Regeneration Among a Range of Dispersed Retention Densities in the Coast-Interior Transition

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Abstract

A trial was initiated in 1993 in a 110- to 140-year-old Douglas-fir forest near Boston Bar, BC (IDFww) to evaluate whether dispersed tree retention improves regeneration success. Five treatments were designed to yield a range of understorey shading, and included three densities of dispersed retention from 15 to 90 stems per hectare (comprising a seed tree and two shelterwood silvicultural systems), a clearcut, and an unlogged control. Treatments were repeated in two neighbouring blocks, with the upper block relatively flat and the lower block featuring a 50-70% slope with a southerly aspect.

A late summer wildfire in 1995 spread through both blocks, consuming most but not all understorey regeneration. Regeneration monitoring 10 years after the fire (15 years after the initial harvest) found highest natural regeneration densities occurred in the two shelterwood treatments. Estimated ages of natural regeneration suggested ingress had been continuous since the fire. Post-fire densities exceeded densities achieved three years after harvest, suggesting fire was a benefit to regeneration establishment, especially in the lower block where little regeneration had developed after harvest. Operational planting survival in both the clearcut and the partially cut treatments exceeded 69%. Free growing height objectives were easily met in the clearcuts (minimum height of 1.5 m) by the tenth year after the fire, while later planting (1998) in the partially cut treatments should meet this goal within three years. Subsequent management of the understorey regeneration requires setting clear target stand objectives for each treatment.

Higher densities of dispersed trees (‘shelterwoods’) promoted abundant natural regeneration with the potential to contribute significantly to meeting stocking goals. Under burning can further enhance regeneration development and may be required to achieve higher levels of regeneration development. Dispersed retention patterns also supplied biological legacies, including snags and coarse woody debris – potentially important for meeting broader biodiversity objectives – but chronic bark beetle attacks continued to kill the remaining residual trees. An aggregated retention pattern may be more suited to specific site conditions while potentially meeting regeneration and biodiversity objectives.

Acknowledgements

Forest Investment Account (FIA) provided funding for the project during the 2005/2006 fiscal year. Students from the BC Institute of Technology re-established the plot centres, while Allan Powelson, MSc, RPF, RPBio (ALTRA Forestry Ltd./ALTRA Ecological) completed the measurements of the regeneration.

1.0 Introduction

Clearcutting historically has been the dominant system for forest harvesting and subsequent management within the Coast Forest Region and in other areas of British Columbia (BC). Interest in alternatives to clearcutting has increased among forest managers in BC, as management requirements call for a greater array of forest-related values. Society's expectations of resource stewardship have also grown, as have aesthetic objections to large clearcuts.

In the early 1990s, the South Coast Silviculture Systems Research Co-operative[1] recognized the need for demonstrating and evaluating alternatives to clearcutting for meeting a range of biological, social, and economic objectives. The co-operative identified four priority areas within the Vancouver Forest Region (now Coast Region) where alternative silvicultural systems should be established and studied. The coast-interior transition zone was one of those areas.

The coast-interior transition zone (IDFww[2] and CWHds1) occurs in the southeastern portion of the Coast Forest Region and in the adjoining Southern Interior Region, and has challenged those responsible for regenerating such sites after clearcutting. While the IDFww represents the wettest and mildest part of the IDF zone, severe water deficits combined with planting stock limitations can result in low plantation survival. Alternative silviculture systems for improving regeneration success by moderating understorey climate and/or enhancing natural regeneration development include shelterwood and seed tree systems, with shelterwoods successfully used on similar sites in Washington and Oregon (Williamson 1973, Seidel 1983). However, in the past there was resistance to evaluating these systems based on concerns about reduced economic returns (dominant trees would be selected for retention), belief that the residual trees would blow down, and lack of operational experience with partial cutting in general.

In 1990, the Ministry of Forests Regional Research group, Fletcher Challenge Canada, and Forest Engineering Research Institute of Canada[3] collaborated to demonstrate seed tree and shelterwood systems on a site near Boston Bar, BC. After harvesting in 1991, on-site monitoring focused on the development of residual trees, natural and planted regeneration, non-crop vegetation, and quantifying micro-climate (light[4], temperature and soil moisture) among the

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[1] The Co-operative, composed of representatives from academia, government, and other interested organizations, was established in 1990 to assess the 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.

[2] Total area of IDFww is 122,646 ha; total area of CWHds1 is 254,660 ha

[3] Harvesting aspects of the trial are presented in: I. B. Hedin and D. L. DeLong. 1993. Comparison of Harvesting Phases in Case Study of Partial-cutting Systems in Southwestern British Columbia. Forest Engineering Research Institute of Canada, Western Division, FERIC Special Report SR-85

[4] Light measurement methodology is summarized in Appendix 1.

alternatives. The project became dormant following staff and base budget reductions. A fire, reportedly started by errant campers several kilometres away, travelled north and swept through both blocks during the second week of September 1995. A subsequent field inspection revealed a uniform hot burn with some overstorey mortality. Seedlings and associated brush, grass, and herbaceous material were consumed by the fire. (Note: IDFww was classified into Natural Disturbance Type 4, defined as ecosystems with frequent stand-maintaining fires and a surface fire return period ranging from four to 50 years). Regeneration was monitored in the second and third year after the fire (D'Anjou 1998), but subsequent requests to external funding sources to finance the assessment of post-fire stand structure and regeneration were unsuccessful, until 2005 when the project was approved for FIA funding.

The current proposal is to monitor understorey regeneration and report trends in regeneration development up to the 15th year after harvest. The proposal also involves monitoring of residual stand structure. A separate report will provide a description of residual stand structure development since harvest (D'Anjou 2006).

2.0 Methods

2.1 Study Area

Locating a site suitable for experiment objectives began in 1989 when several candidate stands were evaluated in areas around Boston Bar (Chilliwack Forest District) and Pemberton (Squamish Forest District). A block within Fletcher Challenge Canada's chart area east of Boston Bar (Block E-104 C90-005) was chosen in 1990 (Figure 1).

The study site is located at the confluence of East Anderson River and Utzlius Creek, within the IDFww BGC subzone. This subzone was considered transitional to the southern Dry Submaritime Coastal western hemlock zone (CWHds1) (Inselberg 1990). Approximately 40 hectares in total area, the study site was almost evenly divided between an upper block (flat portion) and a lower block (steep portion). The upper block (25 ha) was gently sloping (10-30%) with benched topography, while the lower block (18 ha) was steep-sloped (50-70%) with well-defined draws (Figure 2). Douglas-fir (*Pseudotsuga menziesii var. menziesii)*, 110-140 years of age, dominated both blocks and included older Douglas-fir veterans representing a legacy that survived the fire that initiated these stands. Lodgepole pine (*Pinus contorta*) and western redcedar (*Thuja plicata*) were present but represented less than 1% of stand volume. Pre-harvest monitoring found greater gross volume and basal area in the lower block, and greater stand density in the upper block (Table 1). More open crown cover in the upper block provided conditions suitable for Douglas-fir to regenerate in the understorey (averaging 571 sph), thus demonstrating moderate shade tolerance. The lower block had a more closed overstorey, and understorey recruitment was minimal.

