AN ABSTRACT OF THE THESIS OF

Louis W. Beer for the degree of Master of Science in Forest Resources presented on June 3, 1998. Title: Distribution and Growth of Advance Douglas-Fir Regeneration in Commercially Thinned Stands in the Oregon Coast Range.

Abstract approved: ____

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This study examined the abundance, size, growth, and age of advance regeneration Douglas-fir, beneath an eighty year-old overstory at a single site on plots subjected to different overstory thinning treatments. Treatments consisted of keeping overstory basal area within upper and lower limits for periods of 12-17 years which, depending upon the replication, ended 17-24 years prior to this study. Of the three thinning levels, the heaviest thinnings (overstory basal area kept between 22.5 and 29.25 m^2/ha) averaged the most, tallest, oldest, and fastest growing seedlings, while the light thinnings (overstory basal area kept between 36.0 and 45.0 m^2/ha) had the fewest, shortest, youngest, and slowest growing seedlings in 1994. Control plots had almost no regeneration.

Among the seedling characteristics that were measured, treatment differences in seedling density were the most significant. Both the magnitude and the significance of differences in seedling density were greater in 1994 than they were in 1977 when

overstory treatment differences were greater and more significant. Seedling height differences among treatments were somewhat less significant, while age differences were not significant. Seedling density also showed the greatest block differences.

Present (1994) treatment differences in seedling density were well explained by both the relative density of the overstory in 1966 (the year by which each block had been thinned twice) and the cumulative reduction in overstory relative density through 1966. For both these explanatory variables, 1966 values explained 1994 seedling density treatment differences better than values from 1977 (the year the last block received its final thinning) or 1991 (the most recent year for which data are available). Block differences were explained by both the present and past competition from the shrubs Oregon grape and salal. They were also partially explained by the cumulative reduction in relative density through 1966.

Height differences were also explained by 1966 values of both relative density or the cumulative reduction in relative density but seemed unaffected by shrub competition.

The major herb and shrub species in 1974 and 1994 were Oregon grape and bracken fern. Since 1974 the percent ground cover of bracken fern has decreased while that of Oregon grape has increased.

Distribution and Growth of Advance Douglas-Fir Regeneration in Commercially Thinned Stands in the Oregon Coast Range

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 3, 1998
Commencement June 1999

Master of Science thesis of Louis W. Beer presented on June 3, 1998

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Louis W. Beer, Author

ACKNOWLEDGEMENTS

In the time it has taken me to reach this point there have been many people who have helped to make the process much easier. These include the office staff of the Department of Forest Resources, especially Jamie Schaup, Mary Roberts, and Lola Hickey who have always been extremely helpful in helping me, and many other graduate students, deal with various university procedures and red tape. My thanks also go to Arlene Hester and those present and former graduate students in the Department of Forest Resources, especially Kreg Lindberg, Mark Hanus, and Kelly O'Brian, who have taken the time to serve on the Lee Harris Computer Lab committee. Keeping our computer lab up-to-date and functioning is a time consuming and thankless job.

I would also like to thank Steve Tesch and John Tappeiner for serving on my graduate committee and for their help with the drafts of this thesis. My greatest thanks go to my major professor, David Marshall. His willingness to let me approach this research in my own way, and especially his patience, have been greatly appreciated.

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INTRODUCTION

In Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests the transition between mature and old-growth conditions occurs at about 200 years (USDA Forest Service Old-Growth Definition Task Group 1986, Hansen et al. 1991, Spies and Franklin 1991). Characteristics of old-growth forests include the presence of large trees, snags, and downed logs along with a high degree of structural diversity marked by wide ranges in tree heights, diameters, age, spacing, and crown ratio. (Franklin et al. 1981, Oliver and Larson 1990, Franklin and Spies 1991).

Many of these structural differences between old-growth and younger forests are due more to management differences than they are to age differences. Younger forests tend to have a more uniform structure than older forests because they are more likely to be managed for the maximization of wood production. And, much of the structural diversity and greater vertebrate species abundance shown by old-growth forests are also shown by young and mature "natural" forests (Hansen et al. 1991). Many of the structural characteristics associated with old-growth Douglas-fir forests may be created through thinnings in even-aged stands less than 200 years old (Tappeiner et al. 1986, Oliver 1992).

Creation of a wider range of ages, heights and diameters in even-aged managed young and mature Douglas-fir stands will require more than a single cohort of trees. Therefore, thinnings designed to create old-growth conditions will need to be heavy enough to allow the growth of planted seedlings or the germination and growth of natural regeneration. If natural regeneration is used, managers will need to know at what thinning level they can expect it to occur, its expected growth response in the understory, and about other factors likely to affect its survival and growth once it is established.

The purpose of this study is to examine differences in abundance, height, growth, and ages of advance Douglas-fir regeneration, at a single site, among areas that received different overstory thinning treatments (treatment differences) and among areas receiving the same overstory thinning treatments (block differences). This study also addresses whether treatment differences tended to be related more to the amount of the overstory that was left after thinning or to the amount that was removed. Finally, because treated areas each received three to four thinnings carried-out over a twenty year period ending seventeen years prior to this study, it examines whether present treatment or block differences in regeneration are related more to the initial thinnings, later ones, or to present overstory differences.

REVIEW OF LITERATURE

Several workers have looked at the response of advance regeneration conifers to release following the removal of the entire overstory. In southwestern Oregon and northern California, growth of Douglas-fir seedlings, averaging three meters tall and twenty-three years of age at the time of overstory removal, improved with time since thinning. Average annual height growth was better twenty years after overstory removal than it was after ten years, and was about four times better than the pre-release growth rate. Post-release growth rate was positively related to growth rate five years prior to overstory removal while age was negatively correlated with future growth (Tesch and Korpela 1993). When this same advance regeneration was compared to the simulated growth of planted Douglas-fir seedlings over a projected twenty year period, the height advantage of the advance regeneration maintained itself. This height advantage increased with time if heavy shrub competition was included in the simulation (Korpela et al. 1992).

Pre-release height growth, live crown ratio, and whether height growth was increasing, decreasing, or staying the same (rather than age, height, overstory crown cover, overstory basal area, site class, elevation, slope, or aspect) were found to be the best variables for predicting post-release height growth of white fir (Abies concolor) seedlings. Pre-release height growth and live crown ratio correctly predicted 60-90% of the time whether Douglas-fir seedlings would attain, or fail to attain, various levels of height growth over a ten year post-release period (Helms and Standiford 1985).

In spruce-fir forests in Idaho, Wyoming, and Utah understory Engelmann spruce (Picea engelmanii) and subalpine fir (Abies lasiocarpa) ranging in height from 0.06 to 4.30 meters showed greater growth in the second five year period after either complete or partial overstory removal than in the first five year period. Under both types of overstory treatments growth during the first five year post-treatment period was only slightly better than in the five year pre-treatment period. During the second five year post-treatment period, growth on areas whose overstory had been removed was about four times greater than during the five year pre-treatment period. On partially cut areas growth was 2.5 times greater than it was during the pre-treatment period (McCaughey and Schmidt 1982).

When a 43 year-old grand fir (Abies grandis) and Shasta red fir (Abies magnifica var. shastensis) understory whose average height was 1.4 meters was released by the removal of a lodgepole pine (Pinus contorta) overstory, trees responded during the first post-release growing season. And, growth during the third five year post treatment period was significantly greater than during the first two five year post-thinning periods (Seidel 1987).

