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Establishment and Growth of Conifer Regeneration Following Harvest and Residue Treatments in a Western Larch - Douglas-fir Forest

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Abstract

Forest managers often choose prescriptions that promote natural regeneration of various species that differ in relative shade tolerance. Assessing the response of forest vegetation to alternative treatments in the Inland Northwest is challenging, given that the process takes decades to unfold. In this study, conifer regeneration was examined in a western larch (*Larix occidentalis*)/Douglas-fir (*Pseudotsuga menziesii*) forest 25 years after harvest and residue treatments. Harvest treatments included: clearcut, group selection, and shelterwood. Residue treatments included: moderate utilization burned, standard utilization burned, intensive-fiber utilization unburned, and moderate utilization unburned. Subsequent natural conifer regeneration was sampled across all treatments in 2001. Douglas-fir and Engelmann spruce planted between 1976-1979 were remeasured and compared to natural conifer regeneration. In addition, growth of a sub-sample of western larch trees in the shelterwood and clearcut harvests was examined in relation to measures of overstory and understory competition.

Natural regeneration was primarily Douglas-fir in all treatments, though larch saplings were typically among the tallest individuals where they occurred. Natural regeneration densities and stocking levels were highest in the shelterwood harvest treatment, and in the two burned residue treatments. Mean heights of the tallest natural regeneration of each species were greater in the clearcuts and group selections than in the shelterwood harvest treatments, and also greater in the burned than the unburned residue treatments. Planted Douglas-fir and Engelmann spruce total height and growth were greatest in the burned treatments of the clearcuts and group selection. Planted trees were consistently taller than natural regeneration Douglas-fir and spruce. Western larch is surviving under the residual overstory of a shelterwood, though recent growth is lower than in other harvest treatments. Under the residual overstory of the shelterwood, western larch growth was positively correlated with initial tree height, and negatively correlated with canopy cover, stand density index, and tall understory cover. Results suggest that after 25 years, the effects of harvest and residue treatments remain evident in the amount and size of natural regeneration, as well as in the size and survival of planted stock. Further, it appears possible to maintain some component of vigorous young larch recruits in partial retention stands.

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Chapter I: Introduction

Western larch (*Larix occidentalis* Nutt.) is a deciduous conifer that grows in the Upper Columbia River Basin of Montana, Idaho, Washington, Oregon, and British Columbia (Schmidt and Shearer 1995). The western larch forest cover type occupies almost 1.2 million hectares in the northwestern United States and Canada. Western larch is found in relatively cool, moist climates, and often occurs on north and east facing slopes (Schmidt et al. 1983). A seral species across a variety of forest types, western larch is typically found in a mix of other conifer species, especially Douglas-fir (*Pseudotsuga menziesii* (Beissn.) Franco) (Schmidt and Shearer 1990; Barrett 1995).

Western larch forests have considerable commercial value for wood products. Western larch is particularly desirable for lumber, plywood, and house logs. Douglas-fir is comparable to larch in high desirability for these products, and the two species are often grouped together in lumber classification. A substantial amount of wood fiber from western larch and Douglas-fir is manufactured into particleboard, fiberboard, and paper. In the United States, the annual sales value of primary products from Douglas-fir and western larch has been over $1.4 billion dollars (Keegan 1990; Keegan et al. 1995).

Depending on the age of individual trees and stands, western larch forests provide forage and habitat for a variety of wildlife. Black bear (*Ursus americanus cinnamomum*) and moose (*Alces alces*) are among the large mammals that inhabit western larch forests. Small mammals, including red squirrels (*Tamiasciurus hudsonicus*), long-tailed weasels (*Mustela frenata*), and a number of shrews and voles also utilize these forests. Cavity nesting birds, such as the pileated woodpecker

(*Dryocopus pileatus*), use old growth and snags of western larch for nesting (Schmidt and Shearer 1995; Shearer and Kempf 1999).

Western larch forests are also valued for their aesthetic appeal, primarily associated with the changing color of larch foliage (Shearer 1971; Blocker 1995). Having western larch on a forest landscape provides color contrast and diversity. This landscape visual quality is important to recreationists, tourists, and others who live near or visit western larch forests (Blocker 1995).

For all of these various reasons, western larch has long been recognized as a desirable species, and management objectives are often directed toward maintaining or increasing the larch component in forest stands (Roe 1952). Foresters have traditionally promoted larch by simulating the conditions historically created by fire, using even-aged silvicultural systems combined with site preparation (Shearer 1971; Schmidt et al. 1976; Arno and Fischer 1995). More recently, some alternative forest practices involving selective cutting, partial retention, and multi-aged management, have been suggested as alternatives to even-aged silviculture in a variety of forest types. However, there is limited information regarding the effects of these management techniques, particularly on the regeneration and growth of shade intolerant, early-seral tree species such as larch (Swanson and Franklin 1992).

It has long been recognized that the composition and density of natural regeneration could be affected site preparation, both in terms of the seedbed exposed and the level of woody residue left on the site. "Residues" refers to the buildup of living or dead material in the forest caused by both human activities and biological processes. These include snags, coarse woody debris and sub-merchantable, cull, and slash materials from harvesting (Jemison and Lowden 1974; Benson and Schlieter 1981). Heavy residues can increase fire hazard, hinder regeneration, and have a negative impact on aesthetics (Smith et al. 1997). However, residues can also be beneficial by decreasing erosion and the evaporation of soil moisture, and by releasing nutrients during their decomposition (Seidel 1974; Waring and Schlesinger 1985).

The term "residue utilization" describes the removal and use of that forest biomass. As technology and the wood products market developed in the mid 20th century, it became feasible for foresters to remove and process smaller diameter material from harvested stands (Corrick 1981). Simultaneously, there has been increasing concern about the consequences of forest practices that decrease residues. Of particular interest are the effects of different levels of utilization or residue removal on conifer regeneration and site productivity, two important factors to consider for long-term forest management (Seidel 1974; Harvey et al. 1981). For example, because nutrient concentrations are higher in the foliage and small branches than in the bole (Waring and Schlesinger 1985), whole-tree havest (i.e. the removal bole, branches, and foliage) has been shown to remove more nutrients from the forest than conventional harvest (Stark 1982).

Managers need to know what kinds of residue management might benefit or hinder natural and artificial conifer regeneration under different silvicultural systems (Edgren and Stein 1974; Seidel 1974). In order to determine the answers to such questions, the Intermountain Forest and Range Experiment Station of the Forest Service initiated a Forest Residues Utilization Research and Development program. In 1974, a study was initiated at Coram Experimental Forest to investigate the biological consequences of harvesting and residue management practices on a western larch/Douglas-fir forest (Barger 1980; Shearer and Kempf 1999).

Assessing the response of forest vegetation to alternative treatments is challenging, given that the process takes decades to unfold. As a stand develops following a disturbance, trends in species composition and structure will change as growing space fills in and plants tie up resources. A general model of even-aged stand development following a major disturbance describes four phases: stand initiation, stem exclusion, understory reinitiation, and old-growth (Oliver 1981). Seedlings establish following the disturbance as long as growing space is available (i.e. stand initiation stage). Once growing space is fully occupied, vigorous trees continue to grow while weak individuals may die in the stem exclusion stage (Oliver and Larson 1996; Smith et al. 1997). During stem exclusion stage, stands of mixed species with different shade tolerance and height growth patterns will often develop into different stratified layers (Kelty et al. 1992). Fast-growing individuals of shade-intolerant species such as western larch will move into dominant strata, whereas those that remain in lower height strata may not survive under a dense canopy. Shade-intolerant species will not continue to successfully recruit new seedlings In contrast, shade tolerant species such as subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) can continue to recruit new seedlings into the understory and maintain adequate growth for survival even under relatively dense shade (Alexander et al. 1990; Schmidt and Shearer 1990).

As a stand develops, the growth and survival of individual trees play a major role in determining density and species composition (Clark et al. 1999; Coates 2002). Long-term field studies provide empirical data on the development of forest vegetation following disturbances such as timber harvest. In this research, we used remeasurements of the forest vegetation study at Coram Experimental Forest to examine long-term development of conifer regeneration following different harvesting and residue treatments.

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Chapter II: Natural regeneration of conifer species after harvest and residue treatments

Introduction

Forest managers of the Inland Northwest often choose prescriptions that promote natural regeneration of various conifer species that differ in relative shade tolerance. While many of the more valuable seral species such as western larch (*Larix occidentalis* Nutt.) have traditionally been managed by even-aged systems followed by site preparation, there has been growing demand for management practices that employ partial harvest and varying standards of wood utilization. In order to meet long-term goals of maintaining desirable seral species in a stand, managers must consider how various treatments influence germination and establishment, as well as seedling and sapling dynamics (Seidel 1974; Oliver and Larson 1996; Clark et al. 1999).

Historically, fire has been the principal disturbance mechanism of western larch forests, and has promoted regeneration of western larch. Fire regimes in larch-Douglas-fir forests vary by habitat type, with frequent surface fires on warm, dry sites where they grow in association with ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.). Mixed-severity fire regimes occur on cool, dry sites of western larch with lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco). On moister sites, where western larch grows with Douglas-fir and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), fires have historically been infrequent and stand-replacing (Arno and Fischer 1995). The silvical characteristics of western larch are well adapted to this full range of different fire regimes. Mature western larch can survive most fires in low severity, frequent fire regimes due to its thick bark, open crown and its ability to grow new foliage from heat-resistant buds. In mixed severity fire regimes where patches of overstory might be killed and growing space opened, western larch germination and establishment is favored by the mineral seedbed exposed by fire, and seedlings grow rapidly in the open conditions following disturbance (Roe 1952; Schmidt and Shearer 1990; Feidler and Lloyd 1995). Even on sites that experience infrequent fires, long-lived individuals provide seed for regeneration (Arno 1980; Arno and Fischer 1995).

By emulating some characteristics of wildfire, silvicultural practices can favor the regeneration of early successional species such as larch (Smith et al. 1997; Arno and Fischer 1995). In order to promote western larch, foresters have mimicked natural stand-replacing fire disturbances through even-aged silvicultural systems. Reducing overstory density by harvesting increases the level of solar radiation and precipitation to the understory, providing high levels of resources for seedlings (Waring and Schlesinger 1985). Clearcutting allows plenty of sunlight for regeneration, reduces transmission of dwarf mistletoe to the next generations, and facilitates follow-up site preparation, but it provides limited control over the density and species composition of regeneration (Roe 1955; Schmidt et al. 1983). Because of uncertainty in annual seed production and the greater susceptibility of new western larch germinants to desiccation in clearcuts, seed tree and shelterwood systems have often proved more effective than clearcutting for successful natural regeneration (Roe 1955; Schmidt et al. 1976; Schmidt and Shearer 1995). However, because the initial benefit from the shade of a shelterwood can become problematic for shade intolerant species such as larch, the residual overstory is typically removed after seedling establishment (<20 years) to avoid suppression (Schmidt and Larson 1989; Smith et al. 1997). While the density and stocking of conifer regeneration might be expected to be greater under shelterwood, the growth rates of new saplings will likely lag behind that in clearcuts or in large group selection openings.

In addition to overstory removal, micro-environmental and seedbed conditions will substantially affect the density and composition of conifer regeneration. Northern Rocky Mountain conifer species vary in terms of the light, soil moisture, and temperature requirements necessary for seedling germination and establishment (Shearer 1971; Schmidt et al. 1976; Hungerford and Babbit 1987). Soil moisture is the primary limiting factor for western larch seedling survival; drought is a main cause of seedling mortality. Heat is also an important physical factor affecting first year larch mortality, particularly on south-facing aspects. Soil surface temperatures greater than 57° C are usually lethal for first year western larch germinants (Schmidt and Shearer 1990). Surface temperatures are typically lower on exposed mineral soils than on undisturbed forest floor (duff). Germination and early survival of western larch and Douglas-fir have been found to be highest on exposed mineral soil, particularly that resulting from prescribed burning (Schmidt et al. 1976; DeByle 1981; Ryker and Losensky 1983; Oswald et al. 1999). Natural regeneration of western larch is eight to twenty times greater on soil surfaces disturbed by fire or mechanical scarification than on undisturbed duff (Roe 1952). In addition to the mineral exposure, the levels of post-harvest residues may also affect the regeneration success of various species in a treated stand. Although high levels of residue material can hinder regeneration, some amount of forest residue is beneficial to moderate temperature, decrease evaporation of soil moisture, and release nutrients as it decomposes (Seidel 1974; Waring and Schlesinger 1985).

Although previous studies have examined the effects of harvest method and residue management on the initial stages of stand development, these studies have usually focused on the two factors separately. One would expect that there would be greater relative densities of seral western larch in harvest treatments that have lower residual overstory densities, as well as following those site preparation treatments that exposed more mineral soil. However, there is limited information regarding the long-term dynamics of different species following alternative harvest regimes in mixed species forests. The effects of utilization level on regeneration over time are generally unknown. Long-term studies considering combinations of harvest and residue management are rare. This study was initiated to better understand the role of both overstory harvest and residue treatments on long-term regeneration dynamics. This research investigates the effects of clearcut, group selection, and shelterwood harvesting followed by four utilization and prescribed burning treatments. The purpose of this study was to evaluate the response of natural regeneration, 25 years after those management practices in a western larch-Douglas-fir forest. Specific objectives associated with the study were:

1. To examine the effect different harvest systems and site preparation treatments (i.e. burned and unburned, and varying utilization standards) on the species composition, density, and relative size of conifer regeneration.
2. To quantify the long-term effects of these silvicultural treatments on the growth and survival rates of tagged Douglas-fir and western larch saplings over time.

Methods

Study Area

This study was conducted at the Coram Experimental Forest, a 3019 hectare (ha) research forest located within the Flathead National Forest on the Hungry Horse Ranger District. The Coram Experimental Forest is located approximately 45 kilometers east of Kalispell, Montana, just south of Glacier National Park. The study site is situated on an east-facing slope in the Upper Abbot Basin. The climate of Coram Experimental Forest features an average annual precipitation of 89 to 127 centimeters (cm), most of which falls as snow (Shearer and Kempf 1999). Mean annual temperatures in the area range from 2° Celsius at Abbot Creek to 7° C on some slopes. This variation in microclimate reflects the topography of the forest (Hungerford and Schlieter 1984).

Prior to treatment, the study area was classified as a larch/Douglas-fir cover type (Eyre 1980), with Douglas-fir and western larch making up 58 and 20 percent of the total cubic foot volume, respectively. Other conifer species present included Engelmann spruce, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and infrequent western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn.) (Benson and Schlieter 1980). The study site is a relatively moist and productive forest for western Montana. The floristic habitat type over most of the area was classified as *Abies lasiocarpa / Clintonia uniflora* (Schult.) Kunth, which in the absence of disturbance will naturally succeed to subalpine fir (Pfister et al. 1977). From a fire-scar study, Sneck (1977) determined a mean fire interval of approximately 130 years at Coram Experimental Forest.

Study Design

The original study was set up as a two factor randomized split-plot design, with two replications. Three harvest levels were allocated to main plots: clearcut, group selection, and shelterwood. Four different residue treatments were assigned as sub-plots within each main plot. In 1974, the harvest treatments (clearcut, group selection and shelterwood units) were applied to the main plots. The two replications of the harvest treatments were located within the same watershed, but differed in elevation by about 200 meters (m). Area of the harvest units varied with silvicultural system (from 2.4 to 14.2 ha). The clearcut units were 5.5 and 6.7 ha in size. The shelterwood units were 14.2 ha and 8.7 ha. The group selection units were 3.0 ha and 2.4 ha in size, each with eight group selection openings that range in size from 0.2 to 0.6 ha in size.

On the clearcut blocks and within the group selection openings, logging removed all merchantable trees. Approximately 50 percent of the volume was taken off the shelterwoods (Appendix 1), favoring western larch as leave trees. The residual overstory on the shelterwood units has not been removed; these units now exist as two-aged stands.

Within each of the harvest units (main plots), four sub-plots of equal area were assigned one of four "residue treatments". Henceforth, the four residue sub-plots will be referred to by their combination of utilization level (i.e. standard, moderate, intensive-fiber) and burn treatment (burned, unburned). The four combinations examined in this long-term study included the following: moderate utilization burned, standard utilization burned, intensive-fiber utilization unburned, and moderate utilization unburned. Residue treatments consisted of different levels of tree and log utilization and prescribed burning (Table 1). The moderate utilization treatments removed material down to 7.6 cm (3 inches). One of these was followed by fire. The standard utilization treatment simulated the standard utilization level of Forest Service harvests in 1974 and was also burned. One of the unburned treatments had moderate utilization and the other had intensive-fiber utilization, with removal of all material, including large shrubs, down to 2.5 cm in diameter.

Table 1. Residue treatments applied in 1974-1975 to sub-plots within each harvest treatment, Coram Experimental Forest, Montana (Benson and Schlieter, 1980; Shearer and Schmidt, 1999).

Residue sub-plot	Trees Cut	Utilization Specification	Fire Treatment
Moderate utilization, burned	All except designated shelterwood	Remove all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length, and one-third sound	Burned
Standard utilization, burned	All except designated shelterwood	Remove sawtimber material (living and recently dead) of trees down to 17.8 cm DBH, 2.4 m length, one-third sound	Burned
Intensive-fiber utilization, unburned	All except designated shelterwood	Remove all timber (live and dead, standing and down) to 2.5 cm diameter	Unburned
Moderate utilization, unburned	Trees 17.8 cm DBH and greater except designated shelterwood	Remove all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length and one-third sound	Unburned

Moist fuels hindered prescribed burning of residue treatments in September 1975. Although the original study was set up to replicate burns on all harvest units, the lower shelterwood replicates were not burned because of wet conditions (Artley et al. 1978). The data from those sub-plots was not used in subsequent statistical analyses.

Field Measures

In 2001, we completed measurements for two data sets associated with this study. The first component was a systematic sampling of natural regeneration across all the treatments; the second was a remeasurement of tagged, individual western larch and Douglas-fir.

To sample natural regeneration, 20 permanent points were systematically established within each of the four residue treatments (sub-plots) in 1979, for a total of 80 points per harvest treatment (main plot). These points were laid out on a 15.2 m grid within the shelterwood and clearcut treatments, and adjusted with shorter distances between points in order to sample in the group selection openings. To collect information about natural regeneration following no treatment, the study also identified a grid of points within the untreated forest at each elevation. From previous measurements of regeneration, data was available regarding the presence of advanced (prior to treatment) regeneration; this was not included in any counts. Following protocol from prior measurements (Shearer 1980; Shearer and Schmidt 1999), "subsequent" (post-treatment) natural regeneration was sampled on two nested, circular plots centered on each permanent point. On the smaller plot (0.0013 ha; 1.13 m radius) plot, we tallied all subsequent conifer regeneration by species. On the larger concentric plot (0.004 ha; 2.07 m radius), we tallied established conifers and also recorded the total height, DBH (i.e. stem diameter at breast height, 1.37 m above ground), crown length, crown width height, crown width, crown position, vigor, stem form, and any damage of the tallest tree for each species present. "Established" trees were subsequent regeneration that met the following criteria: intolerant western larch, western white pine and lodgepole pine had to be taller than 0.30 m while all other species had to be taller than 0.15 m to be counted as "established". Trees were considered to be in the plot if the center of their stem was within the circular plot defined by the radius; all lengths were recorded to the nearest 0.03 m and all diameters to the nearest 0.25 cm.