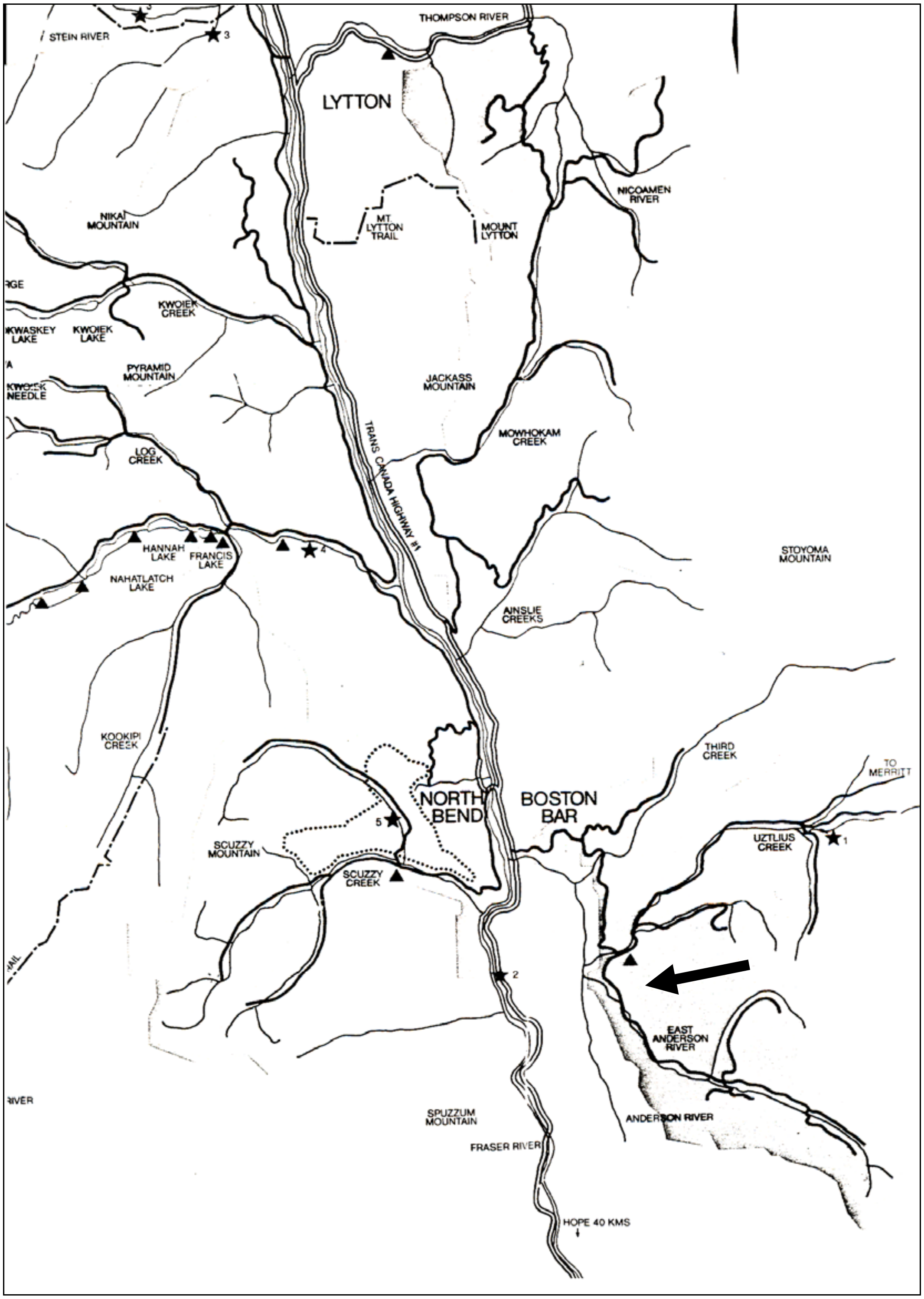

Figure 1. Location of Boston Bar research project.

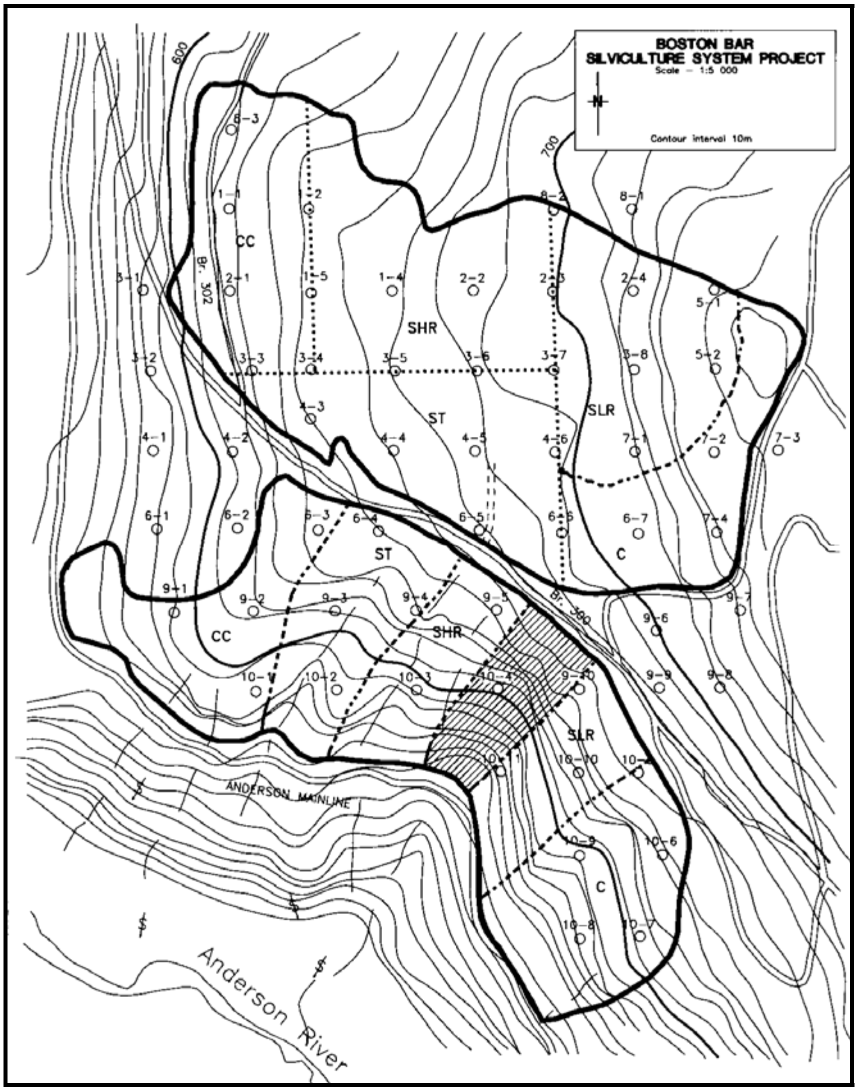

Figure 2. Treatment allocation in the upper block (top of map) and lower block. (CC = Clearcut, SHR = Shelterwood Heavy Removal, SLR = Shelterwood Light Removal, ST = Seed Tree, C = Control)

Table 1. Pre-harvest stand features of upper and lower blocks (min. 17.5 cm dbh).

Property	Upper block	Lower block
Gross vol. (m^3/ha)	391	449
Stems/ha (SPH)	385	332
Average dbh (cm)	40	45
Ave. BA (m^2/ha)	48	52
Ave. vol/tree (m^3)	1.1	1.4
Non-merch SPH	608	36

Ecosystem mapping indicated more uniform site conditions in the lower block. Edaphic conditions ranged from submesic to mesic moisture regime and medium nutrient regime (3-4/C), representing the zonal site for the ecosystem (FdCw-Hazelnut). Over 50% of the upper block was described as similar to the lower block but included both wetter (5/D) and drier (1-2/B) portions. Site index for the zonal site was estimated at 24 (m@50 years)[5].

2.2 Treatment Design

Harvest treatments were designed as a group to yield a range of understorey shading by managing residual overstorey cover with trees retained in a dispersed pattern. Proposed treatments, designated on the basis of silvicultural system terminology, included 0% shading (clearcut), 10-12% shading (seed tree), 30% residual shade (shelterwood heavy removal), 50% residual shade (shelterwood light removal), and 100% shading (unlogged control). The relationship between basal area and overstorey shading (Williamson 1973) was used to determine retention levels based on residual basal area (Table 2). Stand and stock data, available literature, and discussions with foresters experienced in shelterwood management were also consulted for advice[6]. By translating the basal area to stand densities, inter-tree spacing was determined and permitted guidance for residual tree selection in the field.

As the inter-tree distances were established (see Table 2), trees selected for retention were painted. Retained trees had to have the following attributes: dominant or co-dominant, windfirm, thrifty, good form, free of defects, free of insect and diseases, and evenly spaced (although tree quality took precedence over spacing). In the spring of 1990, 15 retained trees per hectare in the shelterwood treatments, and fewer in the seed tree treatments, were stressed in an attempt to stimulate subsequent cone production. Stressing was done by cutting the cambium with two narrow saw cuts on opposite sides of the stem and three quarters of the way around the stem, one above the other.

