Early Height Growth of Douglas-fir on a Dispersed Retention Site in the Coast-Interior Transition of British Columbia, Canada

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Abstract

Establishment of regeneration after clearcutting can be problematic in the dry Douglas-fir forests of the interior of British Columbia, and much of western North America. Mixed fire regimes were typical of this forest type and regeneration often occurred under partial canopies, indicating that a shelterwood silvicultural system might be effective at fostering regeneration. To examine the efficacy of differing amounts of canopy tree retention a field trial was initiated at Boston Bar in the BC coast-interior transition. Here we evaluate the growth of planted Douglas-fir over a seven-year period in three treatments: clearcut, heavy-removal shelterwood, and light-removal shelterwood. All measures of target tree growth and size were greatest in the clearcut, least in the light-removal shelterwood, and intermediate in the heavy-removal shelterwood. Height growth over the seven years averaged 245 cm in the clearcut vs. 151 cm in the light-removal shelterwood. Root collar diameter was over twice as great and crown volume over six times greater in the clearcut as in the light-removal shelterwood. However, conifer regeneration within 7.5 m^2 plots around target trees was much less in the clearcut than in either level of shelterwood, indicating that shelterwoods were effective at promoting natural regeneration. Regeneration >1 m tall in the plots (other than the target tree) averaged 2.0 (2700/ha) in the light-removal shelterwood, 1.3 (1700/ha) in the heavy-removal shelterwood, but only 0.2 (270/ha) in the clearcut. Given that target tree height growth was not that much less in the light-removal shelterwood than in the clearcut (31 vs. 35 cm per year) and that amounts of natural regeneration were much greater, the light-removal shelterwood may hold the greatest potential for effectively establishing fully stocked stands of trees with reasonably good growth rates.

Introduction

Douglas-fir *(Pseudotsuga menziesii)* forests are widespread in western North America, and present a variety of silvicultural challenges because of the wide range of habitats occupied by this species (Hermann and Lavender 1990). On coastal and wet interior sites, regeneration of Douglas-fir following clearcutting is typically effective, which is consistent with the observation that under natural conditions Douglas-fir regeneration typically followed stand-replacing fires (Franklin and Dyrness 1973, Agee 1993). However, on dry sites the natural disturbance regime was more complex, and regeneration often occurred under partial canopies.

In the interior of British Columbia, Douglas-fir dominates on dry sites (IDF biogeoclimatic zone), which on a moisture gradient occurs between the very dry ponderosa pine forest type or grasslands and mesic forests (Meidinger and Pojar 1991). Seedling establishment of Douglas-fir can be very difficult in open areas on dry sites because of summer drought, which can result in both low surface soil moisture and high transpiration rates of seedlings. Thus seedling mortality, both of natural and planted seedlings, can be exceedingly high in the open, precluding establishment of new stands. In dry Douglas-fir forests in BC and throughout western North America, a mixed-fire regime predominated (Agee 1993) in which complete canopy loss occasionally occurred and partial canopy mortality was common. Thus regeneration often occurred under conditions similar to a shelterwood.

After clearcutting, establishment of new Douglas-fir stands is difficult on warm, dry sites in the BC interior, including areas transitional to the coast (Newsome et al.

1990). The standard silvicultural system used in these ecosytems was clearcutting followed by planting of Douglas-fir. However, poor survival resulted in understocked plantations. Furthermore, various attempts to improve survival were not consistently successful. Repeated planting, which is expensive, was thus necessary on some sites to reach stocking standards.

A promising solution to this problem is the use of alternative silvicultural systems that use some form of partial cutting. Shelterwood systems are typically used where moisture stress is a serious problem. Because high evaporative demand is a major cause of seedling mortality on dry sites, the shade provided by a canopy can substantially reduce temperatures in seedling microsites, reducing water loss and increasing survival. In addition, the residual trees can provide a seed source for natural regeneration.