In 1994, a supplementary study of natural regeneration survival and growth was initiated that focused on Douglas-fir and western larch. Thirty trees of each species were permanently tagged in each harvest unit, all within one residue treatment replicated on all harvest units (i.e. the intensive-fiber, unburned treatment). Two exceptions occurred in the group selections where only 24 larch were found and tagged in the lower elevation openings, and 29 larch in the upper elevation openings. Characteristics of western larch and Douglas-fir were initially measured in 1994, and then remeasured in 1997 and 2001 (this study). Subject tree measurements included DBH, total height, crown length, crown width, crown position, vigor, presence or absence of cones, damage, and the height of primary competition.

Analysis

To describe natural regeneration, we summarized data from the 20 sample points within each residue treatment sub-plot. For established regeneration of each species, response variables included density, stocking, and mean tallest height. Density of total regeneration of each species was also a response variable. Density of regeneration was calculated from the average number of trees per sample plot expanded to trees per hectare (TPHA). The "stocking" of regeneration refers to the percentage of sample plots with at least one tree established post-treatment. For the plot size used for established regeneration (0.004 ha), 100% stocking would suggest that there were at least 250 well distributed saplings per hectare, whereas 60% stocking indicates a minimum of 150 saplings/ha. The variable "mean tallest tree height" is the average height of the tallest individual for each species, averaged across all plots where that species was present in a given treatment.

The general linear model in SPSS version 10.0 was used for all statistical testing procedures (SPSS Inc. 1999). Because there was no replication of the burned residue treatments within the shelterwood harvest treatment, statistical analysis could not be completed for all treatment factor combinations. We were able to evaluate the effect of all four residue treatments within the clearcut and group selection harvests. Separately, we evaluated the effect of the unburned residue treatments within all three harvests. Because of differences observed in regeneration and environmental variables between upper and lower treatment areas in previous measurement periods, elevation was treated as a random effect blocking factor rather than as a true replication. Thus, for each response variable, we evaluated treatment effects using a general linear model with residue treatments within harvest treatments as fixed effects, and elevation as a random effect. Simple contrasts were used to make comparisons between residue treatments. Sidak's pairwise multiple comparison test was chosen for post-hoc analyses of fixed factors that had three or more levels because it adjusts the significance level for multiple comparisons and provides tight bounds.

Characteristics of the tagged Douglas-fir and western larch in each harvest treatment were also averaged to provide suitable variables for analysis. Survival was calculated as the number of living trees in 2001 divided by the number of trees originally tagged in 1994. We evaluated the differences among the three harvest treatments using a general linear model and Sidak's pairwise multiple comparison tests. Comparisons between the two species were made with simple contrasts.

Results

Effects of Treatments on Density and Stocking of Conifer Regeneration

In 2001, natural regeneration at the study site included eight conifer species, but was dominated by Douglas-fir. Douglas-fir was the most abundant species in terms of stocking and density on every harvest and residue treatment combination, making up over 80 percent of established conifer regeneration on all harvest treatments (Figure 1). Douglas-fir density ranged from 850-14,000 established seedlings per hectare (Appendix 3). Other major species included western larch, subalpine fir, and Engelmann spruce. Total regeneration showed similar trends as established regeneration (Appendix 2). There was substantially less regeneration found in the untreated control stand for every species sampled, including not a single sampled western larch (Table 2).

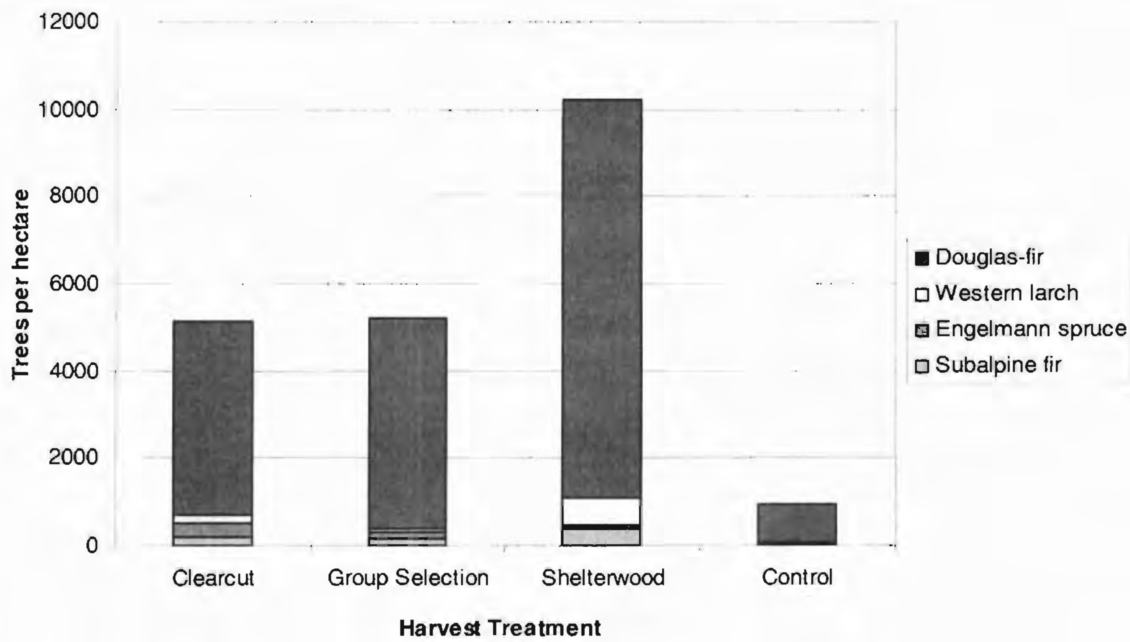

Figure 1: Species Composition of Established Subsequent Natural Regeneration in 2001 by Harvest Treatment, Coram Experimental Forest, Montana.

Table 2: Mean density (trees per hectare) of total and established subsequent natural conifer regeneration in 2001 in the treated and untreated control units, Coram Experimental Forest, Montana.

	Species	TPHA (total)	TPHA (established)
Treated units	Western larch	407	315
	Douglas-fir	10178	6112
	Subalpine fir	329	261
	Engelmann spruce	247	159
	All species	11419	7012
Untreated control	Western larch	0	0
	Douglas-fir	2161	889
	Subalpine fir	21	25
	Engelmann spruce	360	52
	All species	2614	991

Western larch, Douglas-fir, and subalpine fir had consistently greater natural regeneration densities in the shelterwood harvests than in the clearcuts or group selections (Table 3). Where we were able to test the harvest treatments with all residue treatments, total Engelmann spruce density was significantly (p = 0.09) higher in the clearcuts than in the group selections (Table 3, Appendix 6). In analysis of the unburned residue treatments within the clearcut, shelterwood, and group selection, established Engelmann spruce was also significantly different among harvest treatments, but the strong interaction between harvest and residue treatment prevented consistent trends from being identified between harvests (Appendix 7).

Table 3: Mean values for density (trees per hectare) of total and established conifer regeneration in 2001 by species and harvest treatment. Within a row, different letters indicate significant differences between the means (p<0.10). Coram Experimental Forest, Montana.

Species	Clearcut	Group Selection	Shelterwood
Total Regeneration			
Western larch	340	154	726
Douglas-fir	6638	7534	16364
Subalpine fir	309	278	401
Engelmann spruce	463*a*	139*b*	139
Established Regeneration			
Western larch	218	83	644
Douglas-fir	4404	4812	9119
Subalpine fir	204	176	403
Engelmann spruce	292	125	60

Percent stocking of established natural conifer regeneration varied across harvests, but all harvest treatments had considerably greater stocking of each species than the untreated control (Figure 2). Natural regeneration (usually Douglas-fir) was present on most sample plots by 2001. The mean percent stocking of western larch, Douglas-fir, and subalpine fir was greater in the shelterwood treatment than in the group selection or clearcut treatments. The highest stocking of Engelmann spruce (24%) occurred in the clearcut (Table 4). However, statistical analysis did not identify any significant differences in mean percent stocking among harvest treatments (Appendices 6 and 7).

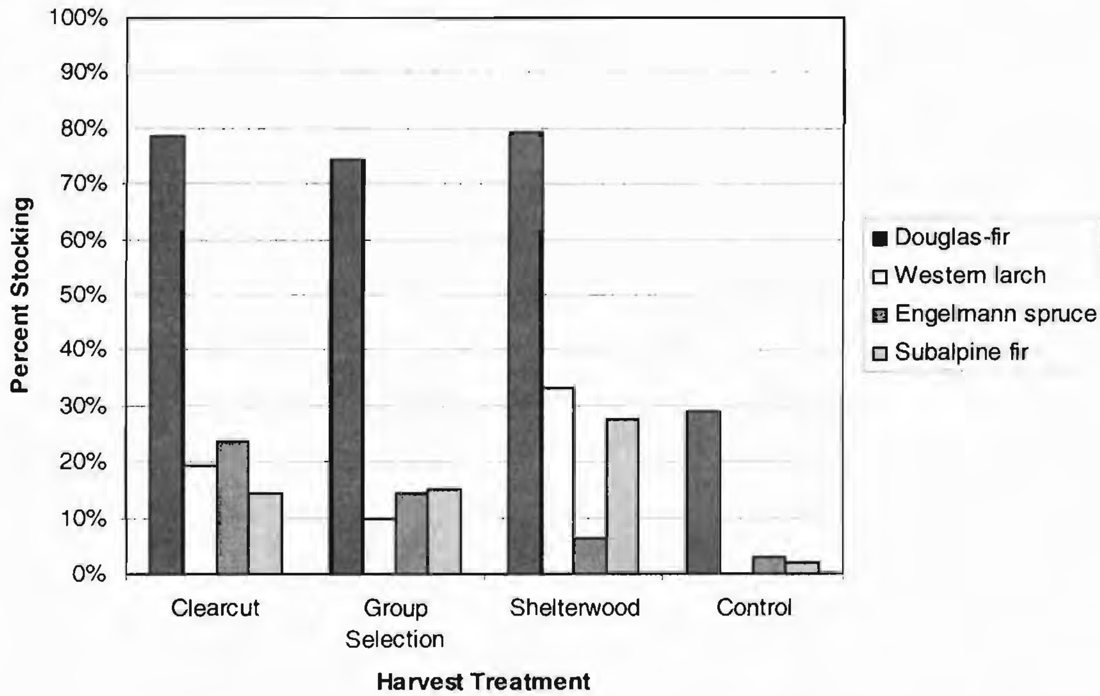

Figure 2: Mean Percent Stocking of Established Subsequent Regeneration in 2001 by Harvest Treatment, Coram Experimental Forest, Montana.

Table 4: Mean values for percent stocking of established conifer regeneration in 2001 by species and harvest treatment, Coram Experimental Forest, Montana.

Species	**Clearcut**	**Group Selection**	**Shelterwood**
Western larch	19	10	33
Douglas-fir	79	74	79
Subalpine fir	14	15	28
Engelmann spruce	24	14	6

Residue treatment had an observable effect on the density of natural conifer regeneration. Densities of established western larch and Douglas-fir regeneration were substantially higher in the burned residue treatments than in the unburned treatments (Figure 3). Comparing moderate utilization residue treatments that were burned vs. unburned, density of larch regeneration was 2, 32, and 46 times greater in burned subplots for group selection, clearcut, and shelterwood treatments, respectively (Appendix 3). Douglas-fir showed similar trends of greater regeneration in burned residue treatments across all harvest types. Where we were able to make comparisons, simple contrasts identified a significantly ($p = 0.053$) greater density of Douglas-fir regeneration in standard utilization, burned treatments than in the moderate utilization, unburned treatments (Appendix 8). In contrast, the density of late successional subalpine fir was somewhat greater in the two unburned residue treatments than in the burned treatments (Table 5).

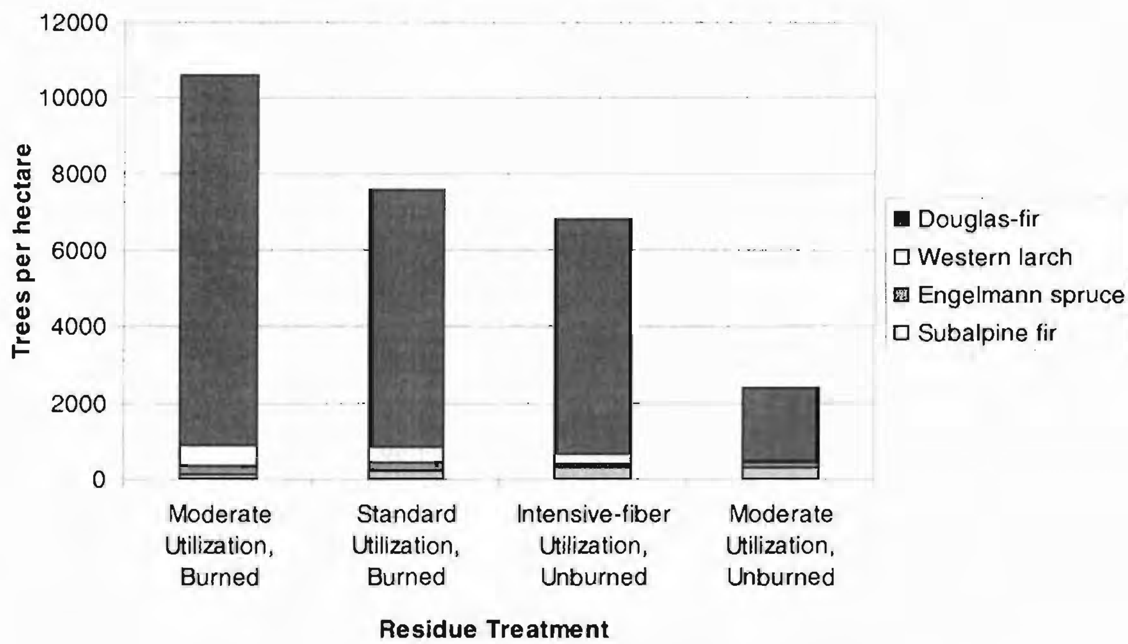

Figure 3: Mean Density of Established Subsequent Regeneration in 2001 by Residue Treatment, Coram Experimental Forest, Montana.

Table 5: Mean values for density (trees per hectare) of total and established conifer regeneration in 2001 by species and residue treatment in all harvest treatments combined, Coram Experimental Forest, Montana.

Species	Moderate Utilization, Burned	Standard Utilization, Burned	Intensive-fiber Utilization, Unburned	Moderate Utilization, Unburned
Total Regeneration				
Western larch	679.3	494.0	370.5	82.3
Douglas-fir	16384.3	9221.3	11176.8	3931.4
Subalpine fir	61.8	370.5	432.3	452.8
Engelmann spruce	288.2	164.7	144.1	391.1
Established Regeneration				
Western larch	512.5	426.1	290.2	30.9
Douglas-fir	9725.6	6687.5	6138.0	1895.7
Subalpine fir	129.7	247.0	333.5	333.5
Engelmann spruce	247.0	197.6	61.8	129.7

Percent stocking of conifer species showed a wide variation by residue treatment (Figure 4 and Table 6). The percent stocking level for western larch regeneration was only 3% in percent in unburned, moderate utilization residue treatment under the shelterwood and clearcut harvests, but exceeded 30% in the burned treatments of both harvest types (Appendix 4). Similarly, percent stocking of Douglas-fir in the moderate utilization, burned residue treatments was significantly (p = 0.03 and p = 0.04) greater than in either of the unburned treatments (Appendix 9). Residue treatment had a significant effect on western larch stocking in the clearcut and group selection harvests (Appendix 6), but differences could not be identified between any individual treatments. Comparing the two unburned residue treatments, percent stocking of Douglas-fir and western larch was generally greater in the intensive-fiber utilization than in the moderate utilization.

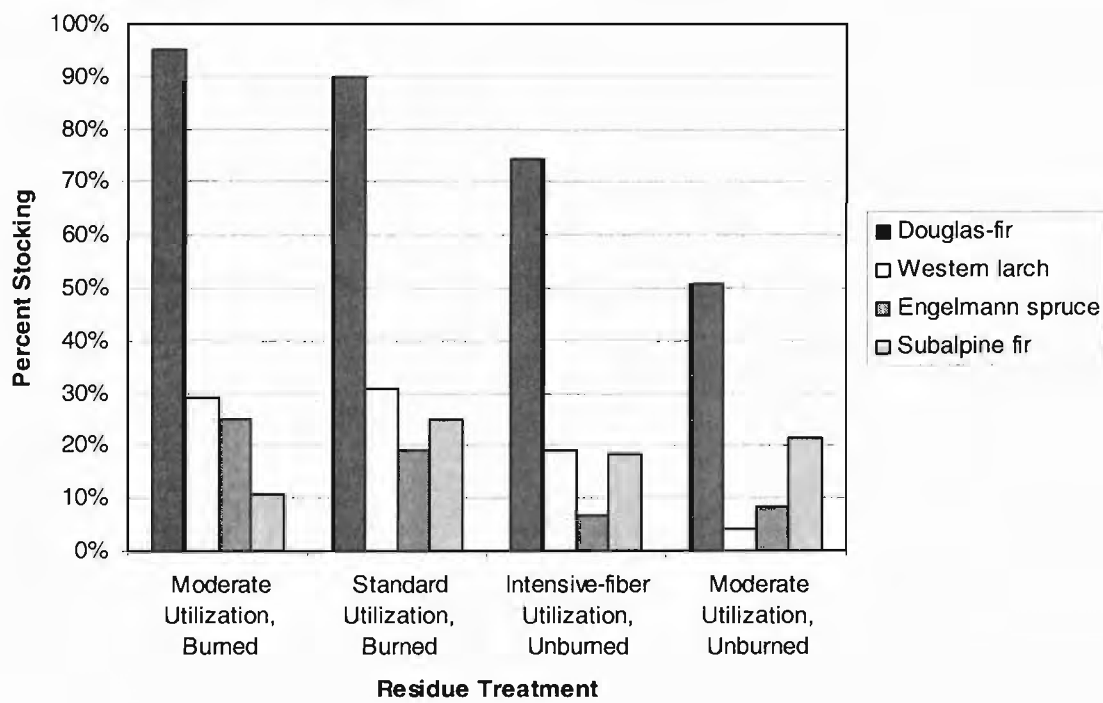

Figure 4: Mean Percent Stocking of Established Subsequent Regeneration in 2001 by Residue Treatment, Coram Experimental Forest, Montana.

Table 6: Mean values for percent stocking of established conifer regeneration in 2001 by species and residue treatment, Coram Experimental Forest, Montana.