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[5] A Field Guide to Site Identification and Interpretation for the Vancouver Forest Region, Green and Klinka 1984.

[6] Because of the deer winter range values of the study area, Fish and Wildlife staff of the Ministry of Environment were involved in layout and design of final prescriptions

Table 2. Partial cutting treatments goals.

	# leave trees	Tree spacing	Crown Cover	Basal Area removed[1]
UPPER BLOCK				
Clearcut	0	-	0	100%
Seed Tree (ST)	15 - 20/ha	24 – 28m	10 - 12%	80 - 85%
Shelterwood Heavy Removal (SHR)	45/ha	15m	28%	64 %
Shelterwood Light Removal (SLR)	83/ha	11m	50%	65 %
Control (Unlogged)			95%	0%
LOWER BLOCK				
Clearcut	0	-	0	100%
Seed Tree (ST)	15 -20 / ha	24 – 28m	8 - 10%	87 – 90%
Shelterwood Heavy Removal (SHR)	45 / ha	16 m	20 - 25%	63 %
Shelterwood Light Removal (SLR)	110 / ha	10 m	50%	53 %
Control (Unlogged)			95%	0%

[1] targets

2.3 Experiment Design

This trial was given a randomized complete block design, with all five treatments (clearcut [CC], seed tree [ST], shelterwood heavy removal [SHR], shelterwood light removal [SLR], and an unlogged control, repeated in both the upper and lower blocks of the study area. In the upper block, each treatment occupied about 5.5 ha, while in the lower block, treatments averaged 4.0 ha in area (see Figure 2).

Numbered stakes, spaced 25 metres apart, were established in a grid pattern in the approximate centre of each treatment and at least two tree-lengths from treatment boundaries. Ecosystem mapping and field measurements used these numbered grid points to reference and record position in the field. The grid was re-established after harvest, as stakes and tagging were disturbed during falling and yarding.

2.4 Measurements

2.4.1 Forest Stand Measurements

Pre- and post-harvest forest stand attributes were sampled by establishing 20 fixed-radius cruise plots (400 m^2 = 11.28 metre radius) in each treatment, utilizing the core grid as plot centres. Trees within the sampling area were numbered, and their species noted. Measurements on individual trees included dbh, condition and health. Additional individual trees selected for retention were sampled for the same measurements as conducted within cruise plots, plus total height and height to lower crown. D'Anjou (2006) includes a complete discussion of forest stand measurements.

2.4.2 Regeneration Measurements

Post-fire regeneration assessment began two growing seasons after the fire (1997). Thirty grid points were randomly selected as reference points for positioning regeneration plots. The centre of each regeneration plot was identified with a metal stake placed 5 to 7 metres from each grid point in the four cardinal directions (north, east, west, south). Regeneration within a 1.55 metre radius of plot centre (7.5 m^2 area) was tallied by species and origin (pre-fire residual, post-fire natural regeneration and planted seedling), determined based on seedling size. The positions of dominant seedlings were recorded on plot maps to assist future identification. Initial post-fire planting was restricted to clearcuts in both blocks, planted in the spring of 1996. Douglas-fir seedlings (2+0 PSB 415D, Seed Lot 6759) were planted in the spring of 1998 for research monitoring in the partially cut stands. The partially cut stands were also planted operationally with Douglas-fir styroblock plugs (Seed Lot 6543).

In 1998, regeneration monitoring was conducted in two of the original four regeneration plots. Measurements included seedling tally by species, and growth measurements (height, root collar diameter) of dominant seedlings. More than 90% of Douglas-fir seedlings planted for research monitoring died by the fall, and their poor performance was attributed to improper stock type selection. Operationally planted seedlings fared better, and those falling within regeneration plots were identified and monitored. Subsequent infill planting included Lodgepole pine (Seed Lot 45681 - 1.890k). Douglas-fir (Seed Lot 60303 - 0.900k) was planted in small amounts in 2001, as was western redcedar in 2005 (Seed Lot 31971 – 1.425k).

Regeneration monitoring in the fall of 2005 included a tally of seedlings by species in all established plots. Seedlings planted since the previous assessment were identified based on age and position. In two of the four regeneration plots, the estimated age of each germinant was tallied using six age classes: 1 to 2 years old, 3 to 4, 5 to 6, 7 to 8, 9 to 10, and pre-fire (seedlings surviving the fire). The two tallest seedlings in each of the four plots were ribbon and position recorded on a plot map. Measurements of dominant seedlings included total height and annual height increment over the last three seasons, root collar diameter, and seedling condition.

3.0 Results

3.1 Stand Structure: Post-harvest

Pre- and post-harvest stand conditions for the treatments are summarized by block and treatment in Table 3. The goal of creating a range in understorey light was met and demonstrates the relationship between basal area and understorey light conditions[7] . Over 92% of sampled advanced regeneration was damaged by harvesting, with saplings scarred on the stem, smothered by debris, or pulled out of the ground. Post-harvest advanced regeneration averaged between 30 and 130 sph in the partially-cut treatments.

Table 3. Pre- and post-harvest stand conditions in harvested treatments in upper and lower blocks.

STAND CONDITIONS	UPPER BLOCK			LOWER BLOCK		
Density(stems/ha)	**SLR**	**SHR**	**ST**	**SLR**	**SHR**	**ST**
Pre-log	326	373	358	385	318	300
Marked	79	50	14	95		
Post-log	85.0	61.3	11.3	95	41.2	13.8
% reduced	76	85	96	72	87	94
Basal Area (m^2/ha)						
Pre-log	52	50	42	46	59	53
Post-log	19	12	3	18	13	5
% reduced	64	76	94	61	78	91
Volume (m^3/ha)						
Pre-log	452	418	341	371	538	480
Post-log	177	108	22	156	129	48
% reduced	61	74	93	58	76	91
Mean DBH (cm)						
Pre-log	45	41	39	39	49	47
Post-log	56	51	48	46	65	60
Understorey Light (% full sun)						
Pre-log	9	8	5	3	2	5
Post-log	55	75	95	54	68	86

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[7] Light measurement methodology is detailed in Appendix A.

3.2 Residual Stand Structure: Year 15

Annual surveys in the five years after harvest found declines in surviving dispersed tree densities, principally in the upper block. Windthrow, bark beetle, and fire were the agents identified for the declines. Windthrow began three months after harvesting (June 1991). Additional windthrow occurred the following October, and over the winter of 1994-95. Trees in the lower block remained resistant to windthrow with no damaged trees observed.

Dead and dying trees in the upper block were first noted in the summer of 1992 and prompted a ground survey by the regional entomologist[8] to assess possible causes. Bark excavation identified the Douglas-fir bark beetle (*Dendroctonus pseudotsugae*) on affected trees, including those attacked in the year of harvest (1991). Identified trees were felled beginning, and along with previously blown down timber, skidded out with horses in the fall to reduce the number of beetles emerging from attacked trees. Treatment-wide surveys located tree mortality related to the fire that swept through both blocks during the second week of September 1995.

Fifteen years after harvest, residual tree densities ranged between 3 stems per hectare (upper seed tree) and 60 stems per hectare (lower SLR) (Figure 3). This represented an 80% and 48% reduction in post-harvest densities respectively, with greater reductions in the treatments with lower retention densities. Residual basal area declines as a percentage of pre-harvest levels were similar to declines in stand density (Figure 4), with greater reductions in those treatments with lower post-harvest basal area.

