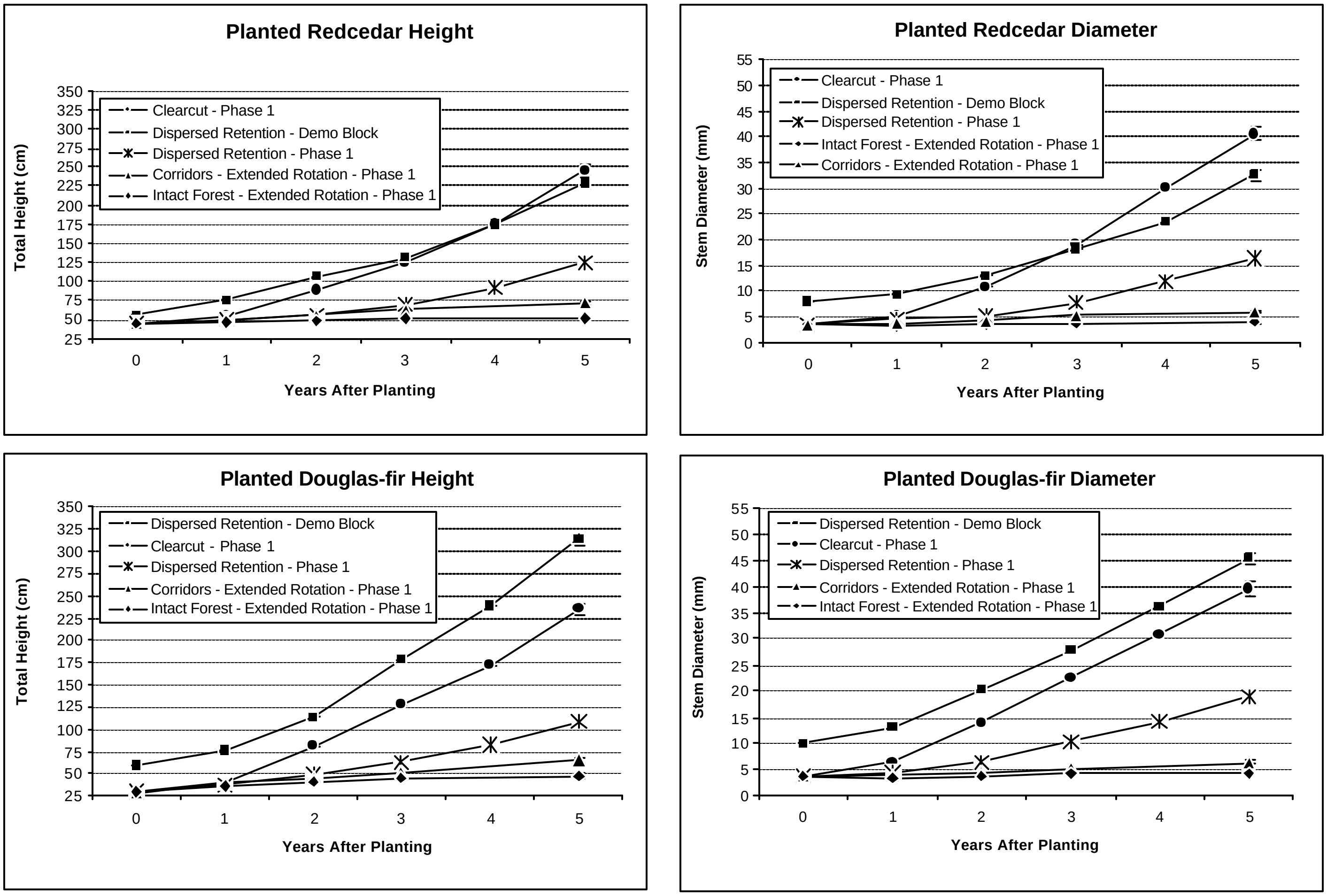


Figure 12. Planted Douglas-fir and redcedar height and stem diameter growth from planting till year 5: Phase 1 treatments and Demo dispersed retention treatment. Error bars indicate 1 s.e. above and below mean.