Species	Moderate Utilization, Burned	Standard Utilization, Burned	Intensive-fiber Utilization, Unburned	Moderate Utilization, Unburned
Western larch	29	31	19	4
Douglas-fir	95	90	74	51
Subalpine fir	11	25	18	22
Engelmann spruce	25	19	7	8

Effects of Treatments on Tallest Tree Heights

By 2001, there were substantial differences in the tallest tree heights of most species among harvest treatments (Figure 5). Mean heights of the tallest western larch, Douglas-fir, and subalpine fir were consistently greater (almost twice as tall) in the clearcut and group selection harvests than in the shelterwood harvest (Table 7). However, in some cases due to empty cells, statistical analysis did not identify any significant differences in the heights of any species among harvest treatments (Appendices 6 and 7).

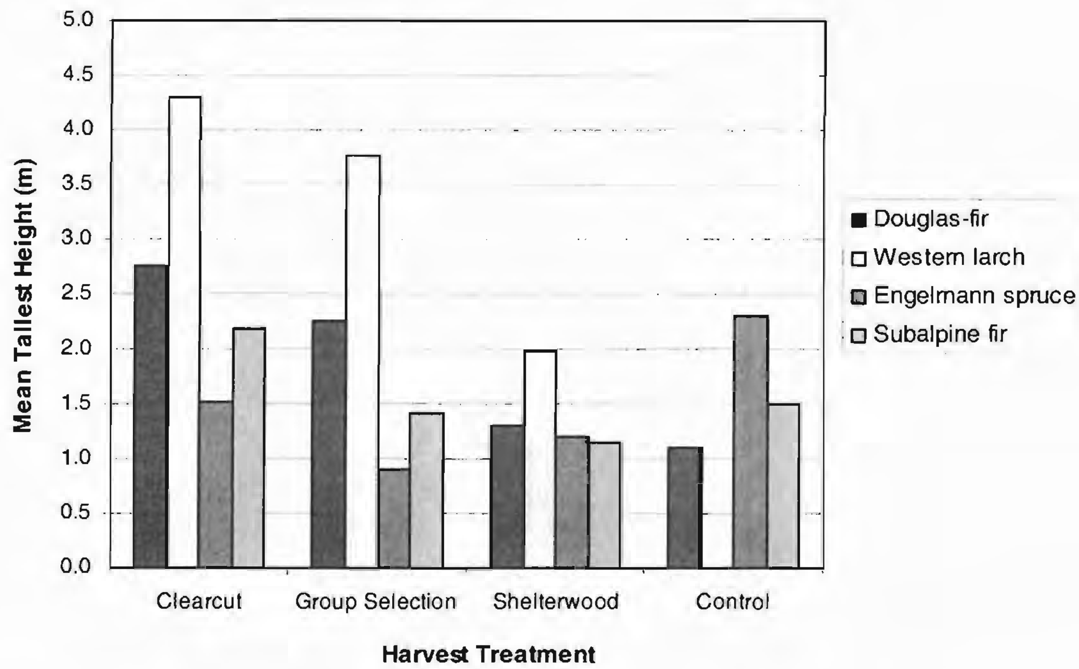

Figure 5: Mean Tallest Tree Height of Established Regeneration in 2001 by Harvest Treatment, Coram Experimental Forest, Montana.

Table 7: Mean values for height (m) of tallest established conifer regeneration in 2001 by species and harvest treatment, Coram Experimental Forest, Montana.

Species	Clearcut	Group Selection	Shelterwood
Western larch	4.3	3.8	2.0
Douglas-fir	2.7	2.3	1.3
Subalpine fir	2.2	1.4	1.2
Engelmann spruce	1.5	0.9	1.2

Trends in tallest tree heights among residue treatments were apparent between the burned and unburned treatments. Mean tallest tree heights of western larch and Douglas-fir were generally greater on the two burned residue treatments than on the two unburned treatments. In contrast, subalpine fir was taller on the unburned residue treatments than the burned treatments (Figure 6). The mean tallest height of larch was surprisingly high in the moderate utilization, unburned treatment (Table 8), but only three of twenty plots had larch trees present in that residue treatment. From statistical analysis of residue treatments within the clearcut and group selection harvest treatments, heights of the tallest Douglas-fir were shown to be greater in each of the burned treatments than in the intensive-fiber utilization, unburned treatment ($p < 0.10$; Appendix 10).

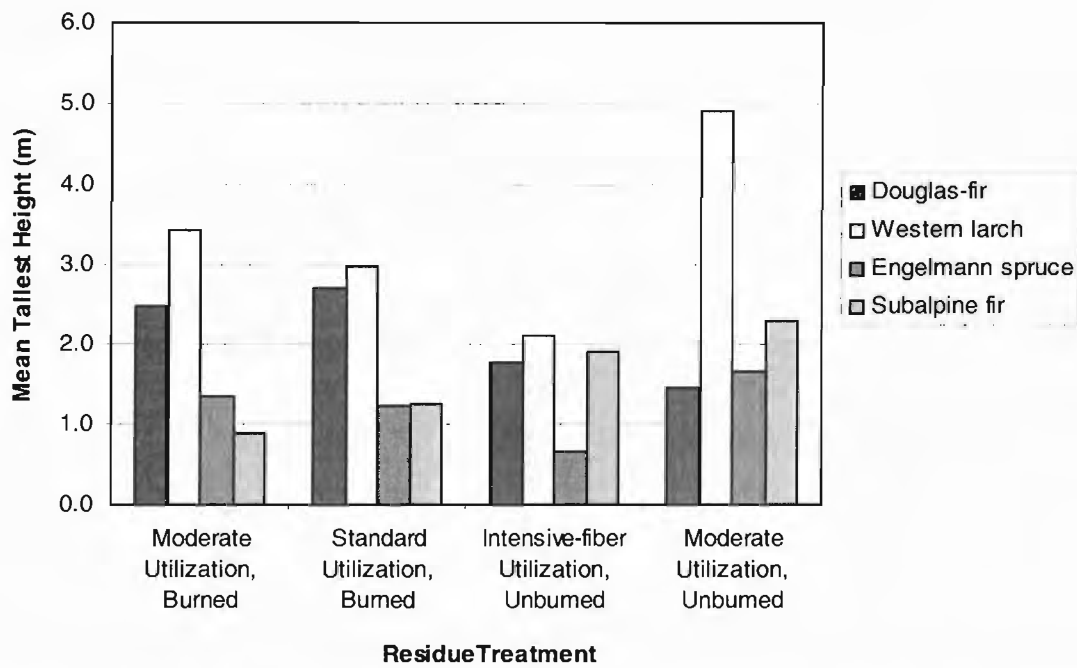

Figure 6: Mean Tallest Tree Height of Established Regeneration in 2001 by Residue Treatment, Coram Experimental Forest, Montana.

Table 8: Mean values for height (m) of tallest established conifer regeneration in 2001 by species and residue treatment, Coram Experimental Forest, Montana.

Species	**Moderate Utilization, Burned**	**Standard Utilization, Burned**	**Intensive-fiber Utilization, Unburned**	**Moderate Utilization, Unburned**
Western larch	3.4	3.0	2.1	4.9
Douglas-fir	2.5	2.7	1.8	1.5
Subalpine fir	0.9	1.3	1.9	2.3
Engelmann spruce	1.3	1.2	0.7	1.7

Tagged Tree Growth and Survival

In 2001, size and growth measurements of both western larch and Douglas-fir varied substantially (Table 10). Both harvest treatment and species had a significant effect on trends of survival (1994-2001), total height, DBH, crown length, and crown width. There were also differences in DBH growth and height growth among harvest treatments. There was no evidence of a difference in DBH growth or height growth between the two species. An interaction of harvest and species was present for the survival rates of tagged trees (Table 9).

Table 9: Summary of p-values from analysis of variance for tagged western larch and Douglas-fir

Source of Variation	df	Survival	Total Height	DBH	Crown length	Crown width	DBH growth	Height growth
Harvest	2	0.017	0.026	0.014	0.014	0.004	0.008	0.006
Species	1	0.008	0.001	0.005	0.002	0.053	0.887	0.986
HxS	2	0.017	0.943	0.776	0.929	0.853	0.994	0.559

Differences between western larch and Douglas-fir were found in terms of survival, total height, DBH, crown length, and crown width (Table 10 and Appendix 11). Although Douglas-fir had a mean survival of 96.7 %, a higher rate than western larch at 86.9%, the difference was not consistent across harvest units. Douglas-fir survival was greater than western larch in the clearcuts and shelterwoods, but western larch survival was slightly greater than Douglas-fir in the group selections. Damage of western larch was most often attributed to bears, while that to Douglas-fir was most often caused by foliar insects or disease. Heights of western larch averaged 6.2 m, significantly taller than Douglas-fir heights that averaged 3.3 m ($p = 0.001$). There was also a significant contrast between DBHs of the two species ($p = 0.005$), which were 6.8 cm for western larch and 3.5 cm for Douglas-fir. Western larch also had consistently greater crown lengths and crown widths than Douglas-fir. The height and diameter growth measurements were not significantly different between the western larch and Douglas-fir (Appendix 11).

Table 10: Mean values of 2001 individual western larch and Douglas-fir measurements. Coram Experimental Forest, Montana.

	Variable	Clearcut	Group Selection	Shelterwood
Western larch	Survival 1994-2001 (%)	73	98	90
	DBH (cm)	9.3	6.2	4.8
	Total height (m)	7.4	5.9	5.3
	Crown length (m)	6.1	4.5	3.9
	Crown width A (m)	2.6	2	1.5
	Crown width B (m)	2.2	1.7	1.2
	Crown width height (m)	3.2	3	2.2
	DBH growth 1994-2001 (cm)	3.9	2.3	1.4
	Height growth 1994-2001 (m)	1.9	1.7	0.7
Douglas-fir	Survival 1994-2001 (%)	97	97	97
	DBH (cm)	5.4	3.1	2.1
	Total height (m)	4.3	2.9	2.5
	Crown length (m)	3.8	2.5	1.9
	Crown width A (m)	2.2	1.7	1.3
	Crown width B (m)	1.9	1.5	1
	Crown width height (m)	1.4	1.2	1.2
	DBH growth 1994-2001 (cm)	3.9	2.3	1.3
	Height growth 1994-2001 (m)	2.1	1.4	0.8

A number of differences in size and growth characteristics were identified among the three harvest treatments. In 2001, tree heights were an average of 1.9 m greater ($p = 0.033$) and diameters were 3.8 cm greater ($p= 0.017$) in the clearcuts than in the shelterwoods. The height and growth of these trees from 1994 to 2001 was also greater in the clearcuts than in the shelterwoods ($p = 0.006$). Additionally, height growth in the group selection was higher than in the shelterwood ($p = 0.046$). At a lower significance level ($p<0.10$), tree heights, DBHs, and DBH growth were greater in the clearcut than in the group selection. (Appendix 12).

Discussion

Across all treatments, Douglas-fir was far more abundant than any other species. Among both harvest treatments and species, differences were found in stand level density, percent stocking, and mean tallest tree heights. The shelterwood harvest treatments had higher numbers of established seedlings and saplings than the clearcuts or group selections. Even early seral western larch was greatest in density and percent stocking on the shelterwood treatments. This was probably due to the presence of more seed producing overstory trees, and because the protection from temperature extremes prevented early seedling mortality. Another possible reason may relate to the level of competition from non-conifer vegetation; potential growing space in the clearcuts may have been quickly occupied by shrub and herb species, while the shelterwood understory remained less dense.

Mean tallest tree heights of western larch, Douglas-fir, and subalpine fir were greater in the clearcut and group selection harvests than in the shelterwood. Although these three species have different shade tolerances, all were greatest in size when growing in open conditions.

Residue treatments affected a number of stand level characteristics of conifer regeneration. On all harvests, the moderate utilization, unburned residue treatment had the least of western larch and Douglas-fir regeneration density and percent stocking. Density and stocking of western larch was consistently higher on the burned residue treatments than on the unburned treatments. As expected, residue treatments that exposed more mineral soil by burning had a greater amount of conifer regeneration. For western larch and Douglas-fir, heights of the tallest trees on the burned treatments were greater than on unburned treatments. From this study, there was no statistical difference between the standard and moderate utilization levels of the burned treatments, nor between the moderate and intensive-fiber utilizations of the unburned treatments. These results suggest prescribed burning of forest stands had a greater impact on regeneration characteristics than residue utilization level.

Although we found statistical evidence of interactions between harvest and residue treatment affecting several of the measured stand variables, inferences were limited due to a lack of replication.

The tagged tree study of western larch and Douglas-fir showed trends similar to those found at the stand level. The effects of harvest treatment on tagged Douglas-fir and western larch demonstrate the advantage of open conditions for maximizing tree growth. Compared to the shelterwood, trees in the clearcuts had significantly greater total heights, diameters, and recent growth; height growth in the group selection was also significantly greater than in the shelterwood. In the shelterwood environment, with both overstory trees and dense regeneration, growth of individuals may be limited by light, moisture, and nutrient availability.

Despite slower growth, neither Douglas-fir nor western larch had significantly lower survival in the shelterwood than in the other treatments. Twenty five years after treatment, western larch survived within the shelterwood, suggesting that currently there are adequate resources there to sustain larch. It would be useful to more closely examine conditions under which western larch grow within shelterwood harvest treatments.

These results corroborate with previous silvicultural research on western larch forests. As a seral species, larch regenerates immediately following a disturbance if there are favorable conditions and a seed source. Larch grows quickly to a dominant position over other species. Without adequate seedbed and growing conditions, larch will not establish or be maintained as a component of these forests (Fiedler and Lloyd 1995). The harvest and residue treatments applied for this study provided some favorable conditions for larch regeneration in every harvest treatment. As other studies identified, larch were more abundant on burned residue treatments (Schmidt et al. 1976; DeByle 1981). As expected, Douglas-fir and western larch regeneration was smaller in size under the residual overstory of the shelterwood (Schmidt et al. 1983; Hermann and Lavender 1990).

In assessing the relative success of different species, we can consider several aspects of regeneration. Twenty five years after treatment, Douglas-fir was by far the most abundant species in terms of density and stocking on all harvest and residue combinations. In 1979, 57% of natural regeneration was western larch (Shearer and Schmidt 1999). Since then, Douglas-fir continued to regenerate, making up 90% of total natural regeneration in 2001, but few, if any, new western larch established. With densities of up to 27,540 trees per hectare, Douglas-fir had an advantage in numbers. In contrast, western larch had less than 1,000 tpha on every treatment unit. However, where larch is present, it is taller than Douglas-fir. In each harvest and residue treatment, mean tallest tree heights were greater for western larch than for Douglas-fir.

Evaluating the individual western larch and Douglas-fir trees, we found significant differences in size between the two species. In 2001, western larch was taller than Douglas-fir, even on the shelterwood units. This may be attributed to the earlier establishment of larch, partially a result of western spruce budworm damage to other species' cone crops of 1974 (Shearer and Schmidt 1999). In general, regeneration of western larch in the study area is likely to be slightly older than all other species (~2-5 years). However, the initial advantage of western larch does not guarantee dominance over other species through time. Despite their difference in size, recent diameter and height growth were similar between the two species.

It should be noted that the prescribed burning treatments resulted in low mineral soil exposure and limited duff reduction (Artley et al. 1978), two important considerations for site preparation. Although the burning did result in increased densities and stocking of regeneration, larch did not regenerate in high numbers. An earlier study of larch regeneration at Coram Experimental Forest found over 18,000 larch seedlings per hectare on burned surface seedbeds under a seed tree harvest (Roe 1952), and overstocking is common in young even-aged larch stands (Schmidt et al. 1976). The relatively low number of larch in this study is attributed to insufficient site preparation and low initial seedfall.

This research emphasizes the importance of harvest and residue treatment in conifer regeneration, particularly for seral species such as larch. After twenty-five years, there are observable differences among treatments. Where western larch has established, it is in a dominant position relative to regeneration of other species. In the clearcuts and group selection openings, it continues to have rapid growth and is expected to be maintained as the stands develop through time. Under the shelterwood, the future of western larch is less certain. Although western larch is still present, growth is lower in those harvest treatments. This suppression by the residual overstory may eventually result in mortality of western larch in the shelterwood. In contrast, more shade tolerant species are expected to survive in the understory despite the overstory trees. Douglas-fir, Engelmann spruce, and subalpine fir can survive in lower light intensities than western larch. These species are expected to continue to survive through time. In managing western larch/Douglas-fir forests, it is necessary to consider the silvics of all species that could regenerate on a site, and choose practices to favor the preferred species.

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Chapter III: Planted Douglas-fir and Engelmann spruce after harvest and residue treatments

Introduction

Regeneration is a crucial part of sustainable forest management. In order to maintain forests on managed lands, it is necessary to ensure that stands are re-established with a new seedling cohort following timber harvest. Artificial regeneration by planting is widely used as a reliable means of stocking a site after logging (Smith et al. 1997). Forest managers plant to hasten site occupancy as well as to influence the species composition, spacing and density of a regenerated stand (Smith et al. 1997; Loftus and Fitzgerald 1989). Silvicultural choices in harvest method and site preparation can influence success of planted trees. In managed forests, intensive silviculture with planting has become increasingly common over the last 50 years (Lautenschlager 2000).

For successful regeneration by this method, management practices that promote the establishment, survival, and growth of planted trees are essential (Cleary et al. 1978; Lavender 1990). Adequate resources, including light, moisture and nutrients, must be available for individual tree growth. At the same time, it is important to protect seedlings from temperature extremes; heat and frost are primary causes of seedling stress (Lavender 1990; Mitchell et al. 1990). All of these factors may be altered by harvesting overstory trees (Kramer and Kozlowski 1979; Oliver and Larson 1996; Smith et al. 1997). In clearcut and seed-tree harvests, there are higher levels of solar radiation and greater temperature fluctuations in the understory than in shelterwoods or selection cuttings (Cleary et al. 1978). Tree removal also usually temporarily increases water availability and yield (Brooks et al. 1997).

In addition to overstory treatment, site preparation and residue management can influence the conditions surrounding planted trees. Ground temperatures are affected by site preparation; burned and litter surfaces have been found to be warmer than wood chips and mineral soil (Hungerford and Babbit 1987). Microbial activity and mineralization increase with greater moisture and soil temperatures (Waring and Schlesinger 1985). Forest residues, such as slash, stumps, brush, and residual trees on sites will slow air movement at the soil surface, lessening evaporation and temperature extremes (Edgren and Stein 1974).

Previous studies have addressed the regeneration requirements of Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). They are important conifer species of the Inland Northwest, and both are regenerated by planting (Ryker and Losensky 1983; Alexander and Engelby 1983). Douglas-fir is promoted by site preparation that exposes the seedbed and decreases competing vegetation (Ryker and Losensky 1983). Douglas-fir is somewhat shade tolerant, and has been successfully regenerated using clearcut, seed tree, and shelterwood systems (Hermann and Lavender 1990). Engelmann spruce seedlings are especially susceptible to heat as well as frost injury. Woody debris or live vegetation can provide protection from high light intensities and extreme temperatures (Ronco 1972; Alexander 1987). An overstory canopy also provides shelter for spruce, especially if there is an even distribution of trees. Roberts and Long (1991) determined that spruce seedling survival was greater in uniform shelterwood units than in strip shelterwoods.