Diameter growth in west central Alberta of suppressed white spruce (Picea glauca) and black spruce (Picea mariana) up to 167 years-old responded immediately after the overstory was harvested. The average annual percentage increase in diameter growth rate over a ten year post-harvest period was 477% for white spruce and 588% for black spruce. Diameter growth in the second five-year post harvest period was better than it was in the first five-year post-harvest period. Height growth also increased but not as much as diameter growth (Crossly 1976).

Other studies have investigated the effects of thinning on the understory as a whole. In a ponderosa pine (Pinus ponderosa) stand in north-central Washington a linear relationship existed between percent overstory canopy cover and the yield of the understory. Compared with an unthinned stand having 100% canopy closure, understory yield was 100% greater at 80% canopy closure and 400% greater at 20% canopy closure. This increase in yield with increasing thinning intensity was greatest for herbaceous vegetation as opposed to shrubs, tree species, or mosses (McConnell and Smith 1970).

Information on the response of advance regeneration to thinning is more difficult to find. Studies that do exist tend to have used heavier thinning treatments such as seedtree and shelterwood cuts. In northern Idaho when mixed species stands were thinned to residual basal areas of less than $9m^2/ha$, $9\text{-}19m^2/ha$, and $19\text{-}23m^2/ha$ the five year growth rate of ten year-old grand fir (Abies grandis), Douglas-fir, western larch (Larix occidentallis), and western white pine (Pinus monticola) seedlings was significantly better on the lowest residual basal area (0.53m/5yrs) than for the two higher residual basal areas (0.31m/5 yrs). After the residual overstory was removed, growth was not significantly different among treatments and averaged 0.92m/5 yrs (Bassman et al. 1992).

When even-aged mature stands of longleaf pine were either clearcut or thinned to 10, 6, or 2 m^2/ha, advance regeneration came in immediately and the number of years needed for the seedlings to enter the active height-growth phase was strongly inversely related to residual basal area (Boyer 1993).

In mixed stands of western hemlock (Tsuga heterophylla) and Sitka spruce (Picea sitchensis) in southwestern Alaska younger stands (12-27 years at thinning), which had open canopies as well as both conifer regeneration and other understory species, had fewer but taller conifer seedlings and more understory vegetation 9-14 years after thinning than did older stands (31-98 years), whose canopies had been closed and which had no regeneration or understory vegetation at thinning. In both types of stands the heavy thinnings (2.6 m^2/ha average residual basal area in younger stands and 22.0 m^2/ha average residual basal area in the older stands) had more conifer regeneration than medium or light thinnings (5.1 and 8.3 m^2/ha average residual basal area in younger stands and 27.7 and 37.1 m^2/ha in older stands) (Deal and Farr 1994).

When a twenty year-old ponderosa pine plantation in the western Sierra Nevada was thinned to 36, 23, and 9 m^2/ha resulting light levels were 15%, 34%, and 58% of full sunlight respectively. Five year growth of understory Douglas-fir, which was between 0.3 and 0.9 meters tall, averaged 0.55, 0.85, and 1.10 meters respectively (Oliver and Dolph 1992).

In a comparison of seedling growth under different regeneration methods average heights of nine year-old Douglas-fir seedlings on a pondersoa pine dominated site in north-central California were: 0.21 meters under a single-tree selection (20% of merchantable volume removed), 0.46 meters under a group selection (creation of openings of 9, 18, and 27 meters in diameter), 0.64 meters under a shelterwood (leaving of 30 large full-crowned overstory trees/ha), 0.94 meters under a seedtree regeneration (leaving of 10-20 vigorous trees /ha), and 1.28 meters in a clearcut (McDonald 1976).

Bailey (1996) investigated differences among thirty-two pairs of thinned and unthinned 50-120 year-old Douglas-fir stands throughout western Oregon. Thinnings had taken place 10-24 years previous with a removal of 8-60% of the overstory volume. Conifer regeneration - primarily western hemlock and Douglas-fir - was significantly better in the thinned stands than it was in the unthinned stands. Among the thinned stands, thinning intensity, although it only accounted for 10% of the variability, was the best variable in explaining seedling density. Conifer frequency was best explained by thinning intensity and site index and accounted for 32% of variability. Twenty-nine of the thinned stands had Douglas-fir in the understory, though in 19 of them Douglas-fir seedling density was less than 300/hectare. Douglas-fir seedlings were most predominant in stands located in southwestern Oregon and on the edges of the Willamette Valley.

In general, these studies show that:

- Advance regeneration of several species, even shade intolerant ones, can maintain itself in the understory for fairly long periods of time.
- The growth response of advance regeneration to overstory treatment (thinning or removal) may occur fairly quickly and increases with time.
- Competition from herbs and shrubs negatively impacts advance regeneration.
- Pre-release and post-release growth rates are directly related.
- Growth response is directly related to treatment intensity.

SITE HISTORY AND DESCRIPTION

The State Forest at Black Rock, located on the east side of the Oregon Coast Range near Falls City, is a 250 hectare tract of Douglas-fir which regenerated naturally from 1908 to 1911 after clearcutting. The climate is wet but mild with a frost free growing season of more than 200 days and an average precipitation of about 200 centimeters per year falling mainly as rain in the winter (Wittler 1974, DelRio 1978). In addition to Douglas-fir, the overstory consists of scattered western hemlock (Tsuga heterophylla), grand fir (Abies grandis), and western redcedar (Thuja plicata). Site class ranges from II to IV. The area of the forest used in this study encompasses three soil series, all formed in residuum and colluvium: the Peavine and Honeygrove series, both silty clay loams described as clayey mixed mesic Typic-Haplohumults, and the Klickitat series, a gravelly clay loam described as a loamy-skeletal mixed mesic Typic-Haplumbrept (USDA Soil Conservation Service, 1982).

In 1957 trials were established to assess the effects of thinning on the growth of the residual overstory. Areas were thinned to maintain the basal area of the residual overstory (trees 19.3 centimeters dbh and larger) between 22.5 - 29.25 square meters per hectare (a heavy thinning), 29.25 - 36.0 square meters per hectare (a medium thinning), or 36.0 - 45.0 square meters per hectare (a light thinning). During thinnings yarding was done by horse in order to minimize damage. Other areas remained unthinned and were kept as controls. Four areas (blocks) of the forest of about eight hectares each were used for these thinnings. Blocks differed from each other primarily in elevation and slope (see table 1) but not in aspect (all are basically south facing). Each of these blocks was divided into four treatment plots of about two hectares. One of the four treatments was randomly assigned to each plot (i.e. a randomized complete block design). A measurement plot was established at the approximate center of each treatment plot (i.e. measurement plots are surrounded by treated buffers). Measurement plots are 0.4 hectare (one acre) square for each of the twelve areas receiving a thinning. Of the control plots, one is also a 0.4 hectare square, one is a 0.4 hectare "L" shaped plot; another is an "L" shaped 0.3 hectare plot; while the final control is split among two 0.1 hectare plots and one 0.2 hectare plot. Borders of the measurement plots are oriented North-South, East-West.

Among the medium and heavy treatments more than a single thinning was needed in order to reduce each of the plots to its target residual basal area. Thus, the plots were not necessarily maintained between their upper and lower limits for the entire period between their first and final thinnings. Three of the blocks received their final thinning between 1969 and 1972. the fourth block (block C) received its final thinning in 1977. This final thinning in 1977 did not reduce the three treated plots to their respective target residual basal areas; rather, it brought them into line with their counterparts on the other blocks. Therefore, it has been over twenty years since any plot has been thinned to its target residual basal area.