fifth-year survival of both species was highest in the clearcut, with Douglas-fir and redcedar survival 13% and 16% greater respectively than in the dispersed retention treatment (Figure 11). Redcedar had greater shade tolerance, out-surviving Douglas-fir within the narrow corridors and in the unlogged portions of the ER, where fewer than 13% of the Douglas-fir survived. While Douglas-fir survival in the Demo DR block was comparable to the Phase 1 clearcut, lower survival of redcedar was attributed to low seedling vigour when planted. The second harvest in the Demo block reduced survival of Douglas-fir and redcedar by 10.5% and 7.9% respectively, due to falling or yarding damage. Among the Phase 2 treatments, survival of both species remained high (> 95%), including within the corridors of the extended rotation block.

4.6.2 HEIGHT AND DIAMETER GROWTH

For planted regeneration in the Phase 1 blocks, height and stem diameter growth of both Douglas-fir and redcedar was greater in the clearcut than in the other blocks (Figure 12) – this despite the fact that greater understory vegetation development in the clearcuts resulted in a greater percentage of seedlings overtopped by surrounding vegetation, reflecting greater understory vegetation development (cover and height) compared with other treatments. In Year 5, seedlings in the clearcut were more than twice the size and two growing seasons ahead of those in the dispersed overstory.

Douglas-fir height growth in the clearcut was enhanced by lammas growth (a second flush of the terminal bud), most frequently observed in Year 2 (55% of sampled seedlings), and associated with favorable conditions for seedling growth (Zedaker et al 1987). Lammas frequency in the dispersed retention treatment was less than half that in the clearcut, and was completely absent in the extended rotation treatment.

Redcedar height and diameter in the clearcut surpassed the initially larger redcedar in the Demo dispersed retention block; fifth-year growth of the initially smaller Douglas-fir in the clearcut was similar to that in the Demo dispersed retention. Seedling growth within the corridors of the extended rotation treatment, while slightly greater than beneath the intact overstory, declined between Year 3 and Year 5, suggesting that understory light levels were declining as the canopy gap re-closed due to crown expansion. Seedling HD ratios for redcedar followed the typical pattern of greater height / diameter ratios under lower light con-