8 Don Heppner, Regional Entomologist, Coast Forest Region.

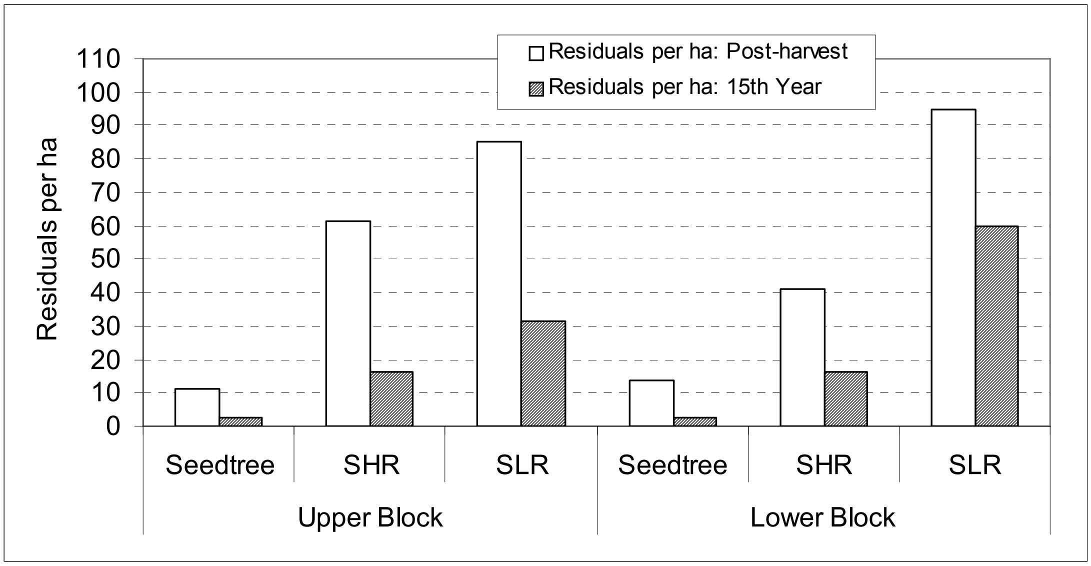

Figure 3. Residual tree density by treatment: post-harvest and 15 years after harvest.

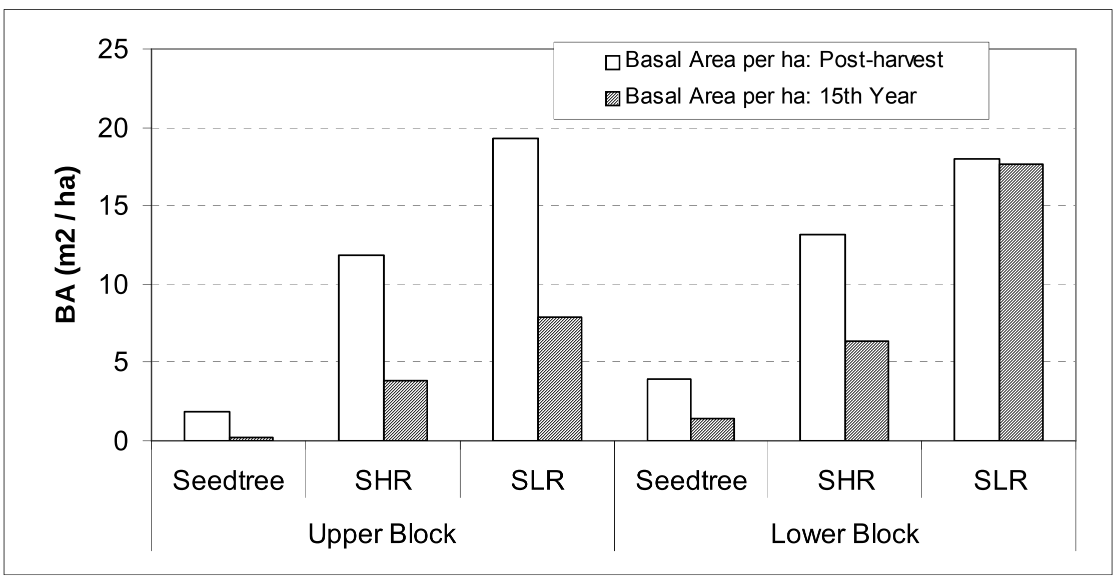

Figure 4. Basal area by treatment: post–harvest and 15 years after harvest.

3.3 Natural Regeneration: Second Growing Season After Fire (1997)

Two growing season after the fire, regeneration was predominately Douglas-fir and included both residuals that had survived the fire (primarily in the upper block) and regeneration established after the fire (Figure 5). Regeneration density in both blocks increased with increasing overstorey density, a trend observed prior to the fire. Despite greater overall basal area and stand densities

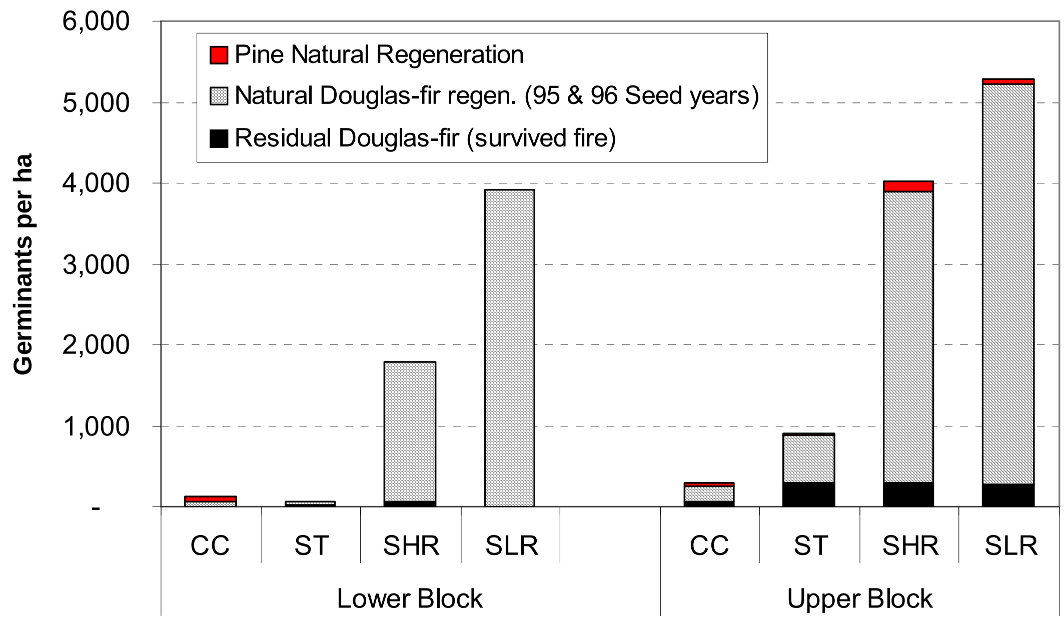

Figure 5. Natural regeneration density by block and treatment, 1997.

in the lower block, natural regeneration density was lower for each partial cutting treatment in the lower block.

The upper block treatments, and those treatments with higher residual overstorey, had a greater percentage of plots with at least one germinant (Figure 6). The highest density in a single plot was in the upper block SLR with 35 germinants, or 46,666 germinants per ha. The 1997 assessment found 1,736 and 1,333 planted seedlings per hectare in the upper and lower block clearcuts respectively.