To examine the potential of alternative silvicultural systems, in 1991 a silvicultural research installation was established near Boston Bar in the coast-interior transition region. The overall objective of the study was to investigate the effects of different levels of retention of dispersed overstorey trees on establishment and growth of regeneration. The specific objective of the component reported herein is to compare and evaluate the growth of planted Douglas-fir under three conditions: clearcut, heavy-removal shelterwood, and light-removal shelterwood.

Methods

Study site and experimental design

The original experimental design (implemented in 1991) was a randomized complete block design with one replication of each of the four treatments (clearcut, seed tree, heavy-removal shelterwood, and light-removal shelterwood) and an unharvested control in two blocks. The whole experimental area included about. 40 ha with each block comprising about half of the area; individual treatments covered 3-5 ha. The upper block is on a gently sloping (10-30%), west-facing bench, whereas the lower block is on the steep (50-70%) southwest slopes below the bench. The site is at 600-800 m elevation and was dominated by Douglas-fir 110-140 years old before treatment. A fire in the late summer of 1995 consumed between 84% and 99% of established regeneration, leaving 11 - 299 seedlings per ha. The site was artificially regenerated after the fire. Post-fire monitoring revealed natural regeneration, predominately Douglas-fir, established in abundance in partially cut stands (D'Anjou 2006a). Densities of dispersed trees have declined since trial establishment due to wind damage (wind throw and stem break), bark beetle attack and fire damage (D'Anjou 2006b).

Data collection

The three treatments used in this study were: clearcut, heavy-removal shelterwood, and light-removal shelterwood. In each treatment unit, 30 grid points (20 for the clearcut) were randomly selected and the Douglas-fir tree closest to the grid point that was 8 – 9 years old (i.e., it established after the fire) was selected for measurement. The following measurements were taken for each sample tree:

- total height (cm) over the last 8 years (taken from annual branch whorls),
- root collar diameter (mm),
- crown length (cm),
- crown width (cm) in the four cardinal directions, and

- distance (m) and direction (degrees) to the nearest living residual tree.

A 1.55 m radius (7.5 m^2) plot was established at each sample tree and the following measurements were taken:

- species and percent cover of all shrub species,
- number of conifers in 50 cm height classes (0 – 50 cm, 50 – 100 cm, 100 – 150 cm, and 150 – 200 cm), and
- number of conifers in 2 year age classes (0 - 2, 2 – 4, 4 - 6, 6 – 8, 8+).

All data used were collected in 2005 and entered into a Microsoft Excel spreadsheet. Data were not available for the lower block because the site was snowed out before the measurements could be taken. Therefore, we only had measurements from the upper block available for analysis.

Data analysis

Crown volume (cubic centimetres) was approximated from the crown width and crown length data. We assumed the crown was conical and averaged the four crown width measurements to derive the radius of the base of the cone. Crown volume was then calculated from the average crown width and the crown length (i.e., height of the cone) using the formula for the volume of a cone ($= \pi \times r^2 \times h \div 3$, r = radius at base of cone, h = height of cone).

Tree height growth was calculated by subtracting the tree's height measured at the end of 2005 from the tree's height measured at the end of 1998 and dividing that by seven (seven year's of growth).

We did three analyses with these data.

1. Assuming the data were from a completely randomized design, we looked for differences in height growth (HtGr) across the three treatments (Tmt) with the following model:

$$\text{HtGr} = \text{Tmt} + \varepsilon$$

Procedure GLM in SAS (SAS Institute Inc. 2004) was used to perform the ANOVA.

2. Assuming the data were from a completely randomized design, we looked for difference in crown volume (CrVol) across the three treatments (Tmt) with the following model:

$$\text{CrVol} = \text{Tmt} + \varepsilon$$

Again, procedure GLM in SAS (SAS Institute Inc. 2004) was used to perform the ANOVA.