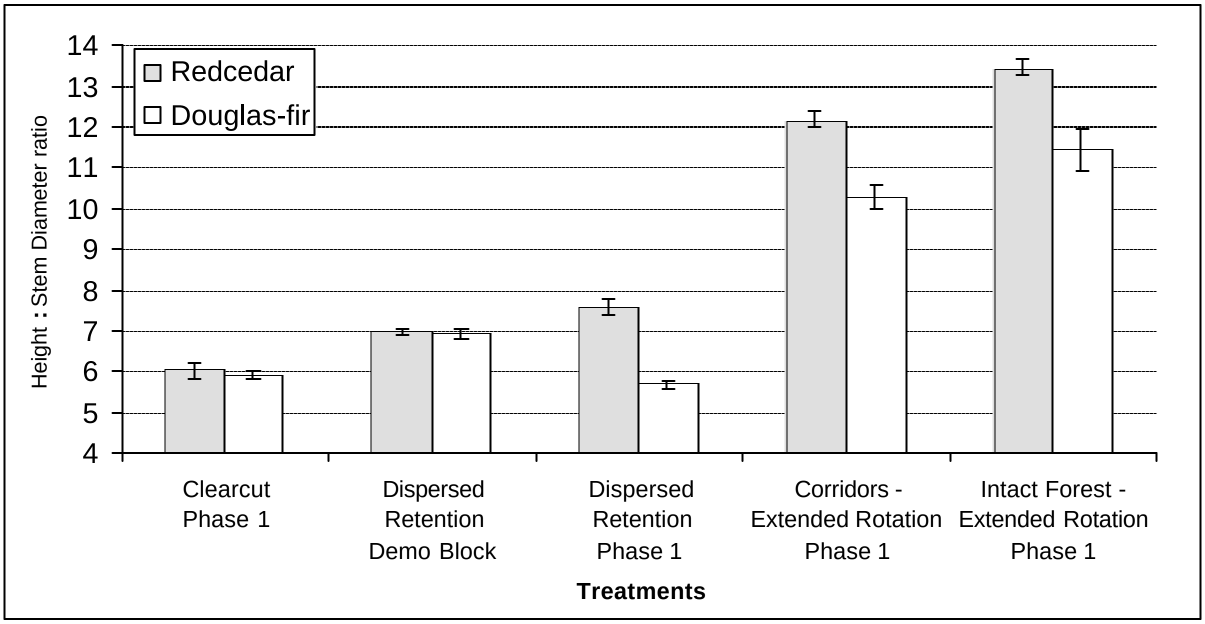


Figure 13. Fifth-year height:stem diameter ratios of planted Douglas-fir and redcedar seedlings by treatment. Error bars indicate 1 s.e. above and below mean.

ditions (Figure 13). The lowest ratio occurred in the clearcut, the greatest in the corridors and beneath the unlogged portion of the extended rotation treatment. The trends were similar for Douglas-fir, except that the HD ratio in the Phase 1 dispersed retention block was slightly lower than that in the clearcut. In phase 2 treatments, the height and stem diameter growth of both Douglas-fir and redcedar were greater in the strip shelterwood; the lowest growth of both species was in the corridor and unlogged portions of the extended rotation treatment.

4.6.3 REGENERATION HEALTH

The only persistent seedling health issue since the start of the trial was the development of stem gall on the planted Douglas-fir seedlings within both dispersed retention treatments (Figure 14). Stem gall frequency increased over time but was higher in the Phase 1 dispersed retention block than in the Demo dispersed retention block. Stem gall not only deforms the lower stems of seedlings, longer-term monitoring has shown it causes mortality rates twice that of unaffected saplings. A second health issue, the forking of Douglas-fir leaders, was more common in the dispersed retention treatment (12.7%) than in the clearcut (1%), although longer-term measurements in the Demo block, over eight years, indicate that trees outgrow this condition over time.

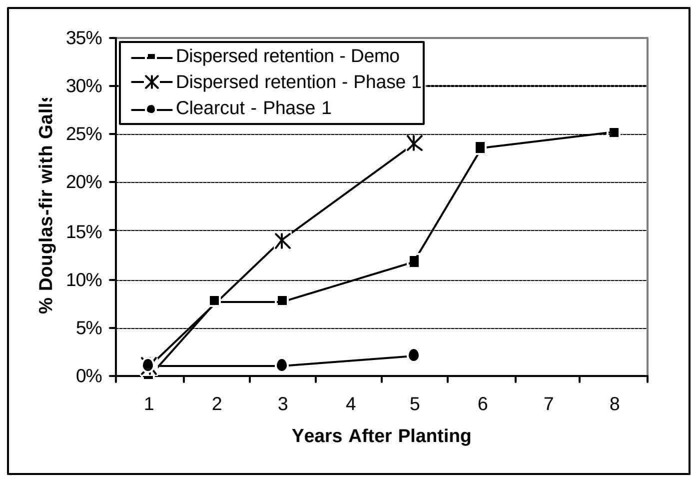


Figure 14. Frequency of stem gall development on planted Douglas-fir in dispersed retention treatments (Phase 1 and Demo) and clearcut.

5.0 MANAGEMENT IMPLICATIONS

Monitoring of post-harvest stand structure (focusing on windthrow) and regeneration development highlights the differences in post-disturbance stand development between treatments. In keeping with the process of adaptive management, the discussion of the three harvest treatments below will include the evaluation phase, which compares actual outcomes with forecasts, including the assessment of how treatments affect future management activities. Discussion will then proceed to the adjustment phase, where suggestions for future development of treatments are provided.