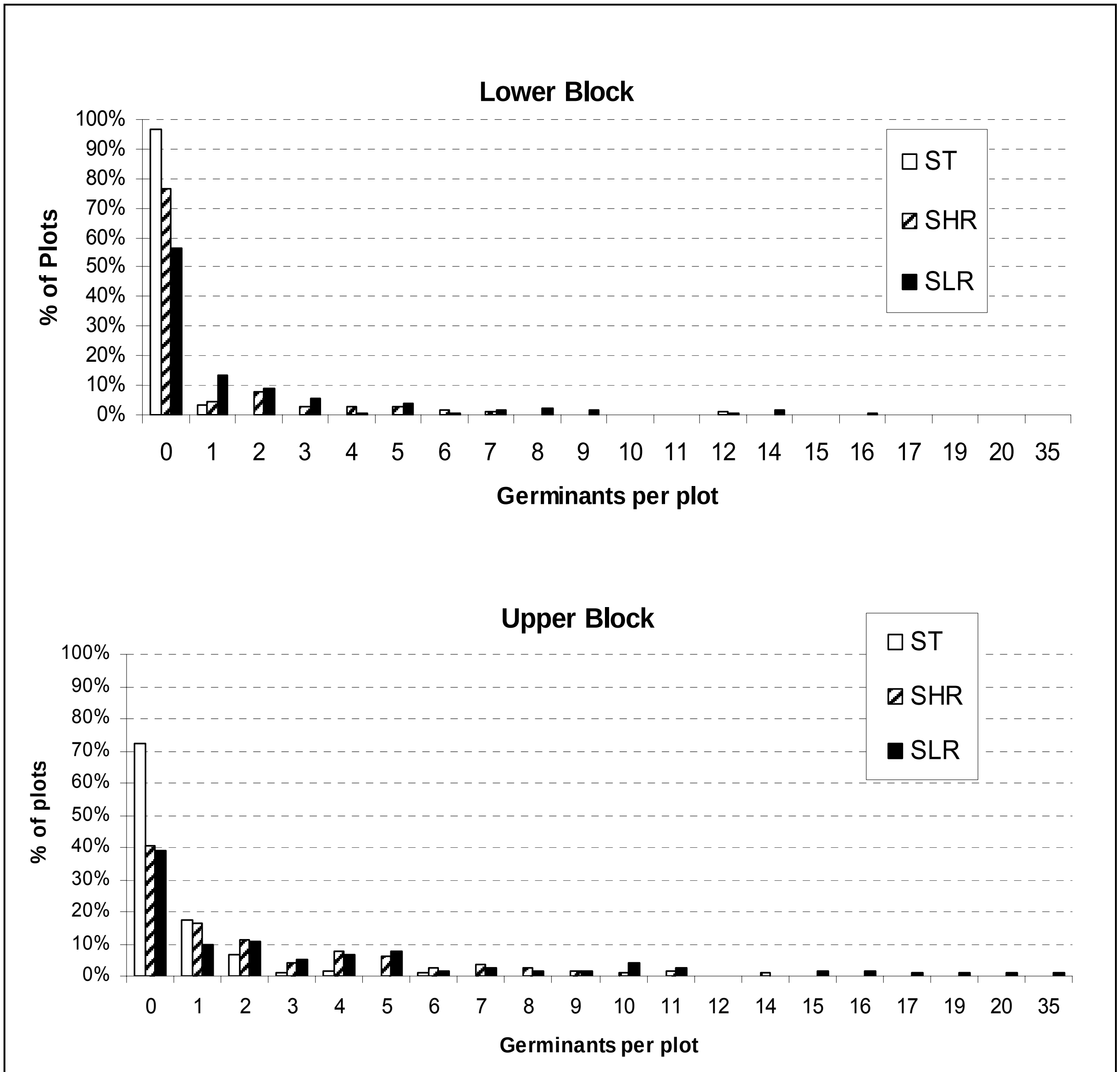

Figure 6. Germinants per plot (7.5 m^2) two growing season after fire, by block and treatment.

3.4 Natural Regeneration: Third Growing Season After Fire (1998)

Third-year post-fire regeneration densities (Figure 7) declined from second-year levels in most treatment/block combinations, as post-fire regeneration mortality rates (ranging from 23% [UST] to 56% [lower SLR]) exceeded ingress from 1997 seedfall. The mortality rates of regeneration established before the fire ranged from 6% (SLR) to 35% (ST), and were generally lower than rates for younger regeneration. Regeneration densities remained higher in the upper block and in the shelterwood treatments.

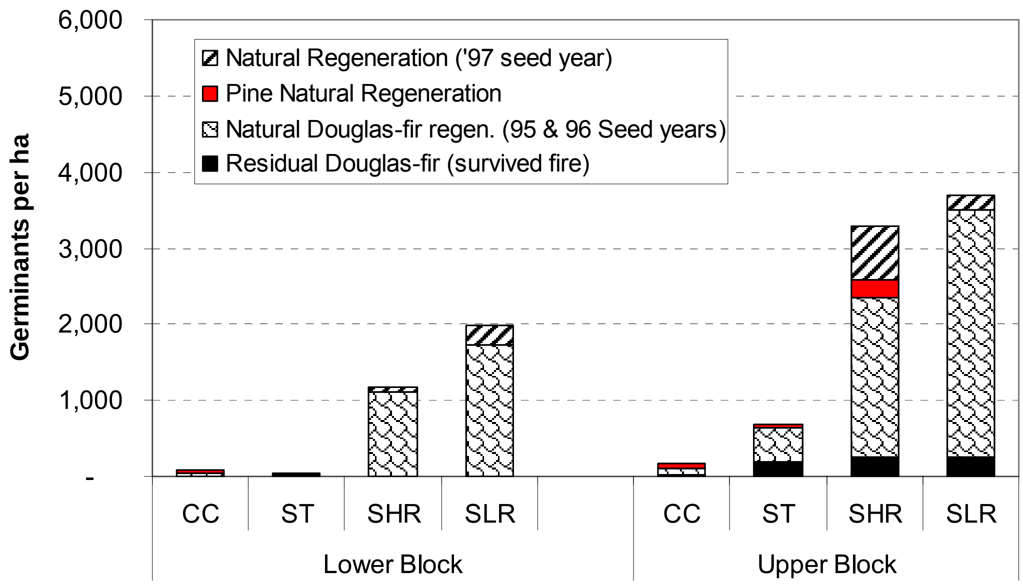

Figure 7. Natural regeneration three growing seasons after fire, by treatment and block.

3.5 Natural Regeneration: Tenth Growing Season After Fire (2005)

Tenth-year total Douglas-fir natural regeneration increased in all treatment/bock combinations over the third-year measurements, except in the lower SLR where total density declined almost 50% (Figure 8). Estimates of natural regeneration ages found establishment during all two-year periods since harvest, suggesting ingress had been continuous since the fire (Figure 9). Survival of pre-fire regeneration levelled off since the previous assessment, as over 95% of seedlings alive in Year 3 survived to the tenth year assessment.

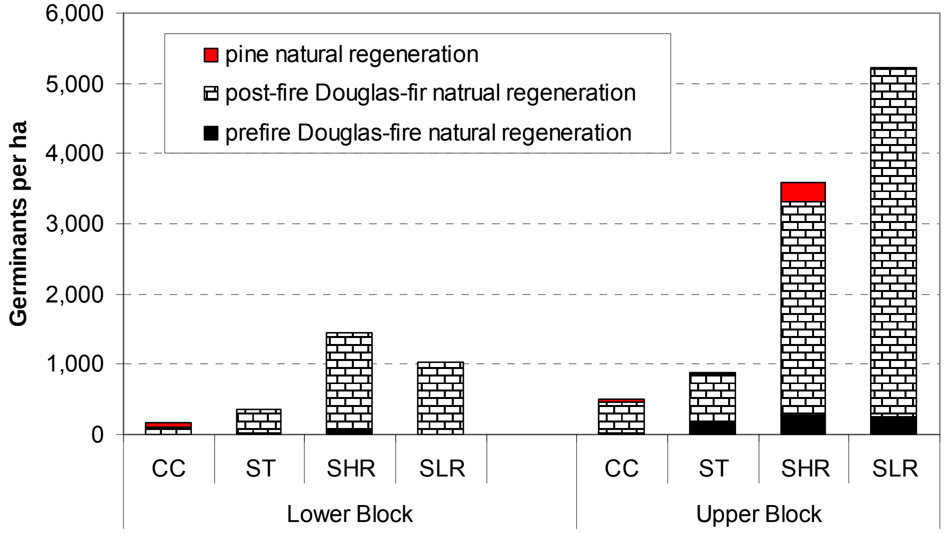

Figure 8. Natural regeneration ten growing seasons after fire, by treatment and block.