3. Using individual tree data, we fit the following model (based on the logistic function) that predicts height growth from crown volume:

$$\text{HtGr} = \frac{a}{1 + e^{b - c \times \text{CrVol}^{d}}} + \varepsilon$$

The analysis was done with procedure NLIN in SAS (SAS Institute Inc. 2004). Using indicator variables (Sen and Srivastava 1990), we tested for differences in the parameters across the different treatments. For example, parameter *a* was re-expressed as:

$$a = a_0 + a_1 \times \text{slr} + a_2 \times \text{cc}$$

where slr = 1 if the treatment is shelterwood light removal, 0 otherwise; cc = 1 if the treatment is clearcut, 0 otherwise; and, a_0, a_1, and a_2 are sub-parameters. If any sub-parameter was not significantly different from zero, then the term containing the least significant sub-parameter was deleted from the model and the regression was re-run until all remaining sub-parameters were significant at α=0.05. This analysis was done for all four parameters.

Results

Height growth during the seven-year period averaged much greater in the clearcut than the light-removal shelterwood; the average for the heavy-removal shelterwood was intermediate, but closer to the clearcut (Table 1). The ANOVA for height growth indicates a highly significant difference among treatments (Table 2). Variability among trees was high in all treatments, but overlap was minimal between trees in the clearcut and light-removal shelterwood (Fig. 1). Total height in 2005 averaged over 3 m in the clearcut, but only 1.8 m in the light-removal shelterwood (Table 1). Notable differences in average height among treatments were already apparent in 1998, and subsequent differences in growth increased the magnitude of differences among treatments.

The ANOVA for crown volume also indicates a highly significant difference among treatments (Table 3). Average crown volume was over six times greater in the clearcut than in the light-removal shelterwood; the heavy-removal shelterwood was intermediate (Table 1). Variability among crown volumes increased from the light-removal shelterwood, where all trees had small crown volumes, to the clearcut, where trees varied greatly in crown volume (Fig. 2). A few trees in the clearcut had very high crown volumes, which increased the average substantially in this treatment. Excluding these exceptionally large trees in the clearcut, overlap was high between the crown volume of trees in the heavy-removal shelterwood and the clearcut (Fig. 2).

Root collar diameter of regeneration averaged twice as large in the clearcut as in the light-removal shelterwood (Table 1). However, the relationship between root collar diameter and height was similar among treatments (Fig. 3). The trees appear to be on a similar growth trajectory in the relationship between diameter and height growth. This may be because crowns still extended to near the ground on almost all trees, indicating limited mortality of low branches as a result of lateral competition. In all treatments, crown length averaged 90% or more of tree height (Table 1)

Table 4 presents the results of the analysis of the height growth model based on crown volume, which includes the parameter estimates and their standard errors. The root mean squared error for this model is 3.910. The parameter *c* was re-parameterized as e^c to reduce the parameter effects nonlinearity (Ratkowsky 1983). We present the re-parameterized value of *c* in the Table 4. The final fitted model is:

$$\text{HtGr} = \frac{56.27}{1 + e^{1.031 - 0.0001285 \times \text{CrVol}^{0.6468}}}$$

Note that in the above model, parameter *c* is not re-parameterized.

The amount of nearby shrub cover did not appear to be related to growth or size of target trees. Total shrub cover averaged about 50% in the light-removal shelterwood, and somewhat less in the other two treatments (Table 5). Only three species occurred in over one-third of the plots, and only one of these, *Symphoricarpos*, showed a clear pattern among treatments with much greater cover in the light-removal shelterwood (Table 5).

The number of conifers regenerating in the 7.5 m^2 plots around target trees averaged much less in the clearcut than in the other treatments (Table 5). Values in the heavy-removal shelterwood were less, but not substantially so, than in the light-removal shelterwood. The same general pattern among treatments also held for regeneration >1 m tall, which were consistently less than half of all regeneration (Table 5). Almost all regeneration were less than eight years old, and ages were well distributed among two-year age classes, indicating continuing establishment of natural regeneration.