A summary of the years in which each plot was thinned along with residual basal area at the time of the thinnings is given in table 2. Data on overstory basal area have been collected every three to five years. Based on these data, as well as on interpolation or extrapolation for non-inventory years, graphs showing the basal area of each plot from 1957 to 1994 are given in figure 1.

Table 1 - Average Elevation, Percent Slope, and Site Index

plot	treatment	block	average elevation (meters)	average percent slope	site index (meters)
27	C	A	334	---	34.2
29	L	A	323	10.7	37.2
28	M	A	314	12.6	34.5
30	H	A	335	23.2	32.9
average		**A**	**326.5**	**15.5**	**34.7**
21	C	B	354	---	38.1
25	L	B	360	30.9	39.0
24	M	B	329	19.3	39.0
22	H	B	360	24.0	37.2
average		**B**	**351**	**24.7**	**38.4**
37	C	C	489	---	36.9
34	L	C	463	30.9	37.5
35	M	C	476	26.9	37.8
36	H	C	503	22.5	35.1
average		**C**	**483**	**26.8**	**36.8**
42-46-50	C	D	534	---	34.8
40	L	D	549	27.9	36.3
38	M	D	497	26.2	33.6
41	H	D	579	36.3	33.6
average		**D**	**540**	**30.1**	**34.5**

(Data on percent slope were not taken from the control pots.)

(Among treatments C = controls, L = light thinning, M = medium thinning, H = heavy thinning)

Table 2 - Initial and Residual Overstory Basal Areas

block-year thinned	controls	light thinning 36.0-45.0 m^2/ha	medium thinning 29.2-36.0 m^2/ha	heavy thinning 22.5-29.2 m^2/ha
A - 1957	47.9	42.3	36.7	38.7
1960	50.2	40.7	34.7	35.1
1965	53.1	39.6	34.7	27.9
1971	57.2	38.5	32.2	25.9
B - 1957	48.6	46.6	48.8	47.9
1960	51.5	40.7	38.2	35.6
1965	55.6	40.5	36.2	30.4
1971	60.1	40.5	32.2	28.3
C - 1957	51.3	56.9	56.7	54.9
1964	56.5	56.7	56.7	56.0
1966	60.5	38.9	32.2	32.6
1977	68.0	40.7	39.8	35.1
D - 1957	54.2	46.6	39.8	43.4
1960	57.4	44.8	38.7	39.8
1963	58.1	42.5	36.0	32.2
1966	61.9	42.3	36.5	30.4
1969	63.7	39.2	33.3	27.5

The forest contains several areas infected by the root rot pathogen Phellinus weirii which kills overstory Douglas-fir. In 1978 twenty-seven infection centers were found within the forest. The limits of these pockets were defined as the area containing all infected trees plus half the distance between the infected trees and surrounding uninfected ones. These root rot pockets ranged from 0.02 hectares containing five trees up to 0.7 hectares containing 148 trees. The total area occupied by these pockets was 7.1 hectares (Lawson, 1980).

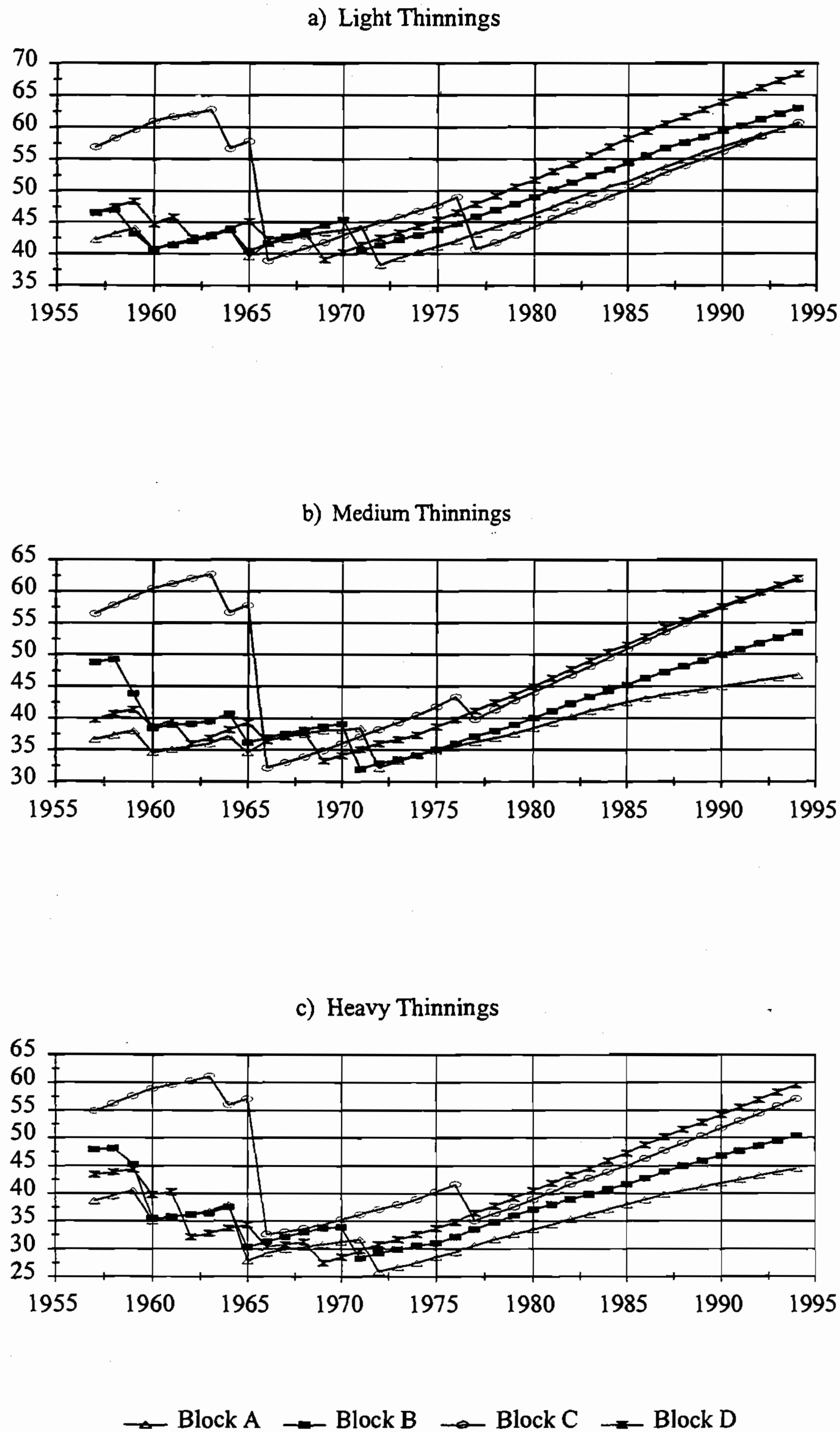


Figure 1a-c, Overstory Basal Area (m^2/ha; **y-axis**) vs. Year (**x-axis**).

Two of these root rot pockets impact plots used in this present study. The first is an area of approximately 0.2 hectares located mostly within the treated buffer of the heavily thinned plot in block A (plot 30). In 1978 its western limit extended to the lower half of the eastern border of the measurement plot. The second, between 0.1 and 0.2 hectares, is also within block A. It is located in the north-western portion of the treated buffer of the moderately thinned plot (plot 28) but does extend slightly into the western portion of the measurement plot.