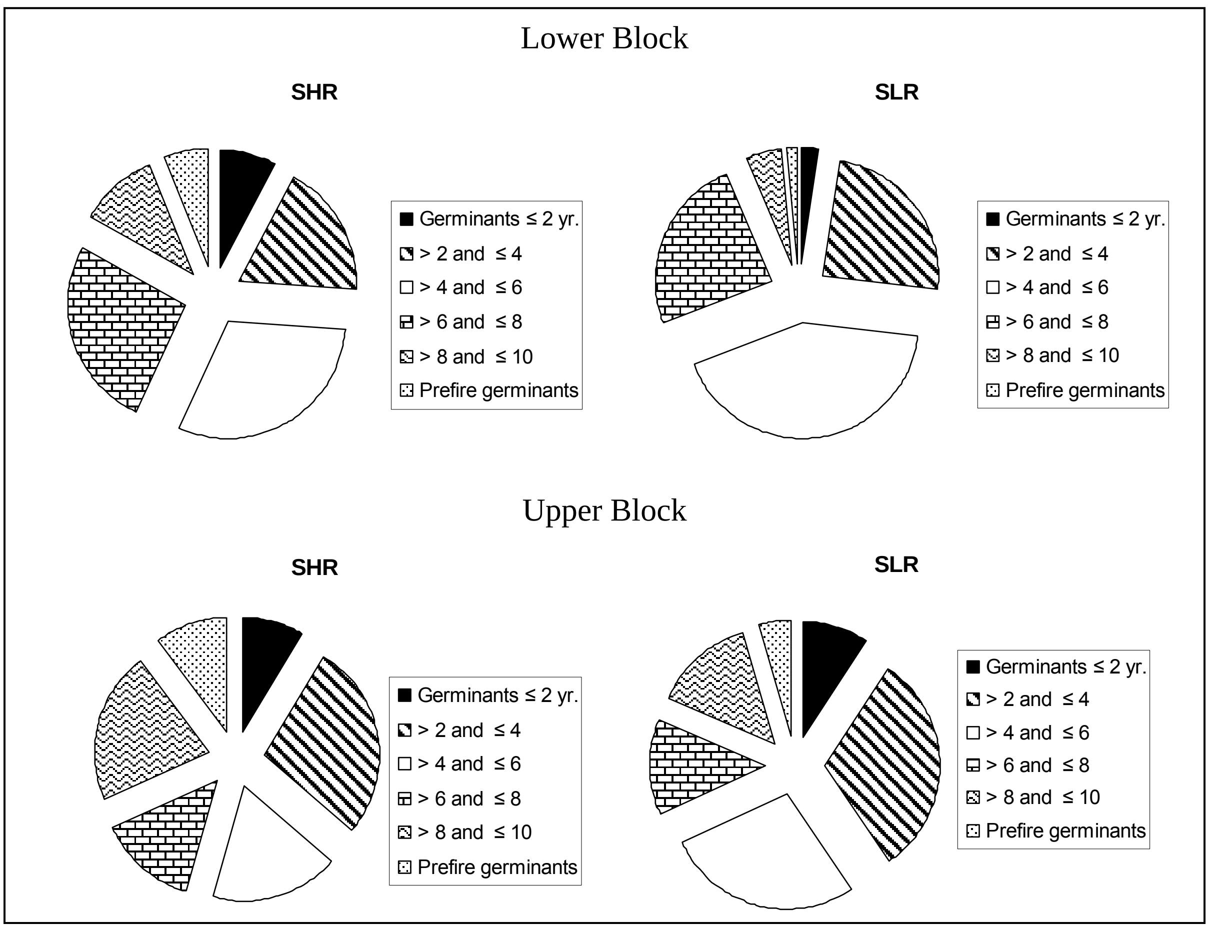

Figure 9. Age class distribution of natural regeneration in shelterwood treatments in the upper and lower blocks.

Percentage of plots with at least one germinant was higher in the upper block, confirming the observation the regeneration was more widely distributed in the upper block (Figure 10). Natural regeneration became more widely distributed in both SLR treatments since the second year assessment as percentage of plots with no regeneration declined. The highest density of regeneration in a single plot was in the upper block SLR with 20 germinants, equivalent to 26,666 germinants per ha.

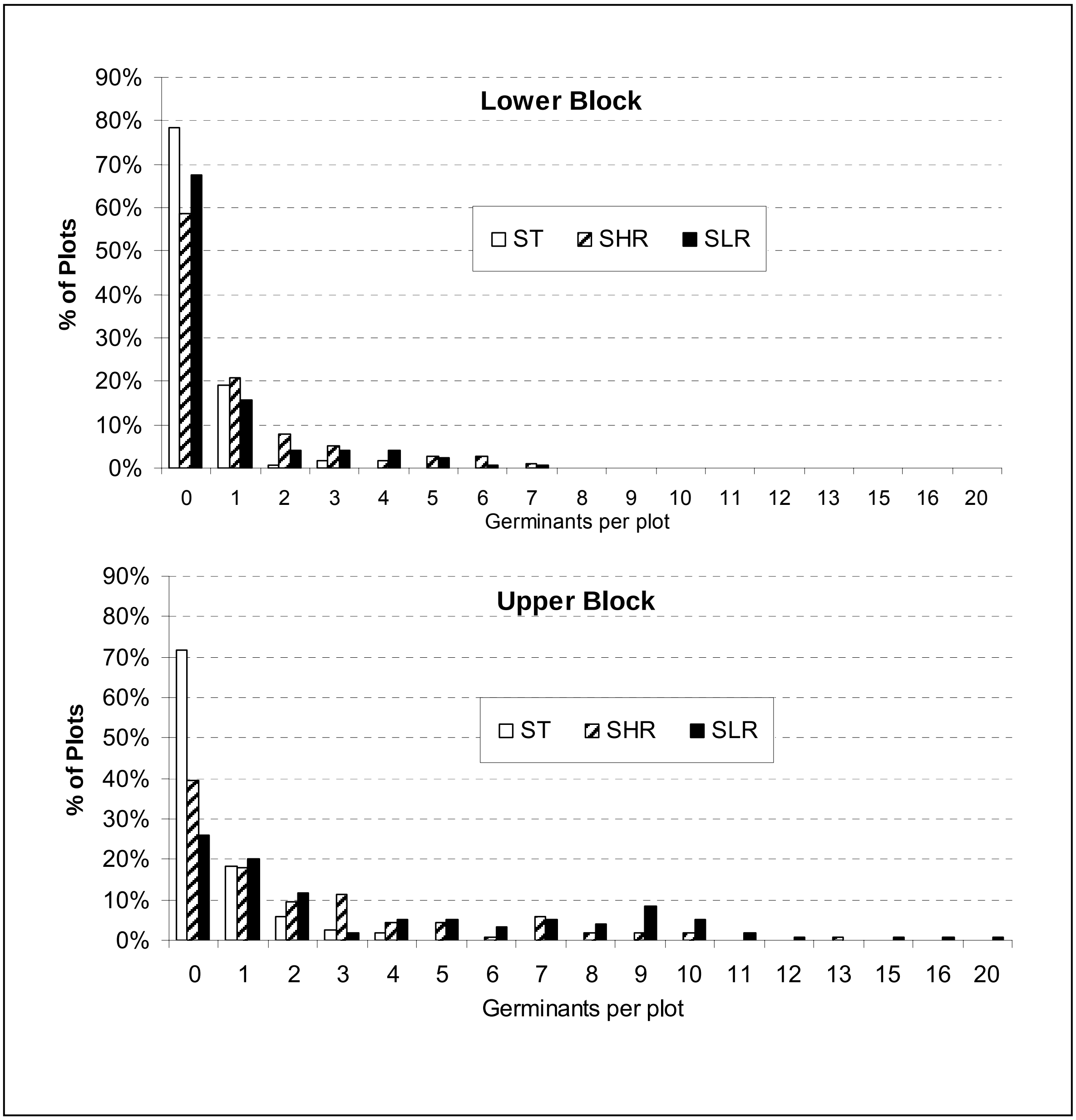

Figure 10. Germinants per regeneration plot (7.5 m^2) 10 growing season after fire, by block and treatment.

3.6 Regeneration Growth: Tenth Growing Season After Fire

All harvested treatments were planted with a single Douglas-fir plug stock in the year after harvest. Planted seedling growth enabled a direct comparison of seedling growing environment between treatments and blocks. Since the fire, several operational plantings have taken place within the research site, but no single planting was common to all treatments and both blocks. A review of Douglas-fir growth data collected in 2005 found the most abundant data came from 1) the 1998 operational planting, 2) natural regeneration from 1996 seedfall, and 3) 1996 operational planting in the clearcuts. Measurements on these three classes of regeneration, plus the regeneration which survived the fire in the upper block, were summarized in this report.