Engelmann spruce is considered a later successional species than Douglas-fir, replacing it over time in mixed conifer forests (Schmidt and Larson 1989). Engelmann spruce is generally listed as being more shade tolerant than Douglas-fir (Alexander and Sheppard 1990). Chen (1997) describes the distinct responses of planted Douglas-fir and Engelmann spruce seedlings under a range of light levels. He notes that with lower light availability, Douglas-fir had greater decreases in diameter growth than Engelmann spruce; however, spruce had greater decreases in height growth. He also found that decreasing light availability was not associated with a change in survival rates for either species over three growing seasons.

Since most plantings occur in clearcut areas, there is limited information on how various combinations of overstory and understory silvicultural treatments affect the survival and growth of planted Douglas-fir and Engelmann spruce. Studies that address the interaction of harvest and residue treatment are rare. In a discussion of forest residues, Edgren and Stein (1974) noted the need for an investigation of various management practices to protect seedlings if residues were decreased by intensive utilization.

Increased yields over natural regeneration are an advantage commonly associated with planted stands. Enhanced growth of genetically improved trees may contribute to higher stand volumes (Loftus and Fitzgerald 1989). On highly productive sites, planting seedlings that are one or more years old can significantly increase volume within a rotation (Smith et al. 1997). Several published studies compare the performance of natural and planted regeneration. Focusing on stand level volumes, Miller et al. (1993) documented increased yields from planted coastal Douglas-fir (*Pseudotsuga menziesii*

(Mirb.) Franco var. *menziesii*) compared to natural regeneration on matched sites. In an individual tree growth study of coastal Douglas-fir, Miller and Anderson (1995) found planted trees to be taller than those of an adjacent naturally regenerated stand. Similarly, a study of Norway spruce (*Picea abies*) under shelterwoods in Sweden determined that heights of planted seedlings were greater than naturally regenerated seedlings (Holgén and Hånell 2000).

Information about the relative success of natural and planted regeneration is rare for either interior Douglas-fir or Engelmann spruce. Although increased yields are generally assumed for planted stands, the long term extent of that growth increase is unknown, particularly under partial harvests. Given the cost of artificial regeneration, it is important to consider the long term performance of planted interior Douglas-fir and Engelmann spruce compared to natural regeneration.

This purpose of this study was to evaluate characteristics of planted Douglas-fir and Engelmann spruce regeneration in response to harvest and residue treatments, and to compare planted trees to natural regeneration of these species. This research was initiated to address these two aspects of planting in the Inland Northwest. We examined the growth response of Douglas-fir and Engelmann spruce planted over 20 years ago to consider the long-term response of planted versus natural regeneration to harvest and residue treatments. Specific objectives associated with the study are:

1. To examine the effect of harvest and residue treatments on the growth rate and survival of planted Douglas-fir and Engelmann spruce.
2. To compare the size of planted trees with the tallest natural regeneration of those species.

Methods

Study Area

The study area is located at the Coram Experimental Forest, within the Hungry Horse Ranger District of the Flathead National Forest. The Coram Experimental Forest is 3019 hectares (ha) in size, and is approximately 45 kilometers east of Kalispell, Montana, just south of Glacier National Park. Mean annual precipitation at the Coram Experimental forest ranges from 89 to 127 cm, most of which falls as snow (Shearer and Kempf 1999). Mean annual temperatures in the area range from 2° Celcius at Abbot Creek to 7° C on some slopes. These variations in microclimate are due to the topography of the forest (Hungerford and Schlieter 1984).

The study site is on an east-facing slope in the Upper Abbot Basin and classified as a larch/Douglas-fir cover type before treatment (Eyre 1980). Douglas-fir and western larch (*Larix occidentalis* Nutt.) made up 58 and 20 percent of the total cubic foot volume, respectively. In this forest, there were also components of Engelmann spruce, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and infrequent western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn.) (Benson and Schlieter 1980). The study site is a relatively moist and productive forest of Montana, mostly classified as an *Abies lasiocarpa* / *Clintonia uniflora* ((Schult.) Kunth) floristic habitat type (Pfister et al. 1977).

Study Design

This study was set up as a two factor randomized split-plot design, with two replications. Main plots each received one of three harvest treatments: clearcut, group selection, and shelterwood. The two replications were within the same watershed but differed in elevation by about 200 m. Area of the harvest units varied with silvicultural system (from 2.4 to 14.2 ha). The clearcut units were 5.5 and 6.7 ha in size. The shelterwood units were 14.2 ha and 8.7 ha. The group selection units were 3.0 ha and 2.4 ha in size, each with eight group selection openings that range in size from 0.2 to 0.6 ha in size.

In 1974, logging removed all merchantable trees on the clearcut blocks and within the group selection openings. About 50 percent of the volume was removed from shelterwood harvest units, favoring western larch as a residual overstory (Appendix 1). These leave trees on the shelterwood units have not been removed, so the shelterwood units now exist as two-aged stands.

Within each of the harvest units (main plots), four sub-plots of equal area were assigned one of four "residue treatments". Henceforth, the residue sub-plots will be referred to by their combination of utilization level (i.e. standard, moderate, intensive-fiber) and burn treatment (burned, unburned). The three combinations examined in this long-term study included the following: moderate utilization burned, standard utilization burned, and intensive-fiber utilization unburned. Residue treatments consisted of different levels of tree and log utilization and prescribed burning (Table 11). The moderate utilization treatment removed material down to 7.6 cm (3 inches) and was followed by fire. The standard utilization treatment simulated the utilization level of

Forest Service harvests in 1974 and was also burned. The unburned, fiber-intensive utilization treatment had the removal of all material down to 2.5 cm in diameter.

Table 11. Residue treatments applied in 1974-1975 to three sub-plots within each harvest treatment, Coram Experimental Forest, Montana (Benson and Schlieter, 1980; Shearer and Schmidt, 1999).

Residue sub-plot	Trees Cut	Utilization Specification	Fire Treatment
Moderate utilization, burned	All except designated shelterwood	Remove all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length, and one-third sound	Burned
Standard utilization, burned	All except designated shelterwood	Remove sawtimber material (living and recently dead) of trees down to 17.8 cm dbh, 2.4 m length, one-third sound	Burned
Intensive-fiber utilization, unburned	All except designated shelterwood	Remove all timber (live and dead, standing and down) to 2.5 cm diameter	Unburned

Moist fuels hindered prescribed burning of residue treatments. Although the original study was set up to replicate burns on all harvest units, the lower shelterwood replicates were not burned because of wet conditions (Artley et al. 1978). The data from those sub-plots was not used in subsequent analyses.

For four consecutive years, 1976-1979, rows of two year old (2-0) bare root Douglas-fir and Engelmann spruce seedlings were planted in three of the residue sub-plots within each harvest unit (i.e. moderate utilization burned, standard utilization burned, intensive-fiber utilization burned). Auger planting of seedlings at 1.8 m spacing was completed in early May of each year.

Field Measures

In 2001, we completed size measurements of all planted trees on the study site. Graduated height poles were used to measure total tree height, current terminal leader length, crown length and crown width of each tree to the nearest 3 cm. Diameter at breast height (DBH, 1.37 m above the ground) was measured with a tape to the nearest 0.25 cm. A categorical crown position (e.g. under brush canopy, free to grow) and a designation of vigor as good, fair, poor or dead was recorded for each tree. In addition, we described a simple condition of the general form of each tree and a specific condition that identified damage agents.

For the comparison of natural regeneration to planted trees, natural regeneration data was obtained from a companion study on the same site. Mean height and DBH measurements of the tallest naturally regenerated Douglas-fir and Engelmann spruce were available from a systematic sample of permanent plots (0.004 ha) within each havest-residue treatment combination.

Analysis

To avoid pseudo-replication, measurements of the individual planted trees were averaged to provide summary information for Douglas-fir and Engelmann spruce of each planted year within each harvest and residue treatment combination. The response variables include means of total height, leader length, diameter at breast height, crown length and crown width. Percent survival was calculated as the number of living trees in 2001 divided by the number of trees originally planted.

Because there was no replication of the burned residue treatments within the shelterwood harvest treatment, statistical analysis could not be completed for all treatment factor combinations. We were able to evaluate the effect of all three residue treatments within the clearcut and group selection harvests. To do so, we used a general linear model with repeated measures. Separately, we evaluated the effect of all three harvests treatments on the intensive-fiber utilization, unburned residue treatment, using an analysis of variance. In these testing procedures, Sidak's pairwise multiple comparison test was chosen for post-hoc analyses of fixed effects because it adjusts the significance level for multiple comparisons and provides tight bounds.

In order to identify differences in heights and DBHs between natural and planted regeneration, we compared each year of planted trees to the tallest natural trees within each sub-plot. This first analysis was done with T-tests. To analyze the influence of harvest and residue treatments, we again used the general linear model with repeated measures. The repeated height and DBH measurements had five levels, consisting of the four years of planted trees and the average tallest natural regeneration. We evaluated the effect of all three residue treatments within the group selection and clearcut harvest treatments. In a separate analysis, we evaluated all three harvest treatments in the intensive-fiber utilization, unburned residue treatment. Simple contrasts were used to compare the natural regeneration with each year of planted regeneration. All statistical analyses were conducted using SPSS version 10.0 (SPSS Inc. 1999).

Results

After 25 years, planted Douglas-fir and Engelmann spruce showed several trends among harvest treatments. For both species on each residue treatment, all mean size measurements were greater for trees in the clearcut and group selection treatments than in the shelterwood treatments (Appendix 13). In each residue treatment, planted trees in the clearcuts were similar in size to those in the group selections, and taller than those in the shelterwoods (Figure 7). Trees in the clearcuts and group selections averaged 4.4 m and 4.6 m in height, respectively; those in the shelterwood averaged 2.9 m. Mean values of DBH were 5.9 cm and 5.8 cm in the clearcuts and group selections, compared to 3.1 cm in the shelterwood. A similar trend is apparent for mean crown length and crown width. (Table 12)

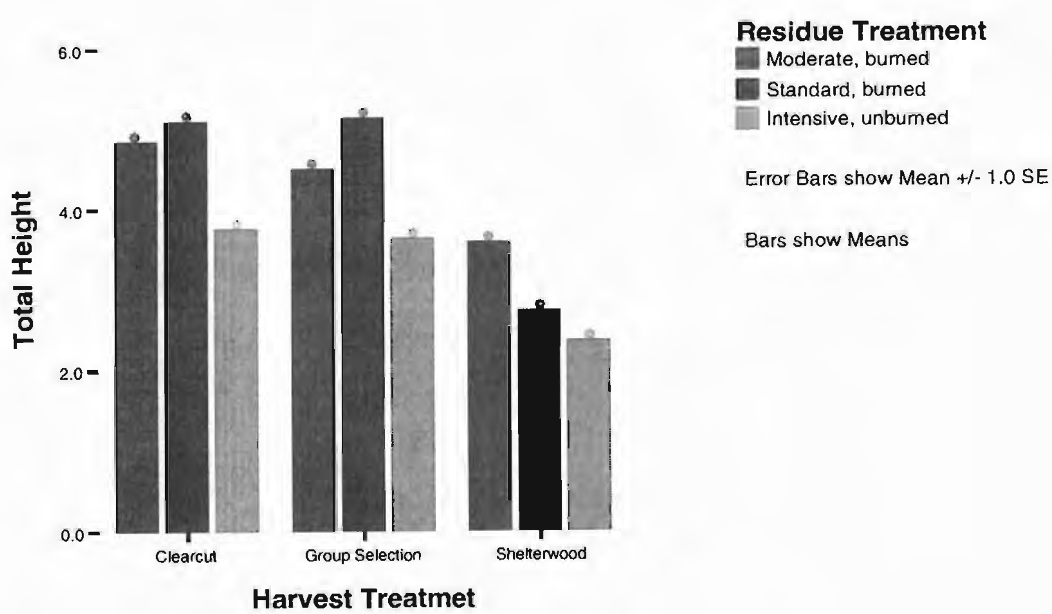

Figure 7: Mean total height (m) of planted trees in 2001 by harvest and residue treatments, Coram Experimental Forest, Montana.

Table 12: Mean values of planted tree variables in 2001by harvest treatment, Coram Experimental Forest, Montana.

Variable	Clearcut	Group Selection	Shelterwood
Total height (m)	4.6	4.4	2.9
Leader length (cm)	24.8	23.6	14.9
DBH (cm)	5.9	5.8	3.1
Crown length (m)	3.8	3.6	2.3
Crown width (m)	2.1	2.1	1.6
Survival (%)	71	63	68

Recent height growth, measured as leader length, of trees in the shelterwood was 14.9 cm, almost ten cm shorter than in the other harvest treatments (Table 12). Where we were able to test all harvest treatments, harvest had a significant ($p<0.10$) effect on the mean leader length of Douglas-fir planted in 1976 and 1977. Those trees planted in the clearcuts in 1976 had significantly greater leader lengths than those in the shelterwoods. For the 1977 trees, statistical analysis showed that leader lengths of planted Douglas-fir in the clearcut and group selection treatments were significantly greater heights of those in the shelterwood (Table 13). None of the size or survival variables were significantly different between the clearcut and group selection treatments in split-plot analysis considering all residue treatments within the group selection and clearcut harvests.

Table 13: Mean leader length (cm) of planted Douglas-fir in the intensive-fiber utilization, unburned residue treatment by harvest treatment. Within a row, different letters indicate significant differences between the means ($p<0.10$).

Planted Year	Clearcut	Group Selection	Shelterwood
1976	23.4*a*	21.5*ab*	9.6*b*
1977	30.1*a*	22.5*a*	9.2*b*
1978	28.1*a*	21.4*a*	8.5*a*
1979	21.4*a*	22.7*a*	9.5*a*

Percent survival varied by species and residue treatment (Appendix 13). Survival of Engelmann spruce planted in the intensive-fiber utilization, burned residue treatment in 1976 and 1977 was significantly different among harvest treatments. For spruce planted in 1976, average survival was 86% in the shelterwoods, substantially greater than the 60% in the clearcuts ($p < 0.10$). The mean survival of Engelmann spruce planted in 1977 was 80% in the shelterwood, significantly greater than in either the group selection or clearcut harvests. (Table 14)

Table 14: Mean percent survival of planted Engelmann spruce in the intensive-fiber utilization, unburned residue treatment by harvest treatment. Within a row, different letters indicate significant differences between the means ($p<0.10$).

Planted Year	Clearcut	Group Selection	Shelterwood
1976	60*a*	79*ab*	86*b*
1977	66*a*	65*a*	80*b*
1978	64*a*	55*a*	86*a*
1979	24*a*	13*a*	40*a*

Planted Engelmann spruce and Douglas-fir mean size and recent growth measurements were all greater on the two burned residue treatments than on the intensive-fiber utilization, unburned treatment (Appendix 13). Mean heights were 4.3 m in both burned treatments, one meter taller than heights in the intensive-fiber utilization, unburned treatment. Mean leader length, DBH, crown length and crown widths values were also lowest in the intensive-fiber utilization, unburned treatment (Table 15). In split plot analysis of residue treatments within group selection and clearcut harvests, none of the measured variables were found to be significantly different between the burned, moderate utilization treatment and the burned, standard utilization treatment. Additionally, the 1976 planted Douglas-fir had a mean leader length of 27.5 cm in the moderate utilization, burned treatment, significantly greater than the 22.4 cm mean leader length of those trees in the unburned, intensive fiber utilization treatment (Table 16).

Table 15: Mean values of planted tree variables by residue treatment.

Variable	Moderate Utilization, Burned	Standard Utilization, Burned	Intensive-fiber Utilization, Unburned
Total height (m)	4.3	4.3	3.2
Leader length (cm)	23.2	22.6	17.5
DBH (cm)	5.5	5.7	3.6
Crown length (m)	3.6	3.6	2.6
Crown width (m)	2.1	2.1	1.6
Survival (%)	69	71	63

Table 16: Mean leader length values (cm) of planted Douglas-fir in the clearcut and group selection harvests by residue treatment. Within a row, different letters indicate significant differences between the means ($p<0.10$).

Planted Year	Moderate Utilization, Burned	Standard Utilization, Burned	Intensive-fiber Utilization, Unburned
1976	27.5*a*	26.4*ab*	22.4*b*
1977	25.0*a*	28.2*a*	26.3*a*
1978	27.3*a*	25.5*a*	24.7*a*
1979	24.7*a*	27.2*a*	22.1*a*

Within residue treatment sub-plots, most years of planted Douglas-fir had significantly greater heights and DBHs than the tallest natural regeneration. However, that trend was not found for either variable in the intensive-fiber utilization, unburned treatments of the shelterwood harvests; where the tallest natural regeneration was comparable in size to the planted regeneration. The 1976 planted Engelmann spruce also had greater heights and DBHs than the tallest natural regeneration in most sub-plots where natural regeneration was present (Appendix 14).

Through split-plot analysis of the planted years and residue treatments within the group selection and clearcut harvests, we found that all years of planted Douglas-fir and Engelmann spruce were 60-330% taller than the tallest natural regeneration. Similarly, the mean DBH from each year of planted Douglas-fir was greater than the mean DBH of the tallest natural regeneration (718).

Table 17: Mean values from 2001 total height (m) and DBH (cm) measurements of planted and tallest natural trees in the group selection and clearcut harvest treatments. Within a row, the "*" symbols indicates a significant difference between that value and the value of natural regeneration ($p < 0.10$)

Variable	Species	Natural	Planted 1976	Planted 1977	Planted 1978	Planted 1979
Height (m)	Douglas-fir	2.8	5.9*	5.7*	5.3*	4.7*
	Engelmann spruce	1.0	4.3*	3.5*	3.6*	3.1*
DBH (cm)	Douglas-fir	3.9	8.4*	7.5*	6.7*	5.7*
	Engelmann spruce	2.4	5.9	4.4	4.8	4.1

From analysis of the intensive-fiber utilization, unburned residue treatment of all three harvest treatments, we found that mean heights of all years of planted Douglas-fir and Engelmann spruce were significantly taller than those of the tallest natural regeneration (Table 18). However, no significant differences in DBHs were identified between natural and planted trees on this residue treatment.

Table 18: Mean values from 2001 total height (m) and DBH (cm) measurements of planted and tallest natural trees in the intensive-fiber utilization, unburned treatment of all harvest treatments. Within a row, the "*" symbol indicates a significant difference between that value and the value of natural regeneration ($p < 0.10$).