Three other studies have looked at different aspects of understory response to these same overstory thinnings at Black Rock. Data for all three were collected between 1974 and 1977. These studies are used for comparison with the results of this present study; however, sampling designs are not the same.

Wittler (1974), investigating vegetative cover and species frequency in the understory, found that in spite of large within-treatment variations, overall species composition and relative ground cover of the different species was similar for plots receiving the same treatments. Eurhynchium oreganum (a moss), Oregon grape (Berberis nervosa), and pacific dogwood (Cornus nutallii) accounted for most of the understory cover on unthinned plots. Species composition among all of the thinned plots was found to be similar in that, despite large plot to plot variations, E. oreganum and bracken fern (Pteridium aquilinum) were the most important species in terms of percent groundcover. Additionally, "total cover was highest on heavily and moderately thinned plots. The most marked change is the increase in herbaceous cover with thinning intensity. The heavy and moderate thinnings each average about 50% cover, whereas light thinnings and unthinned plots averaged 31% and 7% respectively."

In 1977 Temmes (1978) looked at cover and biomass of ground vegetation in relation to light environment on the three treated plots on two of the four replications. Within each replication the most frequently occurring species as well as the species having the greatest groundcover was: Oregon grape on the lower replication (block B) and bracken fern on the upper replication (block D). On all six plots percent groundcover showed great within-plot variation. On the upper replication both percent groundcover and biomass increased with thinning intensity. On the lower replication, the moderately thinned plot had greater percent groundcover and biomass than the heavily thinned plot. When comparing like treatments the average biomass on the lower replication was considerably greater than on the upper replication. However, due to the large within-plot variation, there was not a significant difference in biomass among the six plots. Treatment averages for light intensity were 14.4% , 7.3%, and 6.4% of full sunlight for the heavy, medium, and light thinnings respectively. No meaningful correlation was found between light intensity and biomass of Oregon grape and/or bracken fern.

Del Rio (1978) investigated the effects of the different treatments on heights of Douglas-fir seedlings, their leader growth, and their diameter growth in relation to differences in environmental conditions at twenty points in each of the twelve treated plots. Differences among treatments were greatest for percent daily sunlight received and soil temperature 20 cm below the surface. Smaller differences were found for plant moisture stress, evaporative demand, and air temperature at 1.5 m above the ground. The average percent of full daily sunlight decreased with increasing overstory basal area. Treatment averages were 4.8%, 7.8%, and 11.5% of full sunlight for the light, medium, and heavy thinnings respectively. "Variation in light reaching the understory, from one point to the next, increased with degree of thinning. Growth of understory trees follows this pattern; all growth measurements varied least under lightly thinned plots and greatest under those thinned more heavily." Average seedling height increased with thinning intensity. Both leader and diameter growth increased with increasing light and with seedling height. Budswell and budbreak occurred earliest under the light thinnings and latest under the heavy ones. In the fall of 1976 the ages of seedlings less than or equal to 1.7 meters tall ranged from two years on all plots up to 10-15 years.

Analysis of the Del Rio data using a two-way analysis of variance for treatment and block effects showed the following differences among the treatments:

treatment	average 1977 leader growth (cm)	average seedling height (cm)	1977 basal diameter growth (mm)	average age (yrs)
light	4.0	31.1	0.775	7.5
medium	5.9	39.3	1.025	8.25
heavy	7.4	45.9	1.250	8.25
p-value	0.0624	0.1337	0.0542	0.0837

These results indicate that, although average seedling height, age, leader growth, and basal growth increased with thinning intensity, in no case were differences among treatments significant at the 95% confidence level, though three of the four would be considered significant at the 90% confidence level. Other aspects of this study that apply more to the current research are summarized in later sections of this thesis.

METHODS

Plot Establishment and Data Required

The experimental units in this study were the sixteen 0.4 hectare measurement plots. On each of these sixteen plots a random starting point along the plot's southern edge and a random direction heading into the plot were chosen by multiplying two two-digit random decimals by 63.6 meters (208.7 feet, the length of the side of the measurement plots) and 180 degrees respectively. From this starting point and direction eight parallel lines approximately 8 meters apart were laid-out and sixty-four evenly spaced measurement points - forty-eight in the case of the 0.3 hectare (3/4 acre) plot - were staked-out along these lines. Each of these sixty-four stakes became the center of a two meter radius subplot. These subplots were the sampling units used in this study. When all sixty-four subplots within a plot were used, approximately one-fifth of the measurement plot was sampled. Measurements within these subplots were of four types: (1) conifer regeneration, (2) non-coniferous vegetation (herb and shrub cover and hardwood regeneration), (3) overstory canopy characteristics, and (4) slope.

Conifer Regeneration

Data needed for analysis of conifer regeneration was: abundance, age, size, and growth rate. Within the subplots, measurements consisted of recording the number and heights of all conifer (Douglas-fir) regeneration and measuring height growth rates and the basal diameter of the tallest and a randomly selected seedling. Within each subplot the random seedling was selected by the random selection of a two-digit decimal. This decimal was multiplied by 360 degrees which became the random azimuth. From the center of the subplot the random azimuth was extended to the edge of the subplot and rotated clockwise. The first Douglas-fir seedling encountered, regardless of size, became the random seedling.

Annual growth rates of both the tallest and the randomly selected seedling were determined by cutting the seedling at its base and measuring internode length from the top downwards. Age was then estimated by counting these internodes. Due to bud scale scars and annual whorls being less distinct on the lower (older) portions of the stem, determination of the location of older nodes was less accurate. The problem that this caused in determining growth rates was partially alleviated by noting on the data sheets the point below which it was subjectively determined that there was uncertainty in identifying the next node. Annual growth below this point was not estimated. Therefore, in many cases the annual growth rate for every year that a seedling existed was not possible.

To more accurately determine age a basal section of each seedling that was cut was saved. On a subsample spanning the range of heights and estimated ages, annual rings were examined under a dissecting microscope to determine differences between actual and estimated ages. From this a regression was developed in order to estimate the age distribution of the seedlings.

Herbs and Shrubs

Information on non-coniferous vegetation was estimated at every second subplot. It was recorded as the percent groundcover of all non-conifer species less than one meter tall whose groundcover was greater than five percent. If at least three species did not have groundcover greater than five percent, the three species with the greatest percent groundcover were recorded. Since several layers of vegetation can exist it is possible that groundcover on a subplot could exceed 100%. The percent ground cover of each species was estimated by dividing the two-meter radius subplot into quadrants and visually estimating the percent ground cover of each species in each of the four quadrants and averaging the estimates.

Tall Hardwoods

Because of time restrictions, at each subplot any non-conifer species greater than one meter tall were noted as being present over that subplot, but no estimate of its percent ground cover was made nor were heights recorded.

Due to the importance of bigleaf maple seedlings in affecting the growth of Douglas-fir seedlings (Knowe et al. 1995) it was decided that information more precise than that given by percent groundcover was desired. Measurements for bigleaf maple were done much like that for conifers; all seedlings within a subplot were counted and measured for height; the tallest and a randomly selected seedling were identified in each subplot; and, their age was determined by counting bud scale scars on the main stem. Unlike conifers, no internodal measurements were taken, and only sixteen subplots were sampled per plot.

A systematic sample was used to determine which sixteen points to sample by randomly choosing a number between one and four, choosing that as the first subplot to be sampled, and sampling every fourth subplot.