5.1 DISPERSED RETENTION

One objective of the Demo dispersed retention treatment included "Maintain an overstory following harvesting for wildlife, and other resource values and aesthetics." Although the effect on wildlife may be best assessed at the landscape level, both the original Demo and subsequent dispersed retention treatments have structures ("biological legacies") associated with both natural disturbances and wildlife species habitat, including large live trees, some exceeding 1 m dbh, and downed logs (windthrow). And although lacking the larger-diameter snags found in the surrounding forests, dispersed retention provides for their creation either through natural mortality or through intervention. Eventually, these trees will supply a source of larger coarse woody debris.

Since even dominant trees are prone to windthrow when dispersed, crown pruning, such as conducted in Phase 2 by helicopter, is recommended to control windthrow and ensure residual stand density objectives are met. The effectiveness of topping and branch pruning treatments has been confirmed elsewhere in the region (Rowan et al 2001), but more trials in varied stand types are required. Tree retention immediately beside streams and creeks should be avoided, as such trees are especially prone to blowdown, and sediment can be introduced into streams from overturned root wads (Hudson and D'Anjou 2001).

Conditions under dispersed trees are favourable for natural regeneration establishment, unfavourable for planted regeneration growth and conflicts with reforestation objectives specifying maximum densities and species composition (Table 7). Western hemlock is an aggressive regenerator. Seed released yearly from surrounding trees is capable of germinating on most substrate types including decayed wood, and growth rates are similar to Douglas-fir regeneration. Enhanced hemlock understory has also been found in dispersed retention in retrospective studies in Oregon (Traut and Muir 2000). Douglas-fir is dominated by hemlock (and redcedar) beneath overstory densities as low as 5 trees per hectare in models (Hansen et al 1995). Planting large stock of the preferred species provides some growth advantage over western hemlock but may not prevent hemlock from dominating.

In accepting an increased hemlock component, managers should consider the potential for changing humus form development and impacting site productivity negatively (Klinka pers comm.[3]). Additionally, with 90 to 120 year rotation lengths, drier site conditions induced by global climate must be considered, since hemlock will become less suitable on these sites, further decreasing forest productivity. And finally, with the future canopy expansion of permanently retained overstory trees (including epicormic branching observed on Douglas-fir stems), additional declines in understory light availability will continue to shift toward understory conditions better suited to hemlock.

Natural stand development processes provide guidance for designing silvicultural systems that integrate ecological and economic objectives, maintain forest function, and provide habitat for a full range of native organisms (Franklin et al 2002). Fire, the agent for stand initiation in this ecosystem (whether originating from lightning or from escaped wildfires), can affect thousands of hectares, based on surveys by Hodgins (1933). Dispersed retention prescriptions applied to 7 to 10 ha blocks don't approach the scale of wildfire and lack the direct effect of fires, including consumption of the thin humus layer and smaller woody material and, potentially, the mortality of standing trees. Little evidence suggests these stands were initiated under a uniformly spaced overstory of the character created in the dispersed retention prescriptions. The distribution of surviving old growth

Table 7. Implication of dispersed retention on regeneration development.

- Reduction in seedling growth extending time period for free-growing requirements;
- Enhanced western hemlock (and total) natural regeneration necessitating spacing to meet required stocking density;
- Enhanced Douglas-fir stem gall development, with unknown implications to future survival, growth, and form.

Douglas-fir located within the Study Forest suggests more irregular spacing, at densities probably lower than currently found in dispersed retention, which Hodgins (1933) described as "seed tree plentiful" on maps. And whereas stand initiation of these mature stands could occur over decades, as suggested by the range of Douglas-fir ages, the combination of prompt planting and natural regeneration from trees within and around the dispersed retention blocks has shortened this time period, potentially changing the development of various stand attributes, including understory vegetation and lower crown class development. Modifications to the dispersed retention harvest treatments are suggested (Table 8) which attempt to mimic natural stand disturbance and development, provide forest structure recognized as important for sustaining biodiversity, increase the area free of overstory influence to maintain Douglas-fir in these forests, and create forests more similar in species composition to those being harvested.