Seedlings planted in the clearcuts (1996) were the tallest and fastest growing of regeneration established after the fire, with height (Figure 11) and root collar diameter (RCD) (Figure 12) more than twice that of the other seedlings. Where comparisons were possible, planted seedlings (1998) within a treatment tended to be taller and have greater RCD than the oldest natural regeneration established after the fire. Seedlings, regardless of origin, tended to have lower height increment in 2004 compared with 2005, and may be related to differences in growing season weather (Figure 13).

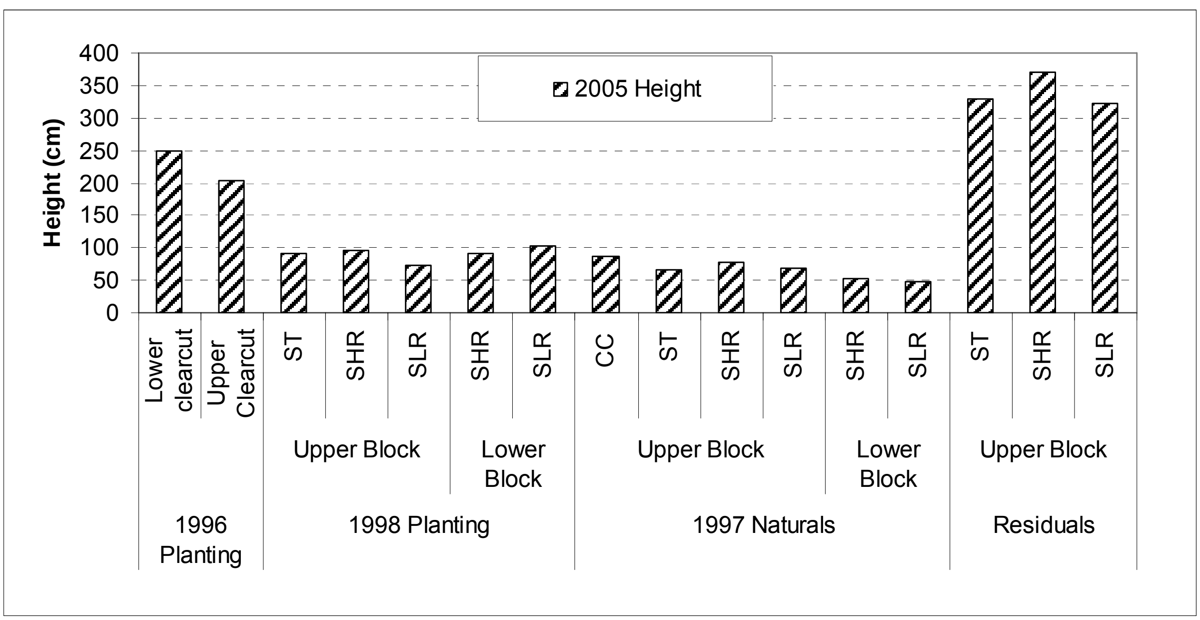

Figure 11. Total height (2005) of Douglas-fir seedlings, by treatment, block, origin (planted or natural), and year of establishment.

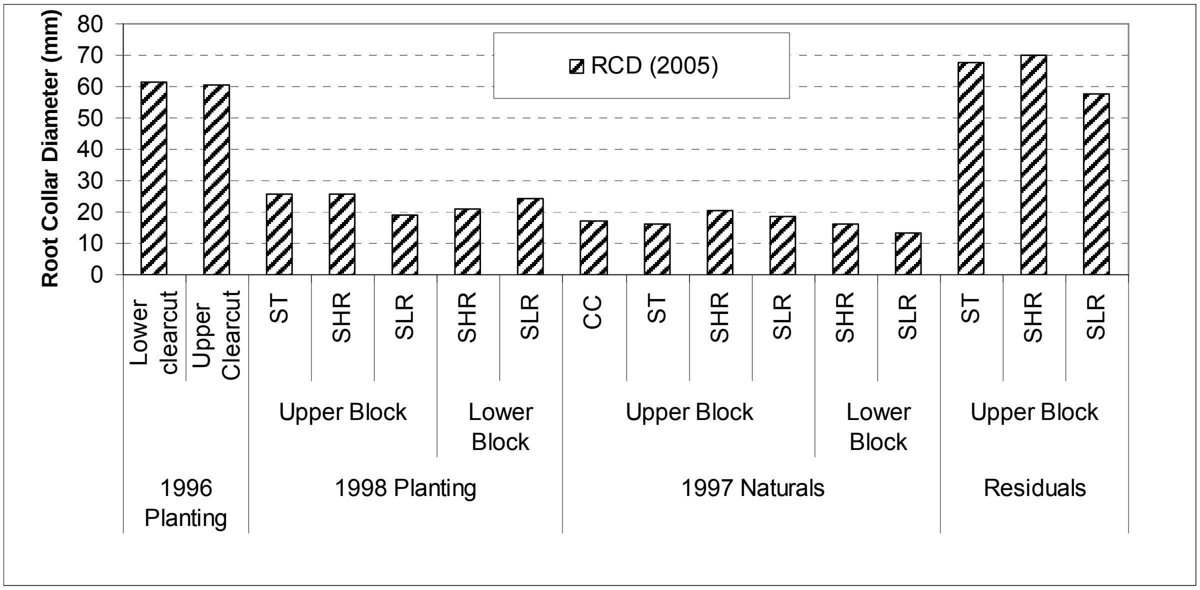

Figure 12.. Root collar diameter in mm (2005) of Douglas-fir seedlings, by treatment, block, origin (planted or natural), and year of establishment.

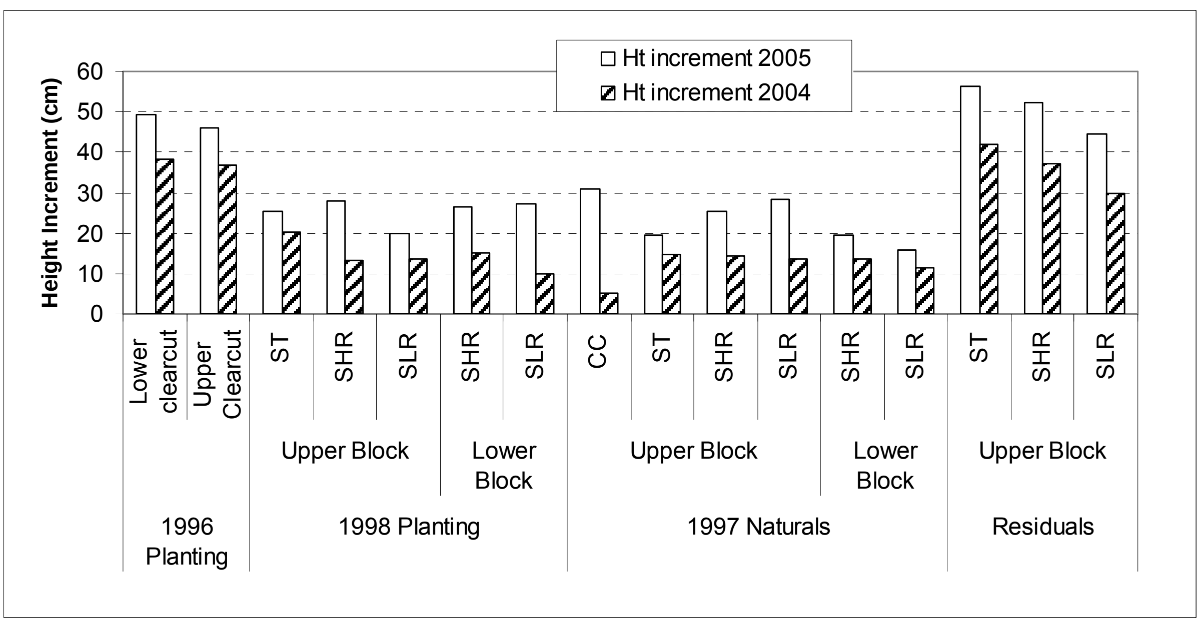

Figure 13. Height growth (2005 and 2004 growing seasons) of Douglas-fir seedlings, by treatment, block, origin (planted or natural), and year of establishment

4.0 Discussion and Conclusions

As fire is the typical stand-initiating event in the IDF, the accidental wildfire provided an opportunity to study regeneration under conditions with some similarities to those under which the current stands initiated. The burning of harvest-related woody material, including branches and tops, and the consumption of the thin humus layer thereby increasing mineral exposure, are two apparent effects of the widespread fire. The reported preference of Douglas-fir for mineral soil exposure for regeneration in shelterwoods in Oregon (Williamson 1973) and local dispersed retention blocks (D'Anjou 2002) suggests the fire would be a positive factor for Douglas-fir regeneration, at least from a soil substrate perspective.