Overstory and Site Characteristics

Present overstory canopy conditions at each subplot were examined by looking at canopy closure and the percent of the sky that was visible. Canopy closure was measured using a cylindrical sighting tube to look at the canopy directly over the center of the subplot. In this method a clear plastic grid composed of sixteen squares was placed over the end of the sighting tube. Percent canopy openness at that point was determined as the percentage of the sixty-four quarter-squares that were not covered by foliage when viewed through the tube. Percent canopy closure was determined as 100 minus percent canopy openness. Canopy closure for the plot was the average of the canopy closure of all subplots in a measurement plot.

At eight randomly selected subplots per plot, at a height of approximately three meters, the percent of visible sky was measured using a LiCor "LAI-2000 Plant Canopy Analyzer" which measured the portion of a near-hemisphere not blocked by vegetation (LiCor, 1992).

On the treated plots but not on the controls, percent slope was measured at the even numbered subplots in each plot using a clinometer.

Data on overstory basal area and the number of trees per hectare have been collected every three to five years. Analysis of the overstory was done on data collected in 1966, the year by which all treated plots had been thinned twice, 1977, the year in which the last block received its final thinning, and in 1991, the most recent year in which overstory data were taken. Based on these data, stand density indices (SDI) were calculated according to Reineke (1933) for 1966, 1977 and 1991 by the following formula.

$$SDI = \text{number of trees per hectare}(\text{quadratic mean diameter}_{\text{in centimeters}}/25)^{1.605}$$

From this, relative density (actual SDI/maximum possible SDI) was calculated using 1450 as the maximum possible stand density index (Long, 1985).

In addition to relative density the cumulative (total) reduction in relative density was calculated for each treated plot by adding together pre- and post-thinning differences in relative density for each successive thinning. This was calculated for 1966 and 1977.

Data Analysis

Unless otherwise specified, analyses were done using a two-way analysis of variance for treatment and block effects. The significance of treatment and block effects was evaluated using a type III sum of squares. Data transformations were used when necessary to create more constant variance among treatments and/or blocks. When the treatment and/or block effect was significant ($p \leq 0.05$) a Waller-Duncan multiple comparison test was used to determine which treatments or blocks were significantly different from one another. Computations were done using SAS (statistical analysis system) programs (SAS Institute Inc. 1990).

A two-way analysis of variance for treatment and block effects indicates whether significant differences exist, but does not give an indication of the source of these differences. As has been stated above, one of the objectives of this study is to see whether regeneration differences among plots are related more to initial or more recent thinnings or to present overstory differences. Although it is not possible to establish cause and effect relationships in this study, in the event of significant differences in regeneration possible causes of the effect were investigated using linear regression and/or analysis of covariance.

In using linear regression it was presumed that if an overstory, site, or understory characteristic were the cause of any significant differences in seedling abundance, height, or age it would explain more of the plot to plot variability in that characteristic than would the remaining characteristics. When more than a single explanatory variable was used to explain seedling differences, forward, backward, and stepwise variable selection techniques were used to determine which variables should be included in the resulting model. In models employing only a single explanatory variable, the coefficient of determination (R^2), the amount of the total variability in the total sum of square that is explained by the regression, is given. In models employing more than a single explanatory variable, the R^2 value that is reported is an adjusted-R^2 which takes the extra explanatory variables into account and allows a better comparison of models using different numbers of explanatory variables.

Analysis of covariance was also used to identify possible sources of block (or treatment) differences in regeneration. It was presumed that if the cause of the significant block (or treatment) effect was due to differences among the replications (or treatments) in one of the overstory, site, or understory characteristics, then inserting that characteristic as a covariate and removing "block" (or "treatment") from the analysis of variance, the result would be a covariate that was also significant. More specifically, a significant covariate, that had been substituted in place of "block", would indicate that it was explaining a significant portion of the variability not explained by the treatment effect. And, a significant covariate, that had been substituted in place of "treatment", would indicate that it was explaining a significant portion of the variability not explained by the block effect.

RESULTS

Douglas-fir Overstory Characteristics

Plot averages of the overstory characteristics that were measured at various times, along with the results of their analyses of variance, are given in tables 3, 4, and 5.

The controls had the highest average relative density and percent canopy closure followed in turn by the light, medium, and heavy thinnings. This order was reversed in the cases of percent visible sky and the cumulative reduction in relative density.

Although the differences among treatments in relative density were highly significant in 1966, 1977, and 1991, whether or not the controls were included in the analysis, it was only in 1977 that all treatment averages were significantly different from each other.

Significant treatment differences also existed in the cumulative reduction in relative density through both 1966 and 1977. At both times it was only the average of the heavy thinnings that was significantly different from the other two.

In 1994, the only time at which percent visible sky and percent canopy closure were measured, treatment differences were also significant, though not all treatments were significantly different from each other. These differences were probably more significant when thinnings were still taking place.

In addition to treatment differences relative density also showed a significant block effect in 1977 and 1991. Since 1966 blocks have become progressively more different. By 1991 each block was significantly different from at least one other block, and among the twelve treated plots the differences among blocks had become more significant than those among treatments.

Due to different initial basal areas (see figure 1a-c) there was also a significant difference among blocks in the cumulative reduction in relative density up through both 1966 and 1977. Block C had significantly more of its relative density removed than did the other three blocks. At both times this block effect was also more significant than the treatment effect.

Table 3 - Douglas-fir Overstory Relative Density

plot	treatment	block	1966	1977	1991
27	C	A	0.71	0.73	0.79
29	L	A	0.53	0.48	0.60
28	M	A	0.49	0.43	0.50
30	H	A	0.39	0.36	0.46
21	C	B	0.73	0.77	0.78
25	L	B	0.51	0.51	0.62
24	M	B	0.45	0.41	0.52
22	H	B	0.41	0.38	0.51
37	C	C	0.79	0.82	0.86
34	L	C	0.49	0.46	0.60
35	M	C	0.38	0.43	0.58
36	H	C	0.42	0.39	0.54
42-46-50	C	D	0.84	0.89	0.99
40	L	D	0.56	0.56	0.70
38	M	D	0.49	0.48	0.65
41	H	D	0.42	0.43	0.62

Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

	1966	1977	1991
C	0.78 a	0.80 a	0.86 a
L	0.52 b	0.50 b	0.63 b
M	0.45 c	0.44 c	0.56 c
H	0.41 c	0.39 d	0.53 c
p-value (w/ controls)	0.0001	0.0001	0.0001
p-value (w/o controls)	0.0058	0.0004	0.0022

Block Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

	1966	1977	1991
A	0.53	0.50 a	0.59 a
B	0.53	0.52 a	0.61ab
C	0.52	0.53 a	0.65 b
D	0.58	0.59 b	0.74 c
p-value (w/controls)	0.1998	0.0057	0.0001
p-value (w/o controls)	0.2130	0.0139	0.0014

Table 4 - Cumulative Reduction in Overstory Relative Density

plot	treatment	block	1957-1966	1957-1977
27	C	A	-	-
29	L	A	0.113	0.202
28	M	A	0.085	0.178
30	H	A	0.207	0.288
21	C	B	-	-
25	L	B	0.090	0.159
24	M	B	0.149	0.239
22	H	B	0.226	0.301
37	C	C	-	-
34	L	C	0.331	0.444
35	M	C	0.406	0.456
36	H	C	0.404	0.497
42-46-50	C	D	-	-
40	L	D	0.145	0.209
38	M	D	0.138	0.207
41	H	D	0.232	0.288

Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

treatment	1957-1966	1957-1977
C	-	-
L	0.17 a	0.25 a
M	0.19 a	0.27 a
H	0.27 b	0.34 b
p-value	0.0118	0.0067

Block Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

block	1957-1966	1957-1977
A	0.14 a	0.22 a
B	0.16 a	0.23 a
C	0.38 b	0.47 b
D	0.17 a	0.23 a
p-value	0.0003	0.0001

Table 5 - Overstory Percent Canopy Closure and Percent Visible Sky in 1994

plot	treatment	block	% canopy closure	% visible sky
27	C	A	96.5	6.5
29	L	A	92.6	7.2
28	M	A	88.9	11.7
30	H	A	84.9	9.6
21	C	B	93.5	5.7
25	L	B	95.5	5.0
24	M	B	95.5	6.7
22	H	B	87.5	6.3
37	C	C	97.0	5.2
34	L	C	94.5	7.8
35	M	C	92.8	6.1
36	H	C	85.8	8.8
42-46-50	C	D	96.3	4.9
40	L	D	94.8	6.5
38	M	D	94.1	7.7
41	H	D	88.2	9.9

Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

C	95.8 a	5.6 a
L	94.3 ab	6.6 ab
M	92.8 b	8.0 b
H	86.6 c	8.7 b
p-value	0.0002	0.0414

Block Averages with Results of Waller-Duncan Multiple Comparisons

A	90.7	8.8
B	93.0	5.9
C	92.5	6.9
D	93.4	7.2
p-value	0.2125	0.0914

Seedling Characteristics

Seedling Density

Data and analysis of seedling density from 1977 (Del Rio 1978), which ware collected prior to the most recent thinning on block C, and from 1994 are presented in table 6. Treatment and block averages for both years are also shown graphically in figure 2. Among the three thinning levels, in both 1977 and 1994 the heavy thinnings averaged the highest seedling densities and the light thinnings averaged the least. This pattern occurred within three of the four blocks. In the fourth (block C) the medium thinning had a higher seedling density than the heavy thinning at both times, though the difference between the two was much less in 1994 than it was in 1977. This may be because block C's heavily thinned plot was the only plot that was never thinned to its target residual basal area. The lowest residual basal area to which it was ever thinned was 32.6 square meters per hectare in 1966 at which time the moderately thinned plot in that block was thinned to 32.2 square meters per hectare. With the exception of its final thinning in 1977 there were almost no post-thinning differences between these two plots (see table 2). Additionally, up until the 1977 thinning the medium thinning had a greater cumulative reduction in relative density than did the heavy thinning. Therefore, although the relative density of the heavy thinning was generally less than that of the medium thinning, the small treatment differences may not have been sufficient to overcome other differences affecting seedling density.

Data from the control plots were not collected in 1977. In 1994 the controls showed almost no plot to plot variation as compared with the other treatments. To make a

Table 6 - Douglas-fir Seedling Densities (seedlings/hectare)

(1977 data are from DelRio, 1978)

plot	treatment	block	1977	1994	percent change
27	C	A	---	0	---
29	L	A	673	162	-76
28	M	A	793	584	-26
30	H	A	3038	7660	+152
21	C	B	---	0	---
25	L	B	380	37	-90
24	M	B	865	311	-64
22	H	B	1608	895	-44
37	C	C	---	12	---
34	L	C	5400	4240	-21
35	M	C	12153	10395	-14
36	H	C	5400	8828	+63
42-46-50	C	D	---	62	---
40	L	D	4848	1032	-79
38	M	D	6055	2251	-63
41	H	D	10353	10428	+1

Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

C	---	19	---
L	2825	1368 a	-66.5
M	4966	3385 ab	-41.7
H	5100	6953 b	+43.0
p-value	0.2147	0.0242	

(Among treatments in 1994, in order to compare significance levels with 1977, the controls were not included in the analysis.)

Block Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

		w/o controls	
A	1501 a	2802 ab	+16.7
B	951 a	414 a	-66.0
C	7651 b	7821 c	+9.3
D	7085 b	4570 bc	-47.0
p-value	0.0058	0.0180	

(Note: Significant differences among both treatments and blocks for 1977 and 1994 are based on square root transformations which were used to reduce unequal variances.)

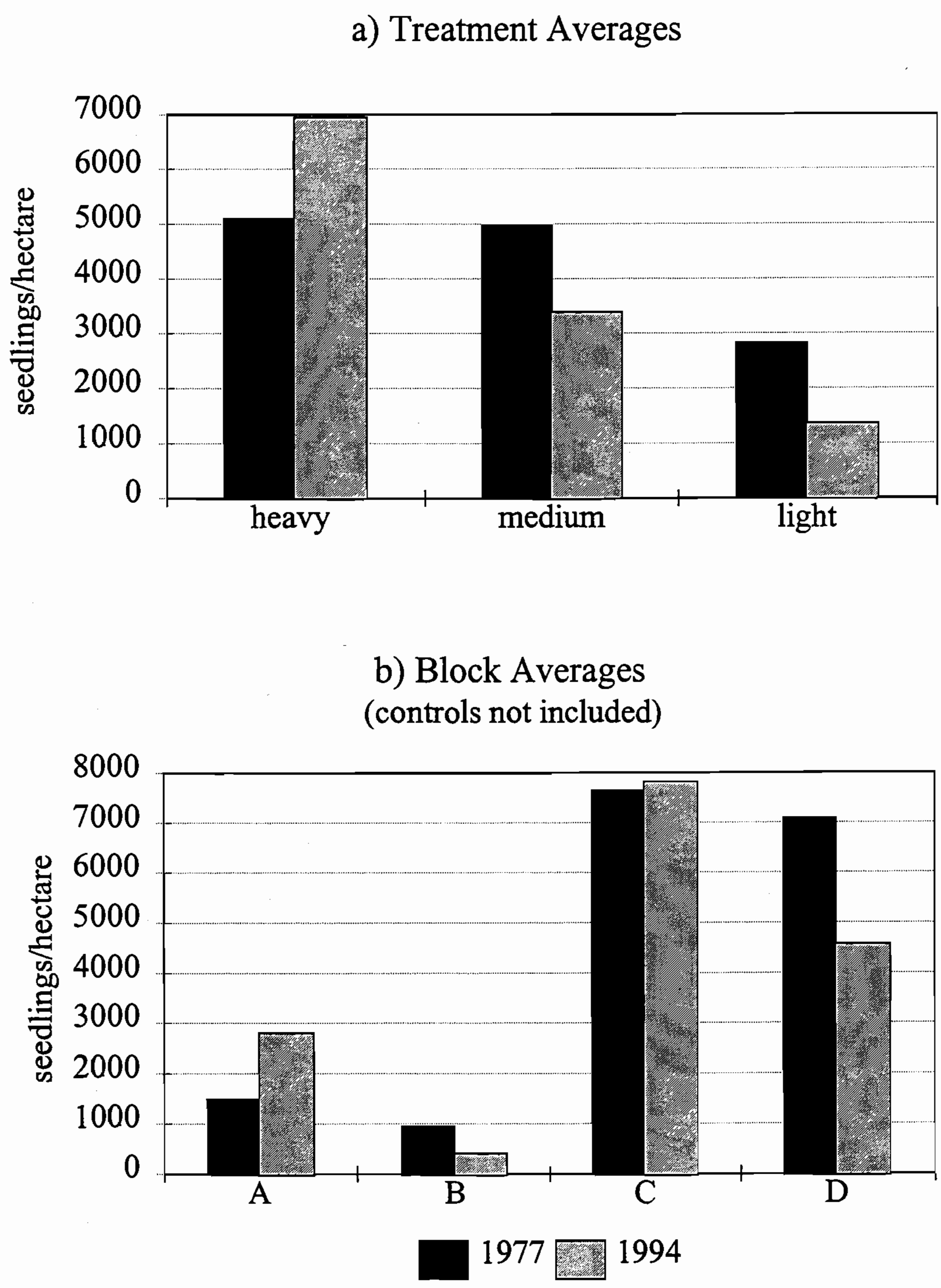


Figure 2a-b, Average Number of Seedlings per Hectare by Treatment (a) and by Block (b) in 1977 and 1994.