5.2 CLEARCUT WITH RESERVES

Monitoring within Phase 1 harvest treatments indicates that both Douglas-fir and western redcedar showed maximum growth (height and stem diameter) in the clearcut. This is consistent with studies that demonstrate greater seedling growth with increasing light, and the most productive growth on the coast under full sunlight (Mailly and Kimmins 1997; Wang et al 1994). Douglas-fir in the drier interior/transition zone (Boston Bar)

Table 8. Suggested modification to dispersed retention treatment.

- Consider larger blocks to reduce edge effect of smaller blocks;
- Consider re-introduction of fire, a disturbance agent in this ecosystem, although air quality condition in local urban areas may preclude this treatment;
- Greater aggregation of retention, less dispersed retention. Establishment of safe working zones around aggregated forest to allow retention of snags;
- Single pass rather than two pass system. Retain target density plus safety factor to accommodate windthrow;
- Crown prune all trees;
- Plant with larger stock to give preferred species growth advantage over natural regeneration.

[3] Klinka, K. University of BC. 2001

had maximum stem diameter growth in clearcuts, declining with increasing densities of dispersed overstory (D'Anjou 1998), although three-year height growth was less affected than at Roberts Creek.

Natural regeneration in the clearcut, with lower hemlock ingress than in the dispersed retention block, was more similar in species composition to the current mature forest, and came closer to meeting reforestation objectives (Douglas-fir with minor components of hemlock and redcedar). Residual tree density in the clearcut (1 tree per ha or 0.6 m^2 basal area), does little to improve site aesthetics, in part because trees considered worthy of retention (large and dominant Douglas-fir with good form) tended to be positioned near block edges. Increasing the tree density for aesthetic or other reasons, even at 5 trees per ha, results in a reduction in understory conifer growth estimated at between 70% (Birch and Johnson 1992) and 75-82% (Hansen et al 1994) of that in a clearcut. Hansen et al also suggest that hemlock and redcedar become dominant over Douglas-fir even at these low overstory densities.

Adjustment to the clearcut prescription may include plantation density management for increasing structural complexity (DeBell et al 1997). Thinning with varying spacing distances, in addition to adjusting species composition, can simulate natural stand development by delaying the crown closure and enhancing the development of early successional understory vegetation. This treatment would increase the range of tree sizes, and by creating gaps in the overstory, assist in shade-tolerant species development and growth which increases vertical structure. The combination of maintaining mixed species plantation of native species and conservation of coarse woody debris has been suggesting as methods for allowing clearcuts to better conserve biodiversity with little or no reduction in fiber production (Hartley 2002).

5.3 EXTENDED ROTATION

The long-term nature of the extended rotation treatment effectively delays final harvest for several decades and prevents the short-term assessment of the effectiveness of the prescription in meeting final management objectives. Windthrow, not an objective at this stage of stand development, was higher in the Phase 2 treatment where corridors were more parallel to dominant winds. Orienting corridors at right angles to dominant winds is therefore recommended. The narrow openings in the Phase 1 yarding corridors appear not to be suitable for the planted or natural regeneration establishment of shade-tolerant redcedar, precluding enhanced understory regeneration. Wider corridors may be required to initiate the regeneration of redcedar, although this may lead to increased windthrow. Another option is to initiate regeneration following the second entry, scheduled 15 years after the first, removing 20% of the remaining volume.

The Roberts Creek Study Forest demonstrates several approaches for harvesting and managing the productive lower-elevation forests along the Sunshine Coast. Early results indicate that overstory retention affects regeneration development. Forest managers should consider this effect on both short-term reforestation goals and longer-term target stand objectives. The selection of a specific harvest treatment follows the setting of block-specific management objectives, which in turn follow landscape-level plans where higher-level objectives and strategies are set. Continued monitoring in the study forest will generate further insight into the long-term implications of the alternative approaches, and will provide a forum for discussing how best to manage for changing values and objectives.

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