Variable	Species	Natural	Planted 1976	Planted 1977	Planted 1978	Planted 1979
Height (m)	Douglas-fir	1.8	4.0*	4.0*	3.9*	3.2*
	Engelmann spruce	0.7	3.5*	2.4*	2.9*	2.0*
DBH (cm)	Douglas-fir	2.9	5.1	4.4	4.3	3.2
	Engelmann spruce	1.7	4.5	2.4	3.4	2.1

Discussion

Harvest and Residue Treatments

The results of this study show that twenty-five years after regeneration, there are substantial differences in planted tree characteristics among various harvest and residue treatments. Although Douglas-fir was consistently taller than Engelmann spruce, the two species showed similar trends in terms of relative size among treatments. As might be expected, both Douglas-fir and Engelmann spruce trees planted in the group selection and clearcut units were larger in size than those in the shelterwoods. Recent growth of the oldest planted Douglas-fir in the intensive-fiber was significantly greater in the clearcuts than in the shelterwoods. These differences may be attributed to a lower availability of resources in the shelterwood environment, limiting growth of the trees planted there. In the shelterwoods, a residual overstory reduces the level of solar radiation reaching regeneration (Cleary et al. 1978; Waring and Schlesinger 1985).

Survival of the oldest Engelmann spruce, however, was significantly higher in the shelterwood treatments than in the clearcut or group selection treatments. This emphasizes the importance of site protection for Engelmann spruce, and is consistent with previous work that showed that the shelter of an overstory can increase planted spruce seedling survival (Alexander and Engelby 1983; Roberts and Long 1991). Approximately one third of the planted spruce trees on each treatment were damaged by cooley spruce gall adelgid. Although the damage was consistent across treatments, insects contributed to a substantial decline in vigor of infested trees.

Residue treatment also had a substantial effect on the size and recent height growth of planted Douglas-fir and Engelmann spruce. In each harvest treatment, trees of both species in the two burned treatments were consistently larger in size and had greater leader lengths than those in the unburned, intensive-fiber utilization treatment. Mean leader length of the oldest Douglas-fir in the clearcuts and group selections was significantly greater on the moderate utilization, burned treatment than on the intensive-fiber utilization, unburned treatment. Burning may have decreased the amount of competing vegetation, increasing the availability of moisture, nutrients, and light for planted seedlings (Cleary et al. 1978). Burning may have also temporarily increased the availability of some nutrients in the soil (Brady and Weil 1999). Ten years after planting, Shearer and Schmidt (1991) found that height growth of Douglas-fir was greater on these burned sites, and this advantage has appears to have continued through time. Between the two burned residue treatments, no significant differences were found related to utilization levels. This suggests that the increasing utilization from standard to moderate levels did not affect planted trees. Intensive-fiber utilization on the unburned treatment may have had some effect on the planted trees, but it was can not be separated from the impact of not burning.

In 2001, trees planted in 1976 were the tallest and most robust. The logical explanation for this is that they are the oldest, and have been through more growing seasons. There was no difference in mean leader lengths among any of the planted years. The low survival rate for the trees planted in 1979 may be attributed to poor stock or the climate of that year.

This research indicates the importance of harvest and residue treatments for planting Douglas-fir and Engelmann spruce. Both species were substantially smaller in size and had lower recent growth under the shelterwood. Management goals should dictate forest practices; if maximum growth of individual trees is the primary objective, partial harvest methods may be inappropriate for either Douglas-fir or Engelmann spruce. Planted Douglas-fir had comparable survival rates under clearcut, group selection, and the partial harvest of the shelterwood. However, to ensure the survival of Englemann spruce seedlings, a shelterwood harvest is preferable. Prescribed burning of slash also increased growth of planted trees, an effect that was still apparent after 25 years.

Planted Versus Natural Regeneration

Planting Douglas-fir and Engelmann spruce within four years of treatment usually resulted in significantly taller trees than the tallest (and probably the oldest) natural regeneration of those species. This is consistent with comparison studies of planted and natural regeneration of other species, including coastal Douglas-fir and Norway spruce. Planted trees of those species were found to be greater in size than natural regeneration under similar conditions (Miller and Anderson 1995; Holgén and Hånnel 2000).

The age of the tallest natural regeneration was not determined in this study. Shearer and Schmidt (1999) noted that most of the natural Douglas-fir and Engelmann spruce regeneration on the site was established from a bumper seed crop in 1980. Although we used the tallest trees of each species, some of those may have been a few years younger than the planted regeneration (2-0 nursery stock).

Planting Douglas-fir and Engelmann spruce ensures the stocking of those species on appropriate sites, and can result in trees of considerably greater size than natural regeneration. This site had little natural regeneration of Engelmann spruce on any of the harvest treatments, so planting was needed to ensure prompt stocking of that species.

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Chapter IV: Variability in western larch sapling characteristics in relation to residual overstory and understory competition after management

Introduction

Currently there is growing interest in alternative silvicultural systems that favor partial harvesting rather than clearcutting. Rising use of partial harvest systems is driven in part by aesthetics and also by the recognition that natural lethal disturbances result in greater levels of structure in the residual stand. Aesthetics, biological diversity, and soil stability are issues that can be negatively affected by intensive management (Shearer 1971; Kohm and Franklin 1997). Harvest methods that maintain residual overstory structure can provide higher diversity and be more aesthetically pleasing. Ecosystem management, or "New Forestry", describes this consideration of human and ecological values such as aesthetics, forest composition, structure, function and processes over time (Davis et al. 2001). These new management strategies emphasize retention of trees and often involves some type of multi-aged management (Swanson and Franklin 1992). The irregular (or aesthetic) shelterwood is one such approach, in that this practice maintains residual trees beyond the traditional removal period, resulting in higher structural diversity and aesthetic appeal.

Reduced use of clearcutting as a harvest system has increased the challenge of regenerating early seral, less shade tolerant tree species. Many of these species are the most desirable from the standpoint of fiber production, as well as the promotion of forest health and restoration of historic conditions. As the use of alternative treatments are employed, there is a critical need to understand the effects on establishment and growth of valuable seral species, and the relative effect of such methods on the sustainability of seral species as a component of the landscape.

Western larch (*Larix occidentalis* Nutt.) is classic example of a valuable early seral species. Native to the Inland Northwest, western larch is commercially valuable for structural lumber, plywood veneer, paper, and binding gum (Keegan et al. 1995). It also has considerable value for the landscape visual quality it provides for recreationists, tourists, and others who live near or visit western larch forests (Blocker 1995). Depending on the age of individual trees and stands, larch forests provide forage and habitat for birds, small mammals, and big game species (Shearer and Kempf 1999). For these reasons, western larch is recognized as a desirable species, and management objectives are often directed toward maintaining or increasing the larch component in forest stands (Roe 1952). As a component of several forest cover types, larch has been the focus of management efforts to retain it as an element of landscape ecosystems within its range.

Western larch typically regenerates, often abundantly with great success, following natural wildfires that reduce overstory density and expose mineral soil. As an intolerant species, western larch will successfully regenerate and achieve maximum growth rates in open stands with some site disturbance. Seedlings undergo rapid height growth relative to surrounding competition (Roe 1952; Shearer 1971; Schmidt et al. 1976).

Foresters have traditionally met these silvical requirements of western larch by managing with even-aged silvicultural systems. The conditions historically created by wildfire can be approximated by timber harvest and site preparation (Arno and Fischer 1995). Seed tree and shelterwood systems are often chosen instead of clearcutting, particularly in cases of uncertain seed production and to avoid exposure of new western larch germinants to extreme temperatures (Roe 1955; Schmidt et al. 1976; Schmidt and Shearer 1995). The seed tree method creates a similar environment to a clearcut by cutting almost all trees, but a seed source is provided by a few dispersed trees throughout the harvest unit. The shelterwood method maintains a higher number of trees that will both provide a seed source and moderate the microenvironment for regeneration (Helms 1998). Shelterwood environments with 50% or less light transmission to the forest floor have been shown to result in fewer occurrences of potentially lethal high and low surface temperatures (Hungerford and Babbitt 1987). Seed tree retention levels of three to ten trees per acre would not reduce the light levels reaching new regeneration of this shade intolerant species, to the same extent that even-aged management with the shelterwood method would (i.e. typically 25-50% crown cover retained). In either case, the residual overstory has traditionally been removed after seedling establishment to avoid shading and suppression (Schmidt et al. 1983; Smith et al. 1997).

Some information regarding the potential effect of partial retention on the survival and growth of early seral species can be gleaned from published findings in various regions. Longleaf pine (*Pinus palustris* Mill.), a southeastern seral species adapted to periodic fire, has been the subject of a long-term (30+ year) study on regeneration and development under residual overstories of both seed tree and shelterwood silvicultural systems. Two-aged stands, created by maintaining crop trees at 5 residual densities, provide information on the effect of variable retention levels on understory tree growth.

This study found that any level of overstory examined significantly reduced longleaf pine growth. At the lowest level of retention (9 square feet of basal area) the stand growth (cubic volume per acre) was 41% of that in a released stand over the same time period (29-35 years). Higher levels of retention showed increasing reduction of growth, with the understory contributing little to stand basal area and volume (Boyer 1993). For stands of relatively intolerant Douglas-fir regeneration (*Pseudotsuga menziesii* (Mirbel) Franco) in Oregon and Idaho, computer modeling suggests growth of saplings is negatively related to the level of residual overstory density (Long and Roberts 1992; Birch and Johnson 1992). A field study in the western central Cascade Range of Oregon, Zenner et al. (1998) also found a negative relationship between residual density (as measured in trees per acre) and understory volume. Additionally, this research determined that in stands with over 15 residual overstory trees per acre, the retention had a greater effect on stands with pure Douglas-fir regeneration compared to those with mixed Douglas-fir/western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) regeneration. These studies confirm that overstory retention will reduce growth of understory trees, and show that seral species are especially vulnerable to suppression. .

From a 3-year study in British Columbia, Chen and Klinka (1998) showed relative base diameter growth of planted western larch was greater with increasing light availability. They also found that height growth was independent of light availability. However, it has been noted that after the first few years, western larch seedlings in partial shade grow more slowly than those in full sunlight (Schmidt and Shearer 1990).

The effects of alternative regimes on regeneration and growth are largely unknown (Swanson and Franklin 1992; Kohm and Franklin 1997). Available research is focused primarily on stand level attributes, and in particular on the effects of residual overstory competition on understory tree growth rates. Less is known regarding variability in growth and survival within the relatively heterogeneous light environment of a shelterwood understory. It is also unclear how growth and survival under partial retention will effect conifer species composition over time.

Furthermore, in water-limited ecosystems of the Inland Northwest, the amount of solar radiation reaching individual saplings of intolerant species is not the only potentially limiting resource. Competition for below ground resources such as soil water and nutrients can come from understory shrubs, grasses, forbs, and other saplings as well as overstory trees.

In addition to overstory effects on regeneration, western larch must compete with understory vegetation for underground resources. Resources such as soil water and nutrients will be allocated to plant species that can most effectively compete for them. Limited nutrients may be tied up in the biomass of these competing (other species) plants, and therefore unavailable (Oliver and Larson 1996). In competition for light, taller individuals have an advantage and reduce light available to shorter plants. Western larch seedlings and saplings are fast growing in height; this enables them to quickly become dominant in mixed-species, even-aged stands (Schmidt et al. 1976). This is the strategy that results in establishment of new larch stands following wildfire or management that imitates such disturbance. Within five to ten years, however, additional new larch seedlings will not continue to become established due to competing vegetation (Shearer and Schmidt 1999). These trends indicate the importance of both favorable initial conditions to obtain natural regeneration as well as adequate resources over time for long-term success of larch.

Although it is generally accepted that the development of shade intolerant, early-seral tree species will be inhibited by an overstory (Schmidt and Larson 1989), the amount and variability of growth loss has rarely been quantified. The primary motivation for this project is the lack of information on the use of partial retention practices in western larch forests and the potential impacts on the composition and growth of western larch regeneration over time. This study examines individual larch saplings and the surrounding forest components in stands that have been harvested with clearcuts and irregular shelterwoods (i.e. partial overstory retained). From field observations, we examined differences between those competitive environments and the size and growth of western larch under each condition. It was an investigation into the relationship of both overstory and understory competition factors to western larch growth. This research characterized height growth rates of western larch as well as overstory and understory vegetation by harvest treatment. This information can be used to develop some simple models of western larch growth as a function of overstory and understory competition. The specific objective of this study was to quantify the variability in size and recent growth of individual western larch saplings growing under a range of conditions within aesthetic shelterwood (i.e. overwood retained) and clearcut harvests.

Methods

Study Area

This study was conducted within the 3019 hectare (ha) Coram Experimental Forest, a research forest on Hungry Horse Ranger District of the Flathead National Forest. The study area is located approximately 45 kilometers east of Kalispell, Montana, and is just south of Glacier National Park. The study area is on an east-facing slope in the Upper Abbot Basin of the forest. The climate has an average annual precipitation of 89 to 127 cm, most of which falls as snow (Shearer and Kempf 1999). Mean annual temperatures in the area range from 2° to 7° Celsius; variations in microclimate are indicative of the topography of the forest (Hungerford and Schlieter 1984).

The study area was classified as a larch/Douglas-fir cover type prior to treatment (Eyre 1980), with western larch and Douglas-fir making up 20 and 58 percent of the total cubic foot volume, respectively. Other species in the study area included Engelmann spruce, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), as well as occasional western hemlock and western redcedar (*Thuja plicata* Donn.) (Benson and Schlieter 1980). The study site is a fairly moist and productive forest of Montana. The floristic habitat type over most of the area was classified as *Abies lasiocarpa* / *Clintonia uniflora* ((Schult.) Kunth). In the absence of disturbance, this habitat type will naturally succeed to subalpine fir (Pfister et al. 1977).

Study Design

The study sites are part of a long-term study that was designed and implemented on the Coram Experimental Forest in the mid 1970's. The initial study design was a two factor randomized split-plot design, with two replications. Three harvest levels were allocated to main plots: clearcut, group selection, and shelterwood. The clearcut and shelterwood units from that design were used for this subsequent study.

In 1974, the harvest units were logged. On the clearcuts, logging removed all merchantable trees. Approximately 50 percent of the cubic meter volume was taken off the shelterwoods, with western larch favored as leave trees. The two replications were within the same watershed but differed in elevation by about 200 m. Harvest units varied in size from 5.5 to 14.2 ha. The clearcut units are 5.5 and 6.7 ha and the shelterwoods are 14.2 and 8.7 ha. The residual overstory on the shelterwood units has not been removed; these units now exist as two-aged stands.

Four different residue treatments were assigned as sub-plots within each main plot. Within each of the harvest units (main plots), four sub-plots of equal area were assigned one of four "residue treatments". Henceforth, the residue sub-plots will be referred to by their utilization level and burn treatment: moderate utilization burned, standard utilization burned, intensive-fiber utilization unburned, and moderate utilization unburned. Residue treatments consisted of different levels of tree and log utilization and prescribed burning (Table 19). One moderate utilization treatment removed material down to 7.6 cm and was followed by fire. The standard utilization treatment simulated the standard utilization level of Forest Service harvests in 1974 and was also burned.

One of the unburned treatments had moderate utilization and the other had intensive-fiber utilization, with removal of all material down to 2.5 cm in diameter.

Table 19: Residue treatments applied in 1974-1975 to sub-plots within each harvest treatment, Coram Experimental Forest, Montana (Benson and Schlieter, 1980; Shearer and Schmidt, 1999).

Residue sub-plot	Trees Cut	Utilization Specification	Fire Treatment
Moderate utilization, burned	All except designated shelterwood	Remove all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length, and one-third sound	Burned
Standard utilization, burned	All except designated shelterwood	Remove sawtimber material (living and recently dead) of trees down to 17.8 cm dbh, 2.4 m length, one-third sound	Burned
Intensive-fiber utilization, unburned	All except designated shelterwood	Remove all timber (live and dead, standing and down) to 2.5 cm diameter	Unburned
Moderate utilization, unburned	Trees 17.8 cm DBH and greater except designated shelterwood	Remove all material (live and dead, standing and down) to 7.6 cm diameter, 2.4 m length and one-third sound	Unburned

Field Measures

In order to measure individual tree growth of western larch under a range of woody competition levels, we returned to permanent regeneration plots in both the clearcuts and shelterwood treatments. Plots were selected from among a set that had larch over 1.37 m in height present in a related study survey. We tallied conifer species within a 15.2 m radius plot by 10.2 cm size classes for all trees greater than 10.2 cm in diameter at breast height (DBH, 1.37 m above ground). For a tally of conifers with less than 10.2 cm and greater than 5.1 cm DBH, a 6.1 m plot was nested within the larger plot. In addition to information on the overstory trees, we visually estimated canopy cover at nine sample points within the plot. The larch sapling nearest to the permanent plot center was selected as a subject tree and measured for total height, DBH, crown length and width, crown condition, and height growth increment over the previous three-year period. To collect data on the understory vegetation, we centered 0.008 hectare plot on each larch and recorded the % cover of total understory cover as well as a separate estimate of understory cover over 1.37 m tall. This plot included grass, shrub, and woody species.

Data Analysis

With the tally of overstory trees by size class, we computed three indices of stocking levels for the plot, trees per hectare, basal area, and stand density index (SDI), as potential variables for explanation of sapling height growth. Stand density index is a calculation of the number of 25.4 cm (10 inch) DBH trees that would be equivalent to a given basal area (Long 1995). Because the trees on each plot had a range of diameters, we calculated a per hectare SDI for the basal area in each tree size class, and then summed those values. Canopy cover was averaged from the nine sample points within the plot. Understory explanatory variables included total understory cover and tall (greater than 1.37 m) understory cover. A median initial height of each larch was calculated as total height minus half of the three year height increment.

First, an analysis of variance was used to test for significant effects of residue treatment on larch characteristics within the clearcut and shelterwood harvests. Next, we used linear regression to identify relationships among the explanatory variables and the response variable, recent mean annual height growth. Annual height growth was calculated by dividing the measured 3 year height increment by 3. All statistical analyses were conducted using SPSS version 10.0 (SPSS Inc. 1999).

Results

The characteristics of western larch trees were widely variable in both the clearcut and shelterwood harvest treatments. Within the clearcuts and shelterwoods, residue treatment did not significantly affect any measured characteristics of western larch trees, so we pooled all larch within each harvest treatment. Individual tree heights ranged from 1.4 to 9.1 meters; averaging 3.2 m in the shelterwoods and 4.8 m in the clearcuts (Figure 8). Mean annual height growth in the shelterwood was 15.2 cm, approximately half the value found in the clearcuts it was 29.6 cm (Figure 9). Diameter at breast height averaged 2.6 cm in the shelterwoods, and 4.8 cm in the clearcuts. Mean crown length of western larch in the shelterwoods was 2.5 m, compared to a mean value of 4.0 m for larch in the clearcuts. Western larch sapling crown width averaged 1.2 m in the shelterwoods and 1.6 m in the clearcuts (Appendix 15).