The size of target regeneration increased with distance to the nearest residual tree, but this effect could be reduced to the major difference in distances among the treatments; there was no apparent within-treatment effect.

Discussion

Tree growth and size

All measures of trees growth and size indicated that the clearcut was most favourable and the light-removal shelterwood least favourable, with the heavy-removal shelterwood intermediate. This is not surprising given that Douglas-fir has only low to moderate shade tolerance (Minore 1979, Hermann and Lavender 1990), and thus even the limited number of residual trees in the heavy removal shelterwood could reduce growth. However, the growth in height was not substantially reduced in the heavy-removal shelterwood, indicating that this level of canopy retention had only a small impact on growth. Thus a decrease in growth rate is unlikely to be a serious concern where benefits of a shelterwood, such as higher survival of regeneration or various habitat considerations, are important.

The reduction in crown volume was much greater than for height growth. This is not surprising given that as trees grow their crown volume increases much more rapidly (in essence a cubed function) than height until lateral crown expansion is limited by adjacent trees and lower branches die. Lateral competition from other regenerating trees or tall shrubs was clearly not a major factor limiting crown length for the trees studied in any of the treatments. At the time of the study, crowns still extended almost to the ground for most trees in all treatments. Crown volume is a good predictor of height growth, but it seems unlikely that the much higher crown volumes in the clearcut will translate into much higher future height growth. Eventually lateral competition is likely to become important and modify crown length and volume. Furthermore, trees appear to be on similar growth trajectories; they differ in size among treatments but do not appear to differ greatly in the relationship among size parameters. However, sample sizes are too small to examine such relationships in detail. Planted Douglas-fir have been shown to vary in height/diameter growth with variation in light (Chen 1997).

A fundamental limitation to interpretation is that the data all come from one block. Thus there is no true replication, only pseudo-replication (Hurlbert 1984, Bergerud 1988). Therefore, the significant results of the F-tests indicate a difference among the treatment units, but cannot confirm that this is due to the treatment vs. some other factor that could happen to differ among units. However, given the overall homogeneity of the block and the lack of any obvious, major habitat gradient, it seems likely that the observed differences are due to the treatment.

There was considerable variation among trees in all three treatments with major overlap among treatments, indicating the importance of local microenviromental conditions or individual tree history. Considerable variation in microsite conditions in the shelterwoods is to be expected because of the distribution of residual trees. However, variation was highest in height growth, root collar diameter, and crown volume in the clearcut, not only in the standard deviation (as would be expected from the higher means), but also in the coefficient of variation (SD/mean, see Table 1). The explanation is not obvious but could relate to microsite conditions unrelated to a canopy or more variation in early growth for unknown reasons in the clearcut. Because of this greater variability, the greater average growth in the clearcut relates, in large part, to a few exceptional trees (Figs. 1 and 2); differences in growth between the heavy-removal shelterwood and the clearcut appear to be trivial for the bulk of the trees. In contrast, the light-removal shelterwood appears to reduce growth consistently.

Sources of regeneration and silvicultural systems

A new stand could develop from three sources: advanced regeneration, natural regenerations establishing post-harvest, and planted stock. On dry sites, especially where more shade-tolerant species that require considerable amounts of moisture are absent, Douglas-fir often establishes in the rather open forests in the absence of disturbance. Consequently, considerable advanced regeneration can be present on such sites. During fires, a small percentage of this advanced regeneration could survive and following other types of disturbances that killed canopy trees (e.g., bark beetles or defoliating insects) surviving small individuals could make a major contribution to forming a new canopy. Advanced regeneration surviving harvesting could contribute to meeting reforestation goals, but is unlikely to be adequate alone given initial amounts (including patchy distribution), damage during harvest, and possible difficulties adjusting effectively to the post-harvest environment if all canopy trees are removed. At Boston Bar, the fire left a small percentage of advanced regeneration but the small sample size and irregular distribution prevented examination in this study. Use of advanced regeneration to contribute to restocking this type of site deserves serious research and operational attention. Douglas-fir in the understory of forests in the BC interior can respond well to partial canopy removal (Kneeshaw et al. 2002), and advanced regeneration has considerable potential for contributing to new stands following harvest in other forest types in BC (e.g., Parish and Antos 2005).