Comparing natural regeneration development three years after initial harvest against the same period after the fire (Figure 14) suggests fire had a positive effect on natural regeneration development, but the lack of unburned areas prevents statistical tests. Post-fire densities exceeded post-harvest densities in most treatments in both blocks, despite declining overstorey densities, which is a negative factor for both seedfall and shading in the understorey. Total reliance on natural regeneration to meet regeneration goals faces the risk of understocked stands if seed crops after harvest are poor. Subsequent infill planting could help to meet the stocking goal, but may require some form of vegetation management as the abundance of competing non-crop species (possible deterrents to successful regeneration survival and growth) increases after harvest. Planting provides several advantages over natural regeneration, including more uniform stocking and immediate height growth benefits, as Douglas-fir natural regeneration took two to three years to reach the height of planted seedlings on this site.

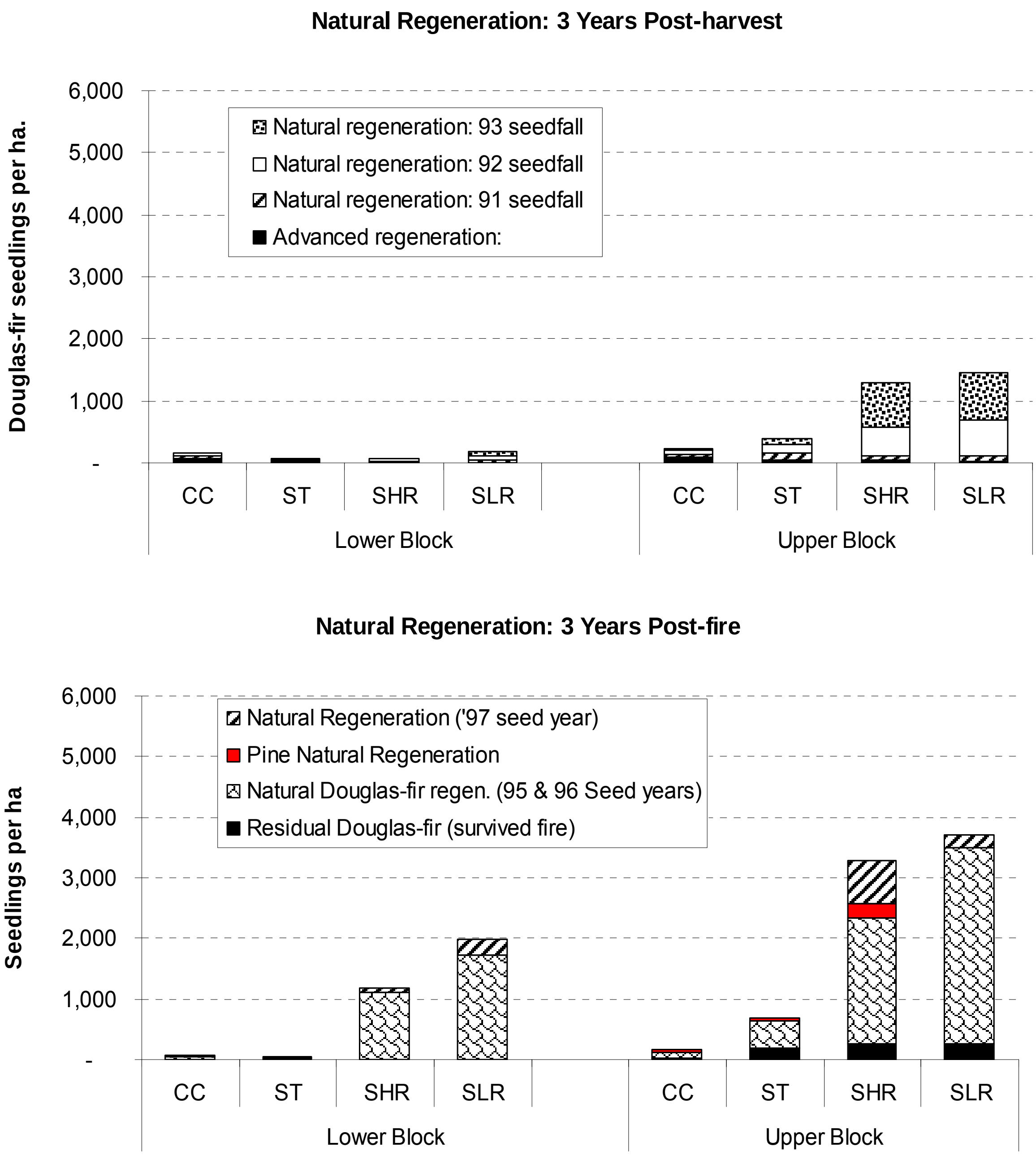

Figure 14. Douglas-fir natural regeneration by block and treatment, three years after harvest and three years after fire.

The individual treatments in this study lack long-term target stand objectives. From the perspective of meeting free growing objectives, minimum heights were met in both clearcuts (minimum height of 1.5 m in Site Series 3) by the ninth year after the fire (BCMoF 2000). The later plantings in the shelterwood and seed tree treatments are currently perhaps three growing season from the minimum height. Whether stocking standards (well-spaced/ha) – including a target of 600 and minimum of 400 for the preferred Douglas-fir species – have been met in the various treatments will require formal surveys. Future management activities (e.g., spacing) must be connected to clear target stand objectives (spacing, density, etc.) for each treatment.

In conclusion, higher densities of dispersed retention (shelterwoods) promoted abundant natural regeneration with the potential to contribute significantly to meeting stocking goals when combined with planting. Under-burning may further enhance regeneration development, and perhaps may be required as in the lower block in this trial, but additional research is required to confirm this observation. Dispersed retention patterns also supplied biological legacies including snags and coarse woody debris, which are potentially important for meeting broader biodiversity objectives. Dispersed tree densities have yet to stabilize as chronic bark beetle attacks continue to kill remaining residual trees. Aggregated retention patterns may be considered more suited to specific site conditions while potentially meeting both regeneration and biodiversity objectives.

A 20-year measurement (2010) of understorey regeneration and residual stand structure is recommended. Monitoring should include evaluating the presence of budworm and mistletoe, both observed on the site and having the potential to affect overstorey and understorey development.

Appendix A: Light Measurements

Overstorey canopy cover was estimated using relative illumination in the understorey. By this method, percent canopy light interception serves as an integrative index of the shading effect of the overstorey (Hopwood 1990). The amount of light reaching the understorey was measured using a sunfleck ceptometer (Decagon Devices, model SF-80) which read instantaneous fluxes of photosynthetically active radiation (400 - 700 nm). The understorey measure was compared to the amount of above-canopy light (full sunlight) obtained using a Li-Cor Datalogger (Model LI-1000). The percentage of above-canopy light (PACL) in the understorey was obtained from a ratio of these two measures. An understorey reading was taken at each core sampling grid plot centre while simultaneous full sunlight measurements was taken from a fixed point in full light for the duration of understorey measurements. Each understorey "reading" was the average of four readings taken at cardinal bearings around plot centre. Canopy interception was calculated for each plot using:

$$CI = 1 - Qu/Qt$$

where Qu is the understorey PAR and Qt is the total PAR as measured in the clearcut. Light measurements were taken during morning and afternoon periods, between 0900 and 1200 and 1300 and 1600 hours respectively, during three separate days between August and September. Repeating measurements on three separate occasions increased replication to compensate for high variability associated with sunflecks which would bias single readings. Data was used to quantify canopy effect for each treatment.

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