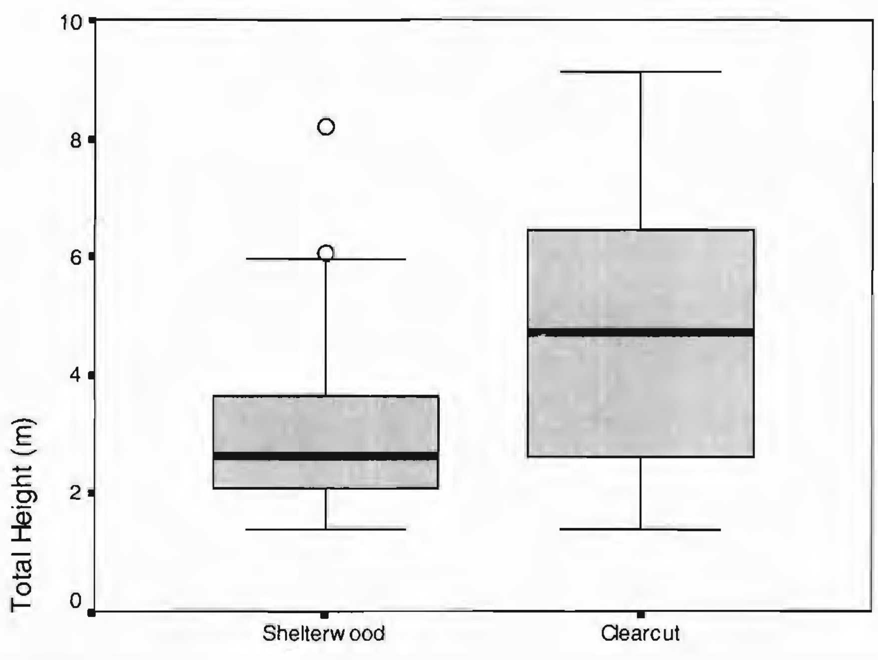

Figure 8: Boxplots displaying the range (whiskers), interquartile (box), outlier (circles), and median (thick line) values for total height (m) of western larch in Coram Experimental Forest, MT

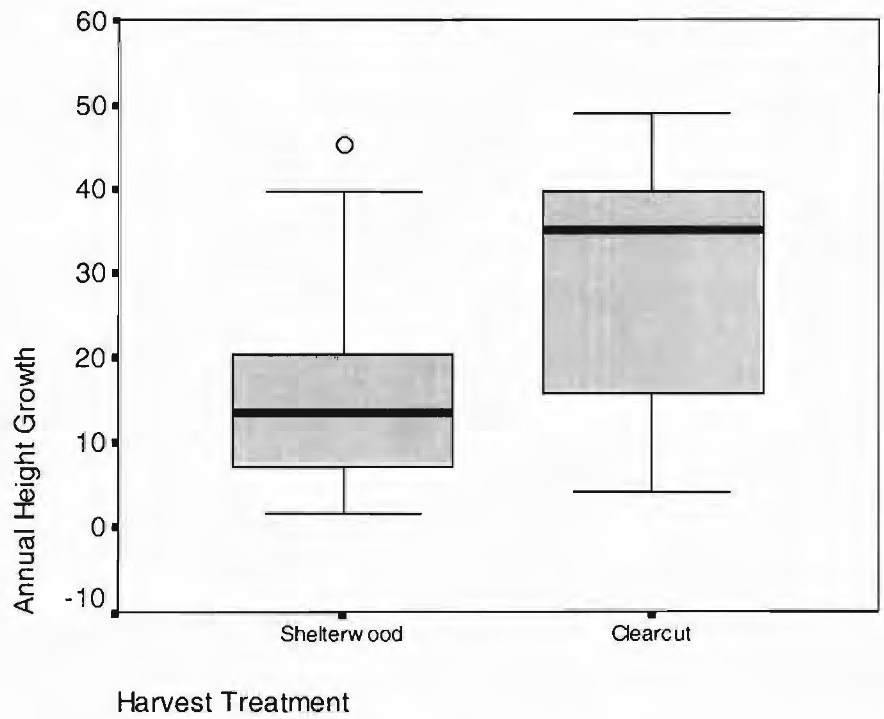

Figure 9: Boxplots displaying the range (whiskers), interquartile (box), outlier (circles), and median (wide line) values for annual height growth (cm) of western larch under different harvest regimes in Coram Experimental Forest, Montana.

Individual western larch were measured under a variety of overstory and understory vegetation levels. Relative to the clearcut plots, the range of overstory competition was broader for larch saplings sampled in the shelterwood. Except for one outlier value of trees per hectare in the clearcut, the ranges of both overstory indices were wider in the shelterwood than in the clearcut (Figure 10).The number of trees over 5.1 cm DBH averaged 461 per hectare in the shelterwood, compared to 770 per hectare in the clearcut. Mean SDI in the shelterwood was 494, in the clearcut it was 157 (Appendix 15).

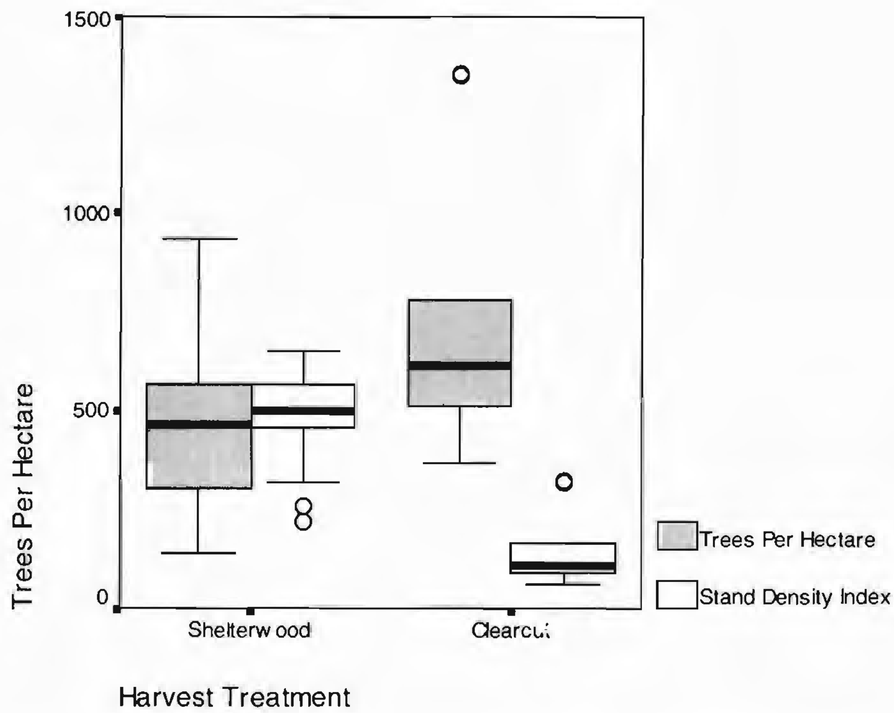

Figure 10: Boxplots displaying the range (whiskers), interquartile (box), outlier (circles), and median (wide line) values for overstory SDI and trees per hectare.

Woody competition measured as total understory percent cover was similar in the clearcut and shelterwood harvests, ranging from about 65% to 100% in both groups. Tall understory cover averaged 27% in the shelterwoods and 40% in the clearcuts. Canopy cover had a wider range of values in the shelterwood than in the clearcut, and averaged 37% in the shelterwoods compared to 6% in the clearcuts (Figure 11 and Appendix 15).

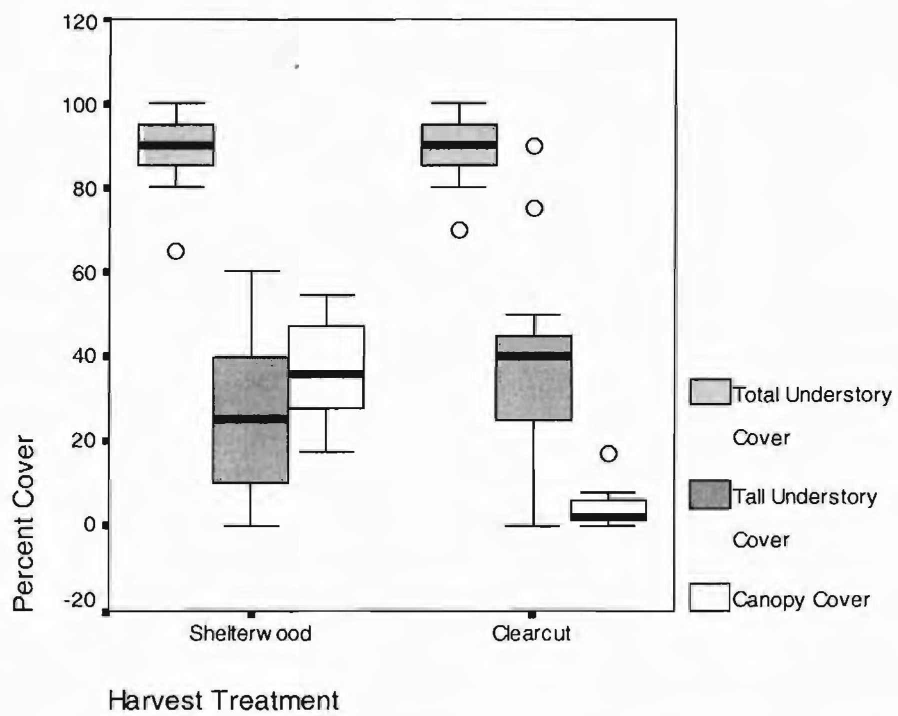

Figure 11: Boxplots displaying the range (whiskers), interquartile (box), outlier (circles), and median (wide line) values of canopy and understory cover.

This variation in overstory and understory competition levels was reflected in variation in the growth rates of larch saplings.

In the shelterwoods, there was a positive correlation of trees per hectare with the total height of western larch ($p < 0.10$; Appendix 16). We also identified positive correlations of tall understory cover with western larch DBH, crown length, and crown width ($p < 0.10$),. Canopy cover was negatively correlated with western larch height and annual height growth. There were no significant correlations between an individual western larch variable and an overstory or understory plot variable in the clearcut harvest (Appendix 17). The correlation between initial height and annual height growth was significant in both harvest treatments (Table 20).

Table 20: Correlations of annual height growth with initial height within the shelterwood and clearcut harvests.

Harvest	n	Pearson Correaltion	p-value
Clearcut	13	0.740	0.004
Shelterwood	30	0.681	0.000

Through regression analysis of all measured western larch within the shelterwood, we found that initial height was the only significant single predictor of height growth ($R^2 = 0.46$). Adding other variables slightly increased the fit of the model; a multiple regression model with initial height, stand density index, canopy cover, and total understory cover to predict height growth had the highest coefficient of determination ($R^2 = 0.51$). However, initial height was the only highly significant predictor variable in that model (Table 21).

Table 21: Linear model to predict annual height growth of western larch trees from initial tree height and canopy cover, stand density index, and total understory cover in the shelterwoods.

Variable	ß	Std. Error	p-value	95% Confidence Interval for ß	
				Lower Bound	Upper Bound
Constant	-2.4	24.6	0.922	-53.0	48.2
Initial Height	4.5	1.0	0.000	2.3	6.6
Canopy Cover	-0.1	0.1	0.446	-0.4	0.2
Stand Density Index	0.0	0.0	0.445	0.0	0.0
Total Understory Cover	0.2	0.2	0.510	-0.3	0.6

From single regression analysis of two separate size classes of western larch, we identified one significant predictor variable for annual height growth in each size class (Table 22). Tall understory cover was a significant predictor of height growth for trees that had an initial height of less than 2.5 m ($R^2 = 0.219$) (Figure 12). Stand density index was a significant predictor of annual height growth for trees that had an initial height of 2.5 to 5.0 m ($R^2 = 0.443$) (Figure 13).

Table 22: Single regressions to predict annual height growth of western larch trees in two size classes from overstory and understory measurements in the shelterwoods. A * indicates significance at the 0.10 level.

Predictor Variable	R^2 value	p-value
Initial Tree Height < 2.5 m		
Trees Per Acre	0.093	0.269
Stand Density Index	0.001	0.930
Canopy Cover	0.004	0.820
Total Understory Cover	0.048	0.434
Tall Understory Cover	0.219	0.078*
Initial Tree Height 2.5-5.0 m		
Trees Per Acre	0.060	0.443
Stand Density Index	0.443	0.018*
Canopy Cover	0.000	0.958
Total Understory Cover	0.048	0.494
Tall Understory Cover	0.014	0.718

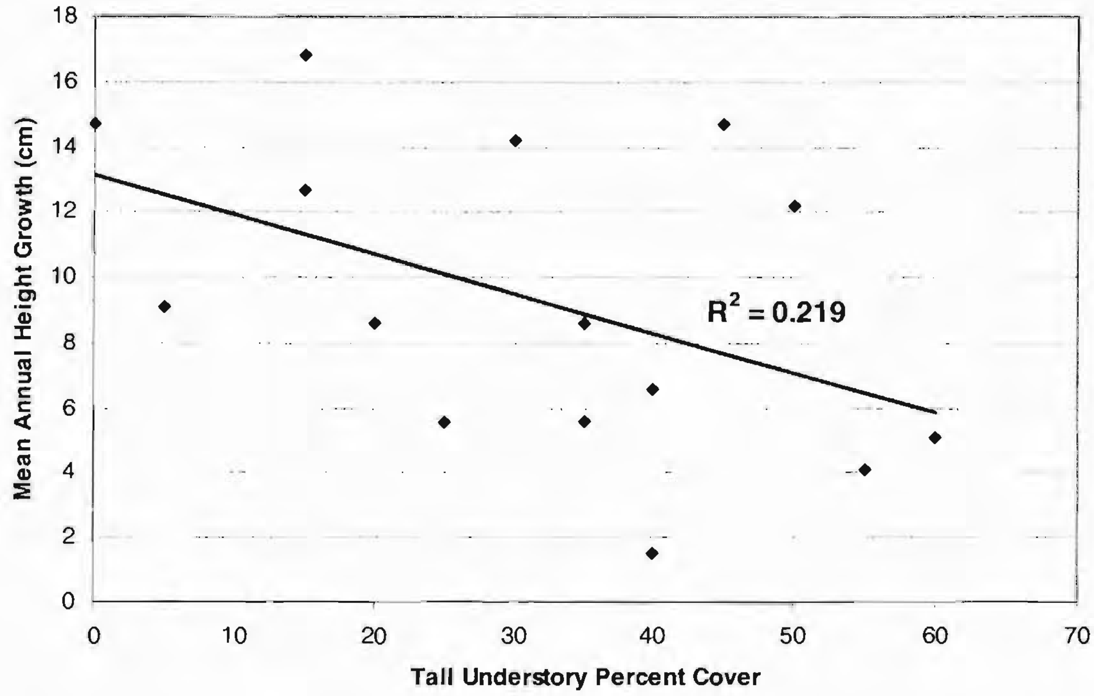

Figure 12: Scatterplot display of tall understory cover and annual height growth for western larch with initial heights less than 2.5 m.

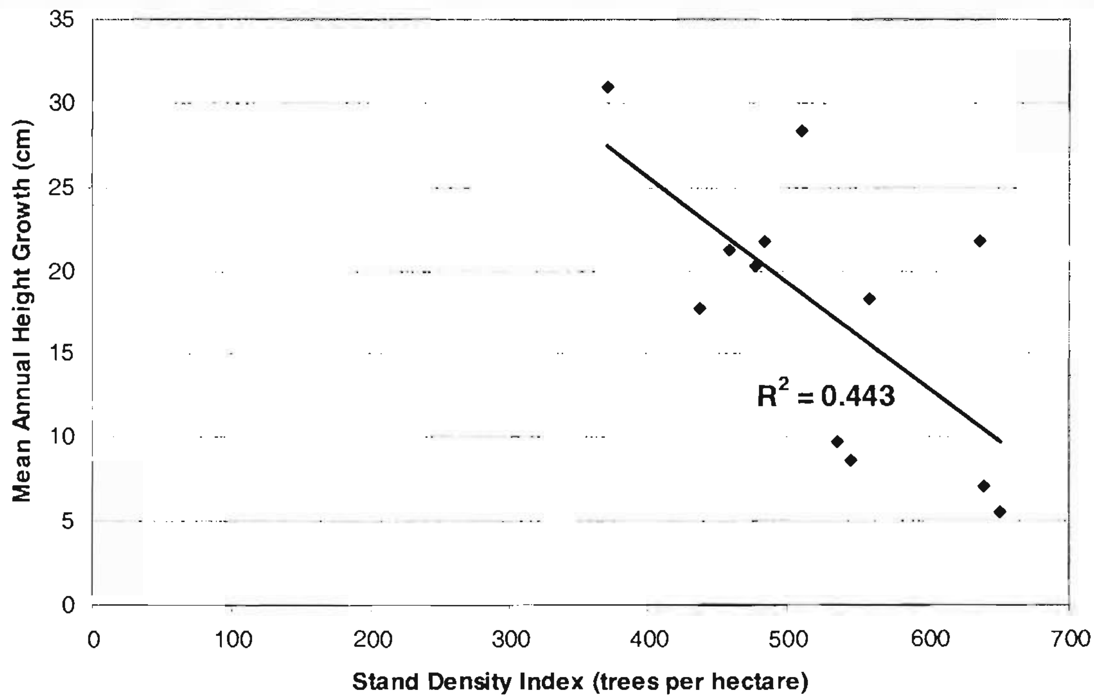

Figure 13: Scatterplot display of stand density index and annual height growth for western larch with initial heights of 2.5-5.0 m.

Discussion

The results of this study are consistent with previous work on western larch growth. In the clearcuts, western larch were taller and had greater growth rates than in the irregular shelterwood. Eighty percent of the western larch measured in the shelterwood were shorter in height than the average of western larch in the clearcut. In describing silvicultural systems for western larch forests, Schmidt et al. (1983) emphasize the importance of timely removal of a shelterwood overstory after larch have been established. This study confirms that after 25 years, larch trees under a residual overstory are growing at a slower rate than larch in a clearcut.

In both harvest treatments, the tallest trees had the greatest annual height growth. This relationship between tree height and growth is not surprising. Larger trees generally have more foliage, more expansive root systems, and greater capacity for photosynthesis, resulting in added growth.

The significant, positive correlation between tree density (trees > 5.1 cm DBH) per hectare and western larch height suggests that some sites within the shelterwood are favorable for both a greater number of trees and growth of those trees. Similarly, there were positive correlations of tall understory cover with western larch DBH, crown length, and crown width. These areas might have had dense vegetation, but there were adequate resources for the individual larch trees to thrive. A significant negative correlation of canopy cover with western larch height and annual growth in the shelterwood indicates that under a more closed canopy, tree growth is limited.

Within the shelterwood, overstory and understory characteristics around western larch trees differed substantially among the plots. Under this wide range of growing conditions, we found the size and recent growth of individual larch to also be quite variable. However, this studydid not find clear relationships between different levels of overstory and understory vegetation within aesthetic shelterwoods and larch sapling growth.

The single most important predictor variable for sapling height growth was initial sapling size. After stratifying the database into sapling size classes for additional regression analyses, some trends were identified between western larch growth and conditions within the shelterwood harvests. Tall understory cover was a significant predictor of height growth for trees that had an initial height of less than 2.5 m, while stand density index was a significant predictor of annual height growth for trees that had an initial height of 2.5 to 5.0 m.