Planted stock would appear to have the greatest reliability and best potential for restocking sites of this type. This gets around the problem of initial seedling establishment, which can be very difficult especially on site with high environmental stress such as the dry forests studied here. As a broad generalization, conditions for regeneration are typically more restrictive than those for subsequent growth (Grubb 1977). However, the frequent failure of planted stock on clearcuts was the initial impetus for this field trial of various levels of canopy tree retention. Survival of planted stock is addressed in D'Anjou (2006). Although growth of planted stock was higher on the clearcut, this does not preclude the possibility that mortality was also higher, especially at the early stages following planting. Thus we cannot conclude anything about the adequacy of planted Douglas-fir for fully stocking any of the treatments; survival of planted stock needs to be assessed directly. Often survival and growth can be only weakly if at all related.

It appears from the data collected for this report that the heavy-removal shelterwood is a viable option for this type of site. Growth of the planted Douglas-fir in this treatment was acceptable and not substantially less than in the clearcut. However, the large amount of natural regeneration in the heavy-removal shelterwood is what makes this treatment attractive. If the plot data are representative of the site, there are 4800 natural regeneration per ha, 1700 of which are over 1 m tall in the heavy-removal shelterwood. Because of the small plot size (radius 1.55 m) these values are unlikely to include other planted trees. Moreover, 73% of the plots contained at least one natural regeneration (50% contained at least one >1 m tall). Thus this natural regeneration can contribute substantially to a fully stocked stand and buffer against mortality of planted stock. In contrast, the clearcut had very little natural regeneration. In essence the shelterwood provides an insurance policy against mortality of planted stock by fostering natural regeneration.

The light-removal shelterwood is also a viable option. Growth of the planted Douglas-fir was reduced substantially, but advanced regeneration was prevalent, although not that much more abundant than in the heavy-removal shelterwood. Thus the light-removal shelterwood is likely to provide a fully stocked stand, but at the cost of considerable reduction in individual tree growth. Overall the heavy-removal shelterwood appears to be the best compromise. However, this conclusion is only based on one block in one study, and thus confidence in generalizations must await further work. Preferred treatments are always directly dependent on specific site management objectives which directly affect long-term target stand structure.

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Table 1. Characteristics of planted Douglas-fir in three treatments (clearcut, heavy-removal shelterwood, and light-removal shelterwood) at Boston Bar. Values are means with standard deviations in parentheses. All values are for 2005 unless indicated otherwise.

	Clearcut	Heavy-removal shelterwood	Light-removal shelterwood
Number of trees sampled	20	30	24
Height in 1998 (cm)	64.7	48.9	28.3
	(36.1)	(25.7)	(11.5)
Height in 2005 (cm)	309.8	266.1	179.1
	(82.7)	(57.4)	(26.7)
Height growth during 7 years (cm)	245.2	217.2	150.8
	(68.5)	(53.1)	(34.9)
Root collar diameter (mm)	70.1	54.7	32.5
	(17.4)	(12.0)	(5.2)
Crown length (per cent of total height	92	96	90
	(15)	(6)	(11)
Crown volume (m^3)	2.80	1.54	0.41
	(2.68)	(0.90)	(0.24)

Table 2. Results of the height growth analysis of variance for Douglas-fir regeneration at Boston Bar.

Source	Degrees of freedom	Sums of squared errors	Mean squared errors	F-value	p-value
Tmt	2	2182	1091	19.09	<0.001
Error	71	4058	57.16		
Total	73	6240			

Table 3. Results of the crown volume analysis of variance for Douglas-fir regeneration at Boston Bar.