comparison between 1977 and 1994, as well as to eliminate problems with unequal variances among treatments, the 1994 data were analyzed without the controls (see table 6) Analysis of the differences among treatments and blocks benefitted from a square root transformation to create more equal variances among the three thinning levels. In 1977 differences among treatments were not significant. By 1994 a significant difference had developed between the heavy and light thinnings.

Between 1977 and 1994, within each block, the light thinning averaged the greatest percent decrease in seedling density, with decreases ranging from 21% to 90%, followed by the medium thinning, whose decreases ranged from 14% to 63%, followed by the heavy thinning which had less of a decrease in one block (44%) or an increase in seedling density ranging from 1% to 152%. The increase of 152% was on plot 30, the heavily thinned plot in block A, which is one of the plots affected by a root rot pocket. The extent to which this is the cause of the large increase is unknown. The overstory measurements of this plot, specifically percent canopy closure and percent visible sky, do not appear greater than those of the other heavily thinned plots (see table 5).

Among the four blocks significant differences in seedling density existed in both 1977 and 1994. In 1977 the significance was greater and more of the blocks were significantly different from each other (see table 6). However, even in 1994, the block effect was more significant, and accounted for more of the variation among the twelve treated plots than did the treatment effect. The two-way analysis of variance for 1994 explained 86% of the variation (total sum of squares) in seedling density among the twelve treated plots; 33.5% of the total variation was due to treatment differences while

52.5% was due to differences among blocks. The order of the blocks, in both 1977 and 1994, from the highest average seedling density to the lowest was C, D, A, and B.

Within-plot Variation of Seedling Density

Results of the examination of differences in seedling density among the subplots within each plot are summarized in table 7. In general, plots with higher average seedling densities tended to have fewer subplots with no seedlings and their most densely populated subplots had more seedlings than those on other plots. Figure 3 shows that seedling frequency, the proportion of the sixty-four subplots within each plot that contained at least one seedling, is strongly related to seedling density; as seedling density increases so does frequency. In this study seedling frequency did not exceed 0.50 until density was greater than 2000 seedlings/hectare and did not exceed 0.90 until density was about 9000 seedlings/hectare.

Seedling Height

Height distributions of all seedlings found within all subplots are shown in table 8 for each of the twelve treated plots. In eleven of the twelve treated plots the greatest number of seedlings are in either the 0-61 cm (0-2 foot) height class or the 61-122 cm (2-4 foot) height class.

Plot averages of both the heights of all seedlings found within each of the subplots and the tallest seedlings within each subplot are given in table 9. In both cases the heavy thinning averaged the greatest heights while the light thinning averaged the least. After square root transformations to create equal variances among treatments, treatment

Table 7 - Seedling Density Summary by Subplot

block - plot #	number of 2 meter radius subplots with no seedlings	most seedlings in a single 2 meter radius subplot	average number of seedlings per 2 meter radius subplot
Heavy Thinning			
A - 30	12	39	9.63
B - 22	37	12	1.13
C - 36	6	41	11.09
D - 41	1	51	13.10
Medium Thinning			
A - 28	50	14	0.73
B - 24	50	4	0.39
C - 35	3	56	13.06
D - 38	30	19	2.83
Light Thinning			
A - 29	59	6	0.20
B - 25	61	1	0.05
C - 34	15	31	5.33
D - 40	42	15	1.30
Controls			
A - 27	64	0	0.00
B - 21	64	0	0.00
C - 37	63	1	0.02
D - 42-46-50	62	4	0.08

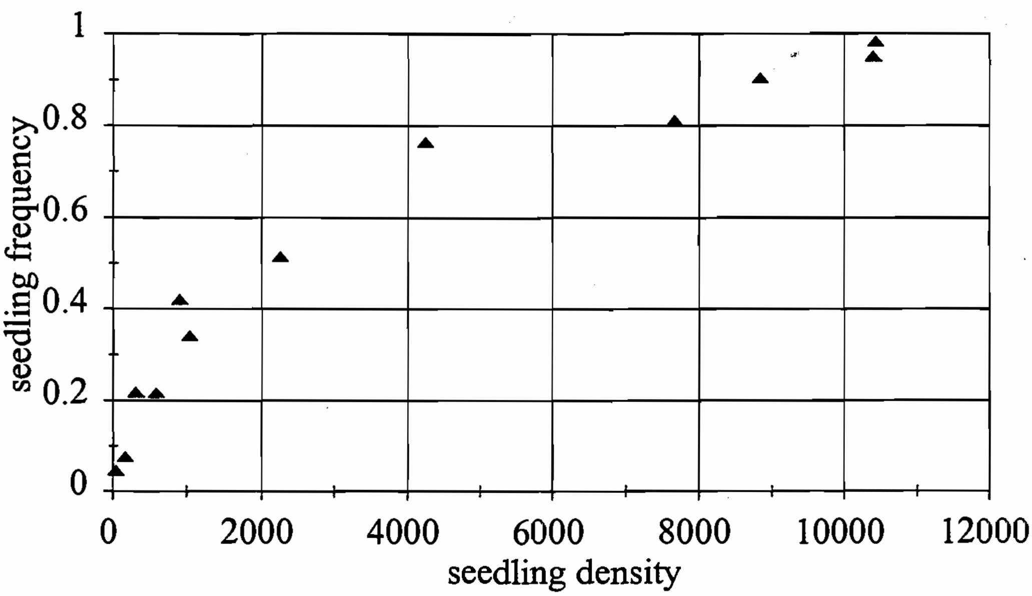


Figure 3, Seedling Frequency (the number of subplots per plot containing at least one Douglas-fir seedling) vs. Seedling Density (number of Douglas-fir seedlings per hectare).