Limitations of the study are primarily related to sampling design. Because we only measured larch that met a minimum height requirement, this study does not accurately describe all western larch in the stand. Comparisons between the clearcut and shelterwood harvests apply only to our data set; average values for all larch in the stands may be quite different. Additionally, as a case study, our results are not proven for other sites.

Tree growth is a function of multiple factors, and it is difficult to adequately describe the variation of growing conditions. Height growth patterns can vary even within trees of the same species in the same stand (Oliver and Larson, 1996). Although this study didn't identify a model capable of predicting height growth from a consistent set of overstory and understory vegetation measurements, future work could provide more insight to the response of larch to differing levels of competition. Most useful would be the analysis of an empirical data set such as the standing inventory of a western larch forest type over time. A larger number of observations might be able to capture variability of both the tree measurements and site characteristics.

To maximize tree growth, even aged management is appropriate for western larch. However, particularly where other management objectives preclude overstory removal, we should further examine the effects of overstory density level on larch regeneration and growth. Land managers should be aware of the decrease in growth of western larch under high levels of an overstory. However, it does appear that some larch saplings growing under heterogenous overstory conditions of a shelterwood have height growth rates comparable to those of the fastest growing saplings in clearcut stands. Further, it may be possible to achieve a larch component (>25% composition) in partial retention stands. Alternative methods, such as the continuous retention of low relative densities of large trees, should be explored for western larch.

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Appendix 1: Estimated volume of all conifers (standing and down >7.6 cm) before and after logging by harvest and residue treatment (Benson and Schlieter, 1980), Coram Experimental Forest, Montana.

Harvest Treatment	Residue Sub-plot	Replicate	Preharvest volume, m^3/ha	Postharvest volume, m^3/ha	Volume removed, m^3/ha
Shelterwood	1	1	480	269	211
Shelterwood	1	2	470	270	200
Shelterwood	2	1	348	257	91
Shelterwood	2	2	308	264	44
Shelterwood	3	1	410	193	217
Shelterwood	3	2	319	134	185
Shelterwood	4	1	369	255	114
Shelterwood	4	2	347	265	82
Group Selection	1	1	654	123	531
Group Selection	1	2	581	146	435
Group Selection	2	1	492	88	404
Group Selection	2	2	1042	184	858
Group Selection	3	1	577	42	535
Group Selection	3	2	530	93	437
Group Selection	4	1	694	92	602
Group Selection	4	2	715	84	631
Clearcut	1	1	570	121	449
Clearcut	1	2	617	170	447
Clearcut	2	1	469	167	302
Clearcut	2	2	563	247	316
Clearcut	3	1	414	66	348
Clearcut	3	2	387	140	247
Clearcut	4	1	484	71	413
Clearcut	4	2	450	168	282

Appendix 2: Mean density (trees per hectare) of total subsequent natural conifer regeneration in 2001 by harvest and residue treatments, Coram Experimental Forest, Montana.

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Western larch	926.25	123.5	988
	Douglas-fir	12658.75	8953.75	27540.5
	Subalpine fir	0	61.75	123.5
	Engelmann spruce	555.75	308.75	0
	Western hemlock	247	0	0
	Western white pine	0	0	123.5
	Western redcedar	61.75	61.75	0
	Lodgepole pine	0	0	123.5
Standard Utilization, Burned	Western larch	370.5	247	864.5
	Douglas-fir	7718.75	11053.25	8892
	Subalpine fir	370.5	247	494
	Engelmann spruce	370.5	0	123.5
	Western hemlock	432.25	0	123.5
	Western white pine	61.75	0	0
	Western redcedar	61.75	0	0
	Lodgepole pine	0	0	0
Intensive-fiber Utilization, Unburned	Western larch	0	123.5	988
	Douglas-fir	4322.5	4569.5	24638.25
	Subalpine fir	370.5	555.75	370.5
	Engelmann spruce	123.5	61.75	247
	Western hemlock	247	0	61.75
	Western white pine	0	0	0
	Western redcedar	0	0	494
	Lodgepole pine	0	0	0
Moderate Utilization, Unburned	Western larch	61.75	123.5	61.75
	Douglas-fir	1852.5	5557.5	4384.25
	Subalpine fir	494	247	617.5
	Engelmann spruce	802.8	185.3	185.3
	Western hemlock	247.0	61.8	247.0
	Western white pine	0.0	0.0	0.0
	Western redcedar	0.0	61.8	308.8
	Lodgepole pine	0.0	0.0	61.8

Appendix 3: Mean density (trees per hectare) of established subsequent natural conifer regeneration in 2001 by harvest and residue treatments, Coram Experimental Forest, Montana.

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Western larch	592.8	92.6	852.2
	Douglas-fir	9262.5	6724.6	13189.8
	Subalpine fir	18.5	148.2	222.3
	Engelmann spruce	407.6	333.5	0.0
	Western hemlock	546.5	26.0	0.0
	Western white pine	18.5	0.0	0.0
	Western redcedar	18.5	18.5	37.1
	Lodgepole pine	0.0	0.0	111.2
Standard Utilization, Burned	Western larch	222.3	129.7	926.3
	Douglas-fir	5353.7	7150.7	7558.2
	Subalpine fir	166.7	129.7	444.6
	Engelmann spruce	407.6	74.1	111.2
	Western hemlock	468.5	0.0	52.1
	Western white pine	0.0	37.1	0.0
	Western redcedar	18.5	0.0	37.1
	Lodgepole pine	0.0	0.0	37.1
Intensive-fiber Utilization, Unburned	Western larch	37.1	55.6	778.1
	Douglas-fir	2148.9	2297.1	13967.9
	Subalpine fir	240.8	240.8	518.7
	Engelmann spruce	37.1	55.6	92.6
	Western hemlock	208.2	52.1	78.1
	Western white pine	0.0	18.5	18.5
	Western redcedar	0.0	0.0	203.8
	Lodgepole pine	0.0	0.0	0.0
Moderate Utilization, Unburned	Western larch	18.5	55.6	18.5
	Douglas-fir	852.2	3075.2	1759.9
	Subalpine fir	389.0	185.3	426.1
	Engelmann spruce	314.9	37.1	37.1
	Western hemlock	364.4	52.1	156.2
	Western white pine	0.0	37.1	0.0
	Western redcedar	0.0	18.5	111.2
	Lodgepole pine	0.0	0.0	18.5

Appendix 4: Mean percent stocking of established subsequent natural conifer regeneration in 2001 by harvest and residue treatments, Coram Experimental Forest, Montana.

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Western larch	45	13	30
	Douglas-fir	95	90	100
	Subalpine fir	3	15	15
	Engelmann spruce	35	40	0
	Western hemlock	28	3	0
	Western white pine	3	0	0
	Western redcedar	3	3	5
	Lodgepole pine	0	0	10
Standard Utilization, Burned	Western larch	25	13	55
	Douglas-fir	98	88	85
	Subalpine fir	15	15	45
	Engelmann spruce	38	10	10
	Western hemlock	28	3	5
	Western white pine	0	5	0
	Western redcedar	3	0	5
	Lodgepole pine	0	0	5
Intensive-fiber Utilization, Unburned	Western larch	5	8	45
	Douglas-fir	73	60	90
	Subalpine fir	18	15	23
	Engelmann spruce	5	5	10
	Western hemlock	10	3	8
	Western white pine	0	3	3
	Western redcedar	0	0	15
	Lodgepole pine	0	0	0
Moderate Utilization, Unburned	Western larch	3	8	3
	Douglas-fir	50	60	43
	Subalpine fir	23	15	28
	Engelmann spruce	18	3	5
	Western hemlock	15	5	13
	Western white pine	0	5	0
	Western redcedar	0	3	13

Appendix 5: Average tallest heights (m) of established subsequent natural conifer regeneration in 2001 by harvest and residue treatments. Dashes indicate no trees of that species were found. Coram Experimental Forest, Montana.

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Unburned	Western larch	4.9	2.8	2.7
	Douglas-fir	3.7	2.5	1.2
	Subalpine fir	0.9	1.0	0.8
	Engelmann spruce	1.5	1.1	-
	Western hemlock	1.5	1.7	-
	Western white pine	1.0	-	-
	Western redcedar	0.2	0.6	0.4
	Lodgepole pine	-	-	2.2
Standard Utilization, Burned	Western larch	2.1	4.0	2.7
	Douglas-fir	3.3	3.4	1.5
	Subalpine fir	1.5	0.8	1.4
	Engelmann spruce	1.3	1.5	0.8
	Western hemlock	2.1	-	1.8
	Western white pine	-	4.4	-
	Western redcedar	0.2	-	0.5
	Lodgepole pine	-	-	0.7
Intensive-fiber Utilization, Unburned	Western larch	1.7	2.6	2.1
	Douglas-fir	2.2	1.6	1.5
	Subalpine fir	2.6	1.8	1.4
	Engelmann spruce	0.2	0.6	1.2
	Western hemlock	2.8	1.0	2.4
	Western white pine	-	2.6	2.6
	Western redcedar	-	-	0.8
	Lodgepole pine	-	-	-
Moderate Utilization, Unburned	Western larch	8.5	5.7	0.5
	Douglas-fir	1.8	1.6	1.0
	Subalpine fir	3.8	2.1	1.0
	Engelmann spruce	3.0	0.4	1.6
	Western hemlock	1.6	1.2	1.5
	Western white pine	-	1.3	-
	Western redcedar	-	0.6	0.4
	Lodgepole pine	-	-	0.4

Appendix 6: Summary of p-values from split plot analysis of all residue treatments within the clearcut and group selection harvests. Dashes indicate no calculated value, due to one or more empty cells of factor combinations in the model. Coram Experimental Forest, Montana.

	Source of Variation	df	Western larch	Douglas-fir	Engelmann spruce	Subalpine fir
Total	Harvest	1	0.295	0.762	0.090	-
Regeneration	Residue	3	0.055	0.146	0.731	0.327
Density	HxR	3	0.057	0.526	0.912	0.726
Established	Harvest	1	0.304	0.752	0.421	0.375
Regeneration	Residue	3	0.08	0.051	0.324	0.599
Density	HxR	3	0.111	0.444	0.622	0.758
Established	Harvest	1	0.278	0.686	0.540	0.910
Regeneration	Residue	3	0.094	0.000	0.177	0.824
Stocking	HxR	3	0.174	0.021	0.555	0.824
Mean Tallest Tree Heights	Harvest	1	-	0.144	-	-
	Residue	3	-	0.036	-	-
	HxR	3	-	0.405	-	-

Appendix 7: Summary of p-values from split plot analysis of the unburned residue treatments within the clearcut, group selection, and shelterwood harvests. Dashes indicate no calculated value, due to one or more empty cells of factor combinations in the model. Coram Experimental Forest, Montana.

	Source of Variation	df	Western larch	Douglas-fir	Engelmann spruce	Subalpine fir
Total	Harvest	2	0.38	0.240	0.567	0.650
Regeneration	Residue	1	0.486	0.148	0.900	0.927
Density	HxR	2	0.531	0.186	0.434	0.581
Established	Harvest	2	0.446	0.179	0.085	0.528
Regeneration	Residue	1	0.369	0.172	0.032	1.000
Density	HxR	2	0.448	0.203	0.014	0.798
Established	Harvest	2	0.35	0.761	0.206	0.520
Regeneration	Residue	1	0.287	0.026	0.368	0.737
Stocking	HxR	2	0.365	0.072	0.065	0.964
Mean Tallest Tree Heights	Harvest	2	-	0.127	-	0.443
	Residue	1	-	0.420	-	0.496
	HxR	2	-	0.803	-	0.651

Appendix 8: Within subject contrasts between mean values of established Douglas-fir density in residue treatments of the clearcut and group selection harvests. Coram Experimental Forest, Montana.

(I) Treatment	(J) Treatment	Mean Square	F	Significance
Moderate Utilization, Burned	Standard Utilization, Burned	12129199.290	0.624	0.574
Moderate Utilization, Burned	Intensive-fiber Utilization, Unburned	133198143.323	38.048	0.102
Moderate Utilization, Burned	Moderate Utilization, Unburned	145438776.040	10.702	0.189
Standard Utilization, Burned	Intensive-fiber Utilization, Unburned	64938616.403	10.082	0.194
Standard Utilization, Burned	Moderate Utilization, Unburned	73566644.410	140.931	0.053
Intensive-fiber Utilization, Unburned	Moderate Utilization, Unburned	268997.823	0.082	0.823

Appendix 9: Within subject contrasts between mean values of established Douglas-fir stocking in residue treatments of the clearcut and group selection harvests. Dashes indicate no calculated value, due to one or more empty cells of factor combinations in the model. Coram Experimental Forest, Montana.

(I) Treatment	(J) Treatment	Mean Square	F	Significance
Moderate Utilization, Burned	Standard Utilization, Burned	0	0	1.000
Moderate Utilization, Burned	Intensive-fiber Utilization, Unburned	2756.25	441	0.030
Moderate Utilization, Burned	Moderate Utilization, Unburned	5625	225	0.042
Standard Utilization, Burned	Intensive-fiber Utilization, Unburned	2756.25	441	0.030*
Standard Utilization, Burned	Moderate Utilization, Unburned	5625	-	-
Intensive-fiber Utilization, Unburned	Moderate Utilization, Unburned	506.25	81	0.070*

* contrasts were significantly affected by an interaction of harvest and residue treatments.

Appendix 10: Within subject contrasts between mean tallest Douglas-fir heights in residue treatments of the clearcut and group selection harvests. Coram Experimental Forest, Montana.

(I) Treatment	(J) Treatment	Mean Square	F	Significance
Moderate Utilization, Burned	Standard Utilization, Burned	2.250	56.250	0.084*
Moderate Utilization, Burned	Intensive-fiber Utilization, Unburned	60.063	106.778	0.061
Moderate Utilization, Burned	Moderate Utilization, Unburned	81.903	7.298	0.226
Standard Utilization, Burned	Intensive-fiber Utilization, Unburned	85.563	282.851	0.038
Standard Utilization, Burned	Moderate Utilization, Unburned	111.303	11.217	0.185
Intensive-fiber Utilization, Unburned	Moderate Utilization, Unburned	1.690	0.250	0.705

* contrasts were significantly affected by an interaction of harvest and residue treatments.

Appendix 11: Between subject contrasts for measurements between Douglas-fir and western larch tagged trees with associated tests and 95% confidence intervals for the differences. Coram Experimental Forest, Montana, 2001.

Variable	Contrast Estimate	Significance	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
Survival (%)	-9.733	0.008	-3.789	-15.678
DBH (cm)	3.216	0.005	4.966	1.466
Total height (m)	2.877	0.001	3.923	1.831
Crown length (m)	2.069	0.002	2.992	1.145
Crown width A (m)	0.311	0.053	0.627	-0.005
Crown width B (m)	0.234	0.132	0.568	-0.101
Crown width height (m)	1.509	0.000	1.892	1.126
DBH growth 1994-2001 (cm)	0.055	0.887	1.005	-0.894
Height growth 1994-2001 (m)	0.003	0.986	0.440	-0.434

Appendix 12: Between subject contrasts among harvest treatments for measurements of tagged trees (western larch and Douglas-fir combined) with associated tests and 95% confidence intervals for the differences.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Significance	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
Survival (%)					
Shelterwood	Group selection	-4.0	0.524	-13.939	5.989
Shelterwood	Clearcut	8.5	0.087	-1.464	18.464
Group selection	Clearcut	12.5	0.021	2.511	22.439
Total height (m)					
Shelterwood	Group selection	-0.5	0.748	-2.246	1.260
Shelterwood	Clearcut	-1.9	0.033	-3.703	-0.196
Group selection	Clearcut	-1.5	0.095	-3.210	0.297
DBH (cm)					
Shelterwood	Group selection	-1.2	0.525	-4.103	1.765
Shelterwood	Clearcut	-3.8	0.017	-6.772	-0.904
Group selection	Clearcut	-2.7	0.070	-5.603	0.265
Height growth (m)					
Shelterwood	Group selection	-0.8	0.046	-1.483	-0.018
Shelterwood	Clearcut	-1.2	0.006	-1.943	-0.478
Group selection	Clearcut	-0.5	0.217	-1.192	0.273
DBH growth (cm)					
Shelterwood	Group selection	-0.9	0.252	-2.531	0.651
Shelterwood	Clearcut	-2.5	0.009	-4.051	-0.869
Group selection	Clearcut	-1.5	0.059	-3.111	0.071

Based on observed means.

Adjustment for multiple comparisons: Sidak

Appendix 13: Mean values of 2001 planted tree measurements. Coram Experimental Forest, Montana.

Table 1: Average total heights (m) of planted Douglas-fir and Engelmann spruce by harvest and residue treatments

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Douglas-fir	5.7	5.4	4.0
	Engelmann spruce	3.9	3.6	3.2
Standard Utilization, Burned	Douglas-fir	6.0	6.1	2.7
	Engelmann spruce	4.2	4.2	2.8
Intensive-fiber Utilization, Unburned	Douglas-fir	4.7	4.5	2.2
	Engelmann spruce	2.8	2.8	2.5

Table 2: Average terminal leader length (cm) of planted Douglas-fir and Engelmann spruce by harvest and residue treatments

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Douglas-fir	28.6	25.1	19.8
	Engelmann spruce	25.9	21.3	18.3
Standard Utilization, Burned	Douglas-fir	25.9	28.6	13.0
	Engelmann spruce	27.1	25.9	15.2
Intensive-fiber Utilization, Unburned	Douglas-fir	25.9	22.9	9.1
	Engelmann spruce	15.6	17.5	14.1

Appendix 13, continued:

Table 3: Average DBHs (cm) of planted Douglas-fir and Engelmann spruce by harvest and residue treatments

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Douglas-fir	7.7	7.2	4.4
	Engelmann spruce	5.2	4.5	4.2
Standard Utilization, Burned	Douglas-fir	8.2	8.3	2.5
	Engelmann spruce	5.8	6.1	3.4
Intensive-fiber Utilization, Unburned	Douglas-fir	5.7	5.4	1.7
	Engelmann spruce	3.0	3.2	2.6

Table 4: Average crown lengths (m) of planted Douglas-fir and Engelmann spruce by harvest and residue treatments

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Douglas-fir	4.8	4.5	3.3
	Engelmann spruce	3.3	2.9	2.6
Standard Utilization, Burned	Douglas-fir	5.1	5.1	2.0
	Engelmann spruce	3.5	3.5	2.2
Intensive-fiber Utilization, Unburned	Douglas-fir	4.0	3.7	1.5
	Engelmann spruce	2.3	2.2	2.0

Appendix 13, continued:

Table 5: Average crown widths (m) of planted Douglas-fir and Engelmann spruce by harvest and residue treatments

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Douglas-fir	2.5	2.4	1.9
	Engelmann spruce	1.9	1.8	2.0
Standard Utilization, Burned	Douglas-fir	2.6	2.7	1.4
	Engelmann spruce	2.0	2.1	1.8
Intensive-fiber Utilization, Unburned	Douglas-fir	2.1	2.0	1.2
	Engelmann spruce	1.4	1.6	1.5

Table 6: Average percent survival of Douglas-fir and Engelmann spruce by harvest and residue treatments

	Species	Clearcut	Group Selection	Shelterwood
Moderate Utilization, Burned	Douglas-fir	81	75	79
	Engelmann spruce	68	47	63
Standard Utilization, Burned	Douglas-fir	86	78	68
	Engelmann spruce	74	59	60
Intensive-fiber Utilization, Unburned	Douglas-fir	66	63	68
	Engelmann spruce	54	53	73

Appendix 14: Comparisons of planted and tallest natural regeneration. 2001, Coram Experimental Forest, Montana.