Source	Degrees of freedom	Sums of squared errors	Mean squared errors	F-value	p-value
Tmt	2	5.886×10^{13}	2.943×10^{13}	12.77	<0.001
Error	71	1.636×10^{14}	2.304×10^{12}		
Total	73	2.224×10^{14}			

Table 4. Results of the analysis of the height growth from crown volume model for Douglas-fir regeneration at Boston Bar.

Parameter	Estimate	Standard error
a	56.27	5.107
b	1.031	0.3807
c	-8.959	3.234
d	0.6468	0.2140

Table 5. Shrub cover and number of Douglas-fir regeneration in 7.5 m^2 circular plots around planted Douglas-fir in three treatments (clearcut, heavy-removal shelterwood, and light-removal shelterwood) at Boston Bar. Values are means with standard deviations in parentheses. All values are for 2005.

	Clearcut	Heavy-removal shelterwood	Light-removal shelterwood
Number of trees sampled	20	30	24
Total shrub cover (%)	38.3	36.8	50.9
	(15.0)	(17.2)	(21.8)
Cover of *Ceanothus* (%)	14.3	19.2	15.2
	(13.0)	(15.9)	(19.2)
Cover of *Mahonia* (%)	6.3	1.3	6.9
	(6.9)	(2.2)	(9.3)
Cover of *Symphoricarpos* (%)	2.5	4.2	16.3
	(4.4)	(6.8)	(19.0)
Total number of conifer regeneration	0.7	3.6	4.3
	(1.5)	(3.8)	(5.0)
Number of conifer regeneration >1 m tall	0.2	1.3	2.0
	(0.5)	(2.0)	(2.5)

Fig. 1. Frequency distribution of height growth of planted Douglas-fir over a seven year period in three treatments (clearcut, heavy-removal shelterwood, and light-removal shelterwood) at Boston Bar.