Table 1: Comparison of mean total height (m) of planted and tallest natural Douglas-fir in 2001 by harvest method, residue treatment, and year of planting. A (*) following a value indicates a significant difference between natural and planted trees ($p<0.05$)

Harvest	Residue treatment	Natural	Planted 1976	Planted 1977	Planted 1978	Planted 1979
Shelterwood (Lower)	Moderate Util., Unburned	1.8	3.4*	3.2*	3.0*	2.3
	Standard Util., Unburned	1.9	4.0*	4.1*	3.8*	2.1
	Intensive-fiber Util., Unburned	1.9	2.4	2.4	2.0	2.3
Shelterwood (Upper)	Moderate Util., Burned	1.2	4.5*	4.6*	3.7*	3.1*
	Standard Util., Burned	1.4	3.3*	2.7*	2.9*	1.9
	Intensive-fiber Util., Unburned	1.7	2.3	2.0	2.2	1.9
Group Selection (Lower)	Moderate Util., Burned	3.0	7.0*	6.1*	6.2*	5.3*
	Standard Util., Burned	3.8	7.1*	6.7*	6.3*	5.6*
	Intensive-fiber Util., Unburned	2.0	5.4*	6.0*	5.4*	4.8*
Group Selection (Upper)	Moderate Util., Burned	2.0	5.0*	5.2*	4.5*	4.5*
	Standard Util., Burned	2.9	6.1*	6.1*	5.5*	5.6*
	Intensive-fiber Util., Unburned	1.2	4.1*	4.0*	3.9*	3.2*
Clearcut (Lower)	Moderate Util., Burned	3.8	7.5*	7.0*	6.3*	5.3*
	Standard Util., Burned	3.3	7.1*	7.0*	5.9*	5.9*
	Intensive-fiber Util., Unburned	2.4	7.2*	6.9*	6.3*	5.1*
Clearcut (Upper)	Moderate Util., Burned	3.6	5.2*	4.8*	5.6*	4.3
	Standard Util., Burned	3.2	6.5*	5.9*	4.8*	4.9*
	Intensive-fiber Util., Unburned	2.0	3.1*	3.2*	3.5*	2.3

Appendix 14, continued:

Table 2: Comparison of mean DBH (cm) of planted and tallest natural Douglas-fir in 2001 by harvest method, residue treatment, and year of planting. A (*) following a value indicates a significant difference between natural and planted trees (p<0.05).

Harvest	Residue treatment	Natural	Planted 1976	Planted 1977	Planted 1978	Planted 1979
Shelterwood (Lower)	Moderate Util., Unburned	1.4	3.6*	2.9*	2.8	1.9
	Standard Util., Unburned	1.9	4.0*	4.1*	3.8*	1.5
	Intensive-fiber Util., Unburned	1.3	2.0	1.9	1.4	2.0
Shelterwood (Upper)	Moderate Util., Burned	1.9	5.4*	5.2*	3.6*	3.5
	Standard Util., Burned	1.2	3.4*	2.2	3.3*	1.2
	Intensive-fiber Util., Unburned	2.1	2.1	1.3	2.2	0.9
Group Selection (Lower)	Moderate Util., Burned	4.1	10.0	8.0	8.4	6.7
	Standard Util., Burned	4.8	10.6*	8.5*	7.8*	6.9*
	Intensive-fiber Util., Unburned	2.7	7.5*	7.4*	6.4*	5.9*
Group Selection (Upper)	Moderate Util., Burned	2.5	6.9*	6.7*	5.7*	5.4*
	Standard Util., Burned	4.6	8.6*	8.9*	7.6*	8.1*
	Intensive-fiber Util., Unburned	5.7	4.8	4.8	4.6	3.2
Clearcut (Lower)	Moderate Util., Burned	3.9	10.5*	10.0*	8.2*	6.3*
	Standard Util., Burned	4.1	10.3*	9.0*	6.5*	7.1*
	Intensive-fiber Util., Unburned	2.4	11.2*	8.5*	7.7*	5.3*
Clearcut (Upper)	Moderate Util., Burned	4.7	7.5*	6.7*	8.2*	5.8
	Standard Util., Burned	4.4	10.2*	9.0*	6.2*	7.2*
	Intensive-fiber Util., Unburned	3.2	3.7	3.3	4.2	1.9

Appendix 14, continued:

Table 3: Comparison of mean total height (m) of planted and tallest natural Engelmann spruce in 2001 by harvest method, residue treatment, and year of planting. A (*) following a value indicates a significant difference between natural and planted trees (p<0.05). Dashes indicate no data for that measurement.

Harvest	Residue treatment	Natural	Planted 1976	Planted 1977	Planted 1978	Planted 1979
Shelterwood (Lower)	Moderate Util., Unburned	0.8	3.0*	2.6*	2.7*	1.8*
	Standard Util., Unburned	0.9	3.3*	3.1*	2.6*	1.7
	Intensive-fiber Util., Unburned	1.0	2.9*	2.2	2.5*	2.4*
Shelterwood (Upper)	Moderate Util., Burned	-	4.4	2.9	2.6	2.8
	Standard Util., Burned	0.8	3.4*	2.8	2.7*	2.3
	Intensive-fiber Util., Unburned	1.4	3.2	2.5	3.1*	1.2
Group Selection (Lower)	Moderate Util., Burned	1.3	4.7*	4.4*	3.6*	2.3
	Standard Util., Burned	1.3	5.1*	3.8*	4.6*	3.5*
	Intensive-fiber Util., Unburned	0.6	4.2*	3.1*	3.9*	2.9
Group Selection (Upper)	Moderate Util., Burned	0.9	3.6*	3.7*	3.6*	3.8*
	Standard Util., Burned	1.8	4.8*	4.0	3.7	3.8*
	Intensive-fiber Util., Unburned	-	2.6	2.0	2.2	1.7
Clearcut (Lower)	Moderate Util., Burned	1.9	5.0*	4.5*	4.5*	3.8*
	Standard Util., Burned	1.6	4.8*	3.9*	4.3*	4.6*
	Intensive-fiber Util., Unburned	0.2	5.3*	2.6	3.6	2.7
Clearcut (Upper)	Moderate Util., Burned	-	3.7	3.2	3.0	3.0
	Standard Util., Burned	1.1	4.9*	4.0*	3.8*	3.6*
	Intensive-fiber Util., Unburned	-	2.9	2.0	2.2	1.1

Appendix 14, continued:

Table 4: Comparison of mean DBH (cm) of planted and tallest natural Engelmann spruce in 2001 by harvest method, residue treatment, and year of planting. A (*) following a value indicates a significant difference between natural and planted trees (p<0.05). Dashes indicate no data for that measurement.

Harvest	Residue treatment	Natural	Planted 1976	Planted 1977	Planted 1978	Planted 1979
Shelterwood (Lower)	Moderate Util., Unburned	-	3.9	2.8	2.6	1.3
	Standard Util., Unburned	0.8	3.9	3.7	2.5	1.3
	Intensive-fiber Util., Unburned	0.5	3.7	2.1	2.6	2.1
Shelterwood (Upper)	Moderate Util., Burned	-	6.3	3.9	2.8	3.8
	Standard Util., Burned	-	4.3	3.0	3.5	2.6
	Intensive-fiber Util., Unburned	0.5	4.0	2.6	3.9*	-
Group Selection (Lower)	Moderate Util., Burned	1.8	6.9*	6.0*	5.1	1.0
	Standard Util., Burned	0.5	6.6*	4.3*	6.1*	4.5*
	Intensive-fiber Util., Unburned	-	6.0	3.4	5.1	3.4
Group Selection (Upper)	Moderate Util., Burned	2.7	4.7	5.1*	4.4*	5.3*
	Standard Util., Burned	1.0	6.8*	5.3	4.7	5.3*
	Intensive-fiber Util., Unburned	-	2.5	1.8	2.0	1.1
Clearcut (Lower)	Moderate Util., Burned	2.9	6.9*	6.2*	6.1*	4.5*
	Standard Util., Burned	3.0	6.5*	4.7	5.5	6.5*
	Intensive-fiber Util., Unburned	-	6.9	2.9	4.3	2.9
Clearcut (Upper)	Moderate Util., Burned	-	5.7	3.9	3.8	3.7
	Standard Util., Burned	2.5	6.8*	5.5	5.0	5.1
	Intensive-fiber Util., Unburned	-	3.4	1.6	2.0	0.2

Appendix 15: Mean values of plot and tree characteristics measured in 2001 on shelterwood and clearcut harvests. Coram Experimental Forest, Montana.

	Shelterwood (n=43)			
	Mean	**Std. Error**	**Minimum**	**Maximum**
Overstory and Understory Plot Variables:				
Trees Per Hectare	461	33	137	935
Stand Density Index	494	20	217	651
Canopy % Cover	37	2	18	54
Total Understory % Cover	90	1	65	100
Tall Understory % Cover	27	3	0	60
Western Larch Sapling Variables:				
Total Height (m)	3.2	0.3	1.4	8.2
Annual Height Growth (cm)	15.2	1.9	1.5	45.2
Diameter at Breast Height (cm)	2.6	0.3	0.3	7.4
Crown Length (m)	2.5	0.3	0.8	5.9
Crown Width (m)	1.2	0.1	0.7	3.0

	Clearcut (n=13)			
	Mean	**Std. Error**	**Minimum**	**Maximum**
Overstory and Understory Plot Variables:				
Trees Per Hectare	770	114	370	1644
Stand Density Index	157	33	62	429
Canopy % Cover	6	3	0	39
Total Understory % Cover	89	2	70	100
Tall Understory % Cover	40	7	0	90
Western Larch Sapling Variables:				
Total Height (m)	4.8	0.7	1.4	9.1
Annual Height Growth (cm)	29.6	4.1	4.1	48.8
Diameter at Breast Height (cm)	4.8	0.8	1.3	9.9
Crown Length (m)	4.0	0.5	1.2	6.6
Crown Width (m)	1.6	0.2	0.8	2.7

Appendix 16: Pearson's correlations between measured western larch tree and plot variables in the shelterwood harvest treatment, 2001, Coram Experimental Forest, Montana.

		Total height	Initial height	Annual height growth	DBH	Crown length	Crown width	Total understory Cover	Tall understory Cover	Trees per hectare	Stand density index	Canopy cover
Total height	Pearson Correlation	1.000	0.998*	0.730*	0.150	0.171	-0.018	0.077	-0.277	0.374*	0.097	-0.331*
	Sig. (2-tailed)	.	0.000	0.000	0.428	0.368	0.923	0.685	0.138	0.042	0.611	0.074
	N	30	30	30	30	30	30	30	30	30	30	30
Initial height	Pearson Correlation	0.998*	1.000	0.681*	0.131	0.147	-0.034	0.064	-0.273	0.379*	0.113	-0.321*
	Sig. (2-tailed)	0.000	.	0.000	0.491	0.439	0.856	0.737	0.145	0.039	0.553	0.084
	N	30	30	30	30	30	30	30	30	30	30	30
Annual height growth	Pearson Correlation	0.730*	0.681*	1.000	0.296	0.351*	0.142	0.183	-0.238	0.216	-0.088	-0.326*
	Sig. (2-tailed)	0.000	0.000	.	0.113	0.057	0.453	0.334	0.205	0.252	0.642	0.078
	N	30	30	30	30	30	30	30	30	30	30	30
DBH	Pearson Correlation	0.150	0.131	0.296	1.000	0.972*	0.852*	0.011	0.350*	0.290	-0.128	0.260
	Sig. (2-tailed)	0.428	0.491	0.113	.	0.000	0.000	0.953	0.058	0.120	0.501	0.165
	N	30	30	30	30	30	30	30	30	30	30	30
Crown length	Pearson Correlation	0.171	0.147	0.351*	0.972*	1.000	0.816*	-0.010	0.320	0.196	-0.110	0.272
	Sig. (2-tailed)	0.368	0.439	0.057	0.000	.	0.000	0.958	0.084	0.300	0.563	0.146
	N	30	30	30	30	30	30	30	30	30	30	30
Crown width	Pearson Correlation	-0.018	-0.034	0.142	0.852*	0.816*	1.000	0.003	0.318	0.121	-0.165	0.303
	Sig. (2-tailed)	0.923	0.856	0.453	0.000	0.000	.	0.989	0.087	0.524	0.383	0.103
	N	30	30	30	30	30	30	30	30	30	30	30
Total understory cover	Pearson Correlation	0.077	0.064	0.183	0.011	-0.010	0.003	1.000	-0.019	-0.212	-0.366*	0.035
	Sig. (2-tailed)	0.685	0.737	0.334	0.953	0.958	0.989	.	0.921	0.261	0.047	0.853
	N	30	30	30	30	30	30	30	30	30	30	30
Tall understory cover	Pearson Correlation	-0.277	-0.273	-0.238	0.350*	0.320*	0.318*	-0.019	1.000	0.021	-0.019	0.239
	Sig. (2-tailed)	0.138	0.145	0.205	0.058	0.084	0.087	0.921	.	0.910	0.921	0.203
	N	30	30	30	30	30	30	30	30	30	30	30
Trees per hectare	Pearson Correlation	0.374*	0.379*	0.216	0.290	0.196	0.121	-0.212	0.021	1.000	0.354*	-0.230
	Sig. (2-tailed)	0.042	0.039	0.252	0.120	0.300	0.524	0.261	0.910	.	0.055	0.222
	N	30	30	30	30	30	30	30	30	30	30	30
Stand density index	Pearson Correlation	0.097	0.113	-0.088	-0.128	-0.110	-0.165	-.366*	-0.019	0.354*	1.000	0.047
	Sig. (2-tailed)	0.611	0.553	0.642	0.501	0.563	0.383	0.047	0.921	0.055	.	0.803
	N	30	30	30	30	30	30	30	30	30	30	30
Canopy cover	Pearson Correlation	-0.331*	-0.321*	-0.326*	0.260	0.272	0.303	0.035	0.239	-0.230	0.047	1.000
	Sig. (2-tailed)	0.074	0.084	0.078	0.165	0.146	0.103	0.853	0.203	0.222	0.803	.
	N	30	30	30	30	30	30	30	30	30	30	30

* Correlation is significant at the 0.10 level (2-tailed).

Appendix 17: Pearson's correlations between measured western larch tree and plot variables in the clearcut harvest treatment, 2001, Coram Experimental Forest, Montana.

		Total height	Initial height	Annual height growth	DBH	Crown length	Crown width	Total understory Cover	Tall understory Cover	Trees per hectare	Stand density index	Canopy cover
Total height	Pearson Correlation	1.000	0.998*	0.781*	0.400	0.510*	0.280	-0.301	0.090	-0.052	0.169	0.349
	Sig. (2-tailed)	.	0.000	0.002	0.175	0.075	0.354	0.318	0.771	0.866	0.580	0.243
	N	13	13	13	13	13	13	13	13	13	13	13
Initial height	Pearson Correlation	0.998*	1.000	0.740*	0.374	0.482*	0.252	-0.301	0.071	-0.032	0.191	0.373
	Sig. (2-tailed)	0.000	.	0.004	0.208	0.095	0.406	0.318	0.817	0.917	0.532	0.210
	N	13	13	13	13	13	13	13	13	13	13	13
Annual height growth	Pearson Correlation	0.781*	0.740*	1.000	0.560*	0.666*	0.485*	-0.233	0.248	-0.235	-0.084	0.031
	Sig. (2-tailed)	0.002	0.004	.	0.046	0.013	0.093	0.443	0.413	0.440	0.786	0.921
	N	13	13	13	13	13	13	13	13	13	13	13
DBH	Pearson Correlation	0.400	0.374	0.560*	1.000	0.954*	0.959*	-0.275	0.035	0.035	0.187	0.304
	Sig. (2-tailed)	0.175	0.208	0.046	.	0.000	0.000	0.363	0.910	0.910	0.542	0.312
	N	13	13	13	13	13	13	13	13	13	13	13
Crown length	Pearson Correlation	0.510*	0.482*	0.666*	0.954*	1.000	0.939*	-0.326	0.054	0.018	0.220	0.382
	Sig. (2-tailed)	0.075	0.095	0.013	0.000	.	0.000	0.277	0.861	0.953	0.471	0.198
	N	13	13	13	13	13	13	13	13	13	13	13
Crown width	Pearson Correlation	0.280	0.252	0.485*	0.959*	0.939*	1.000	-0.256	0.041	0.175	0.298	0.347
	Sig. (2-tailed)	0.354	0.406	0.093	0.000	0.000	.	0.398	0.895	0.567	0.324	0.245
	N	13	13	13	13	13	13	13	13	13	13	13
Total understory cover	Pearson Correlation	-0.301	-0.301	-0.233	-0.275	-0.326	-0.256	1.000	0.199	-0.223	-0.422	-0.494
	Sig. (2-tailed)	0.318	0.318	0.443	0.363	0.277	0.398	.	0.514	0.464	0.151	0.086
	N	13	13	13	13	13	13	13	13	13	13	13
Tall understory cover	Pearson Correlation	0.090	0.071	0.248	0.035	0.054	0.041	0.199	1.000	-0.444	-0.491	-0.380
	Sig. (2-tailed)	0.771	0.817	0.413	0.910	0.861	0.895	0.514	.	0.129	0.088	0.200
	N	13	13	13	13	13	13	13	13	13	13	13
Trees per hectare	Pearson Correlation	-0.052	-0.032	-0.235	0.035	0.018	0.175	-0.223	-0.444	1.000	0.934*	0.694*
	Sig. (2-tailed)	0.866	0.917	0.440	0.910	0.953	0.567	0.464	0.129	.	0.000	0.009
	N	13	13	13	13	13	13	13	13	13	13	13
Stand density index	Pearson Correlation	0.169	0.191	-0.084	0.187	0.220	0.298	-0.422	-0.491	0.934*	1.000	0.883*
	Sig. (2-tailed)	0.580	0.532	0.786	0.542	0.471	0.324	0.151	0.088	0.000	.	0.000
	N	13	13	13	13	13	13	13	13	13	13	13
Canopy cover	Pearson Correlation	0.349	0.373	0.031	0.304	0.382	0.347	-0.494	-0.380	0.694*	0.883*	1.000
	Sig. (2-tailed)	0.243	0.210	0.921	0.312	0.198	0.245	0.086	0.200	0.009	0.000	.
	N	13	13	13	13	13	13	13	13	13	13	13

* Correlation is significant at the 0.10 level (2-tailed).