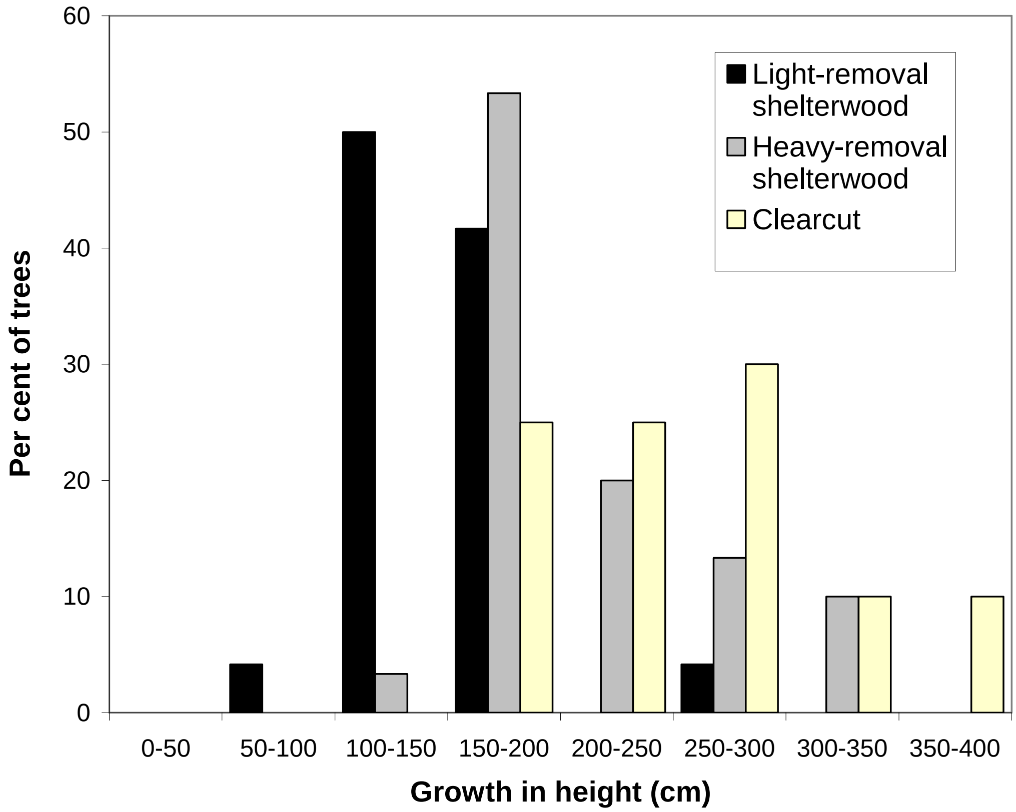

Fig. 2. Frequency distribution of crown volume of planted Douglas-fir in three treatments (clearcut, heavy-removal shelterwood, and light-removal shelterwood) at Boston Bar in 2005.

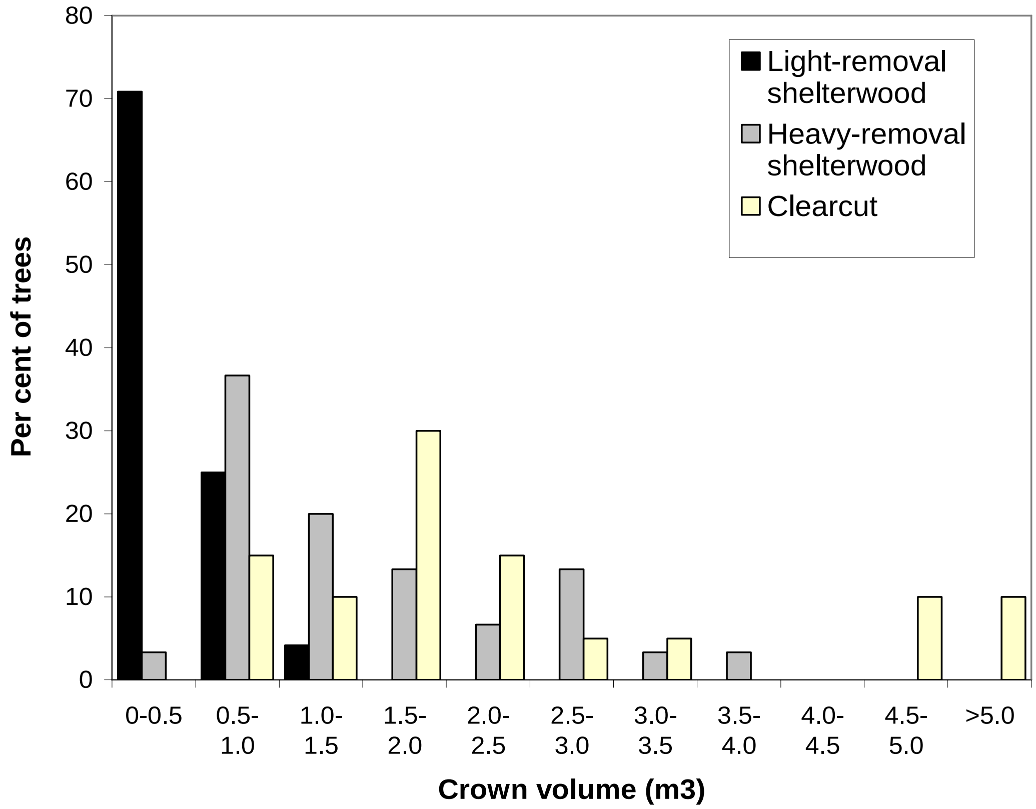

Fig. 3. Root collar diameter vs. height of planted Douglas-fir in three treatments (clearcut, heavy-removal shelterwood, and light-removal shelterwood) at Boston Bar in 2005.