Table 8 - Distribution of Seedlings by Height Class

plot - block	0-61cm (0-2 ft)	61-122 cm (2-4 ft)	122-183cm (4-6 ft)	183-244cm (6-8 ft)	244-305cm (8-10 ft)	305+ cm (10+ ft)
			Heavy Thinning			
30 - A	173	224	118	51	29	21
22 - B	25	39	9	0	0	0
36 - C	159	228	166	99	29	32
41 - D	319	362	105	37	14	7
			Medium Thinning			
28 - A	39	5	1	2	0	0
24 - B	13	7	4	1	0	0
35 - C	86	198	259	203	74	19
38 - D	158	23	0	0	0	0
			Light Thinning			
29 - A	11	1	1	0	0	0
25 - B	2	0	1	0	0	0
34 - C	198	121	17	0	0	0
40 - D	74	9	0	0	0	0

Table 9 - Average Heights of All Measured Seedlings and of the Tallest Seedlings

plot	treatment	block	all measured seedlings (cm)	tallest seedlings (cm)
29	L	A	31	59
28	M	A	30	63
30	H	A	112	158
25	L	B	65	65
24	M	B	71	85
22	H	B	80	93
34	L	C	57	80
35	M	C	151	217
36	H	C	126	213
40	L	D	34	45
38	M	D	36	47
41	H	D	86	148

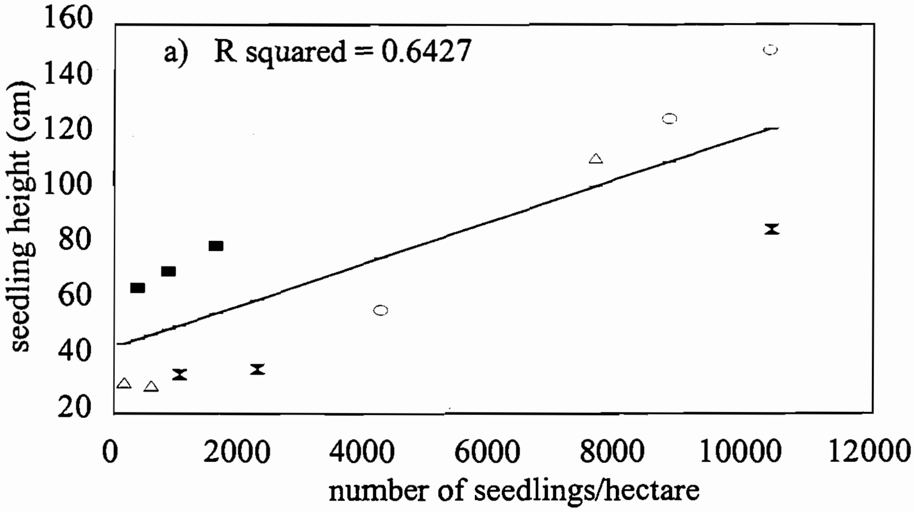
Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

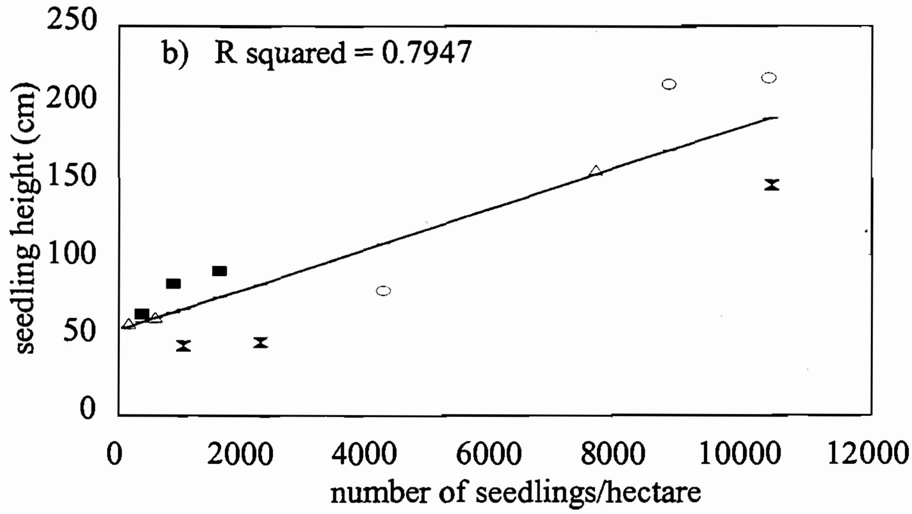
treatment	all measured seedlings (cm)	tallest seedlings (cm)
L	47	62 a
M	72	103 ab
H	101	153 b
p-value	0.0771	0.0337

Block Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

block	all measured seedlings (cm)	tallest seedlings (cm)
A	58	93
B	72	81
C	111	170
D	52	80
p-value	0.1437	0.0870

(Note: Differences among both treatments and blocks for 1977 and 1994 are based on square root transformations which were used to reduce unequal variances.)





△ Block A ■ Block B ○ Block C ⧗ Block D

Figure 4a-b, Average Seedling Height (**y-axis**) vs. Seedling Density (**x-axis**). a) y-axis = average height of all seedlings in each of the sixty-four subplots/plot b) y-axis = the average height of the tallest seedling in each of the sixty-four subplots/plot differences for all measured seedlings were not significant at the 95% confidence level while among the tallest seedlings the significant difference was between the heavy and light thinnings. In spite of a greater than two-fold difference in average height between the block with the tallest seedlings (block C) and the block with the shortest (block D), differences among blocks were significant neither for the average height of all measured seedlings nor for the tallest seedlings.

Seedling height was strongly related to seedling density; as seedling density on the plots increased so did the average height of seedlings. Significant linear relationships were found between the average heights of both the tallest seedlings and all measured seedlings when they were plotted against average seedling density (figure 4a-b).

Relatively few seedling were found greater than 2.4 meters tall (see table 8). For comparison, an eight and a ten year-old planted seedling from a nearby clearcut were examined and found to be 1.8 meters tall and 2.7 meters respectively.

Seedling Age

In developing a regression to predict the age of the Douglas-fir seedlings, the explanatory variables that were investigated for possible use were: the estimated age of the seedling, the height of the seedling, the basal diameter of the seedling, the distance from the base of the seedling to the first recognizable node, and the ratio of the distance from the first recognizable node to the top of the seedling divided by the height of the seedling. Sixty-five seedlings from all twelve treated plots were used in developing the regression. Seedlings were stratified by estimated age and height and specific numbers of seedlings were chosen randomly from each stratum. Models using all combinations of the explanatory variables were evaluated. Adjusted coefficients of determination (R^2) ranged from 0.8723 to 0.3897.

By far the most important single explanatory variable was the estimated age of the seedling (i.e. the age that was determined by counting all recognizable nodes on the stem). By itself, the estimated age accounted for 85.7% of the variation in the model. Estimated age combined with either seedling height, basal diameter, or the height to the first recognizable node produced R^2 values between 0.8651 and 0.8694. The use of indicator variables to distinguish between the tallest and the random seedlings, the three thinning treatments, and the four blocks were also investigated and were found to be insignificant. The model chosen contained estimated age and basal diameter as the explanatory variables and had an adjusted R^2 value of 0.8673. This model was used because it was felt that the measurements of basal diameter were the freest from measurement error.

The final model was:

$$\textit{predicted age} = 2.626 + 0.877(\textit{estimated age}) + 0.553(\textit{basal diameter})$$

This model was used to predict ages of seedlings whose estimated ages ranged from thirty-two years (the oldest seedling found) down to eight years. The basal sections of seedlings from this site whose estimated ages were less than eight years were too small to have their annual rings accurately identified and counted under the microscope that was used.

Because height alone was not a good predictor of age, it was not possible to get an age estimate of all seedlings within each of the sixty-four subplots within each plot. Therefore, age distributions of only the randomly selected seedlings and the tallest seedlings are possible. The age distribution of the randomly selected seedlings gives an indication of when germination began and ended on each plot, as well as an indication of the distribution of seedling ages throughout the plot. Yet, such a distribution is not necessarily the true age distribution of seedlings on the plots. A single random seedling was chosen from each subplot regardless of the number of seedlings on that subplot. And, the subplots were systematically established from a single random starting point. Thus, all combinations of seedlings did not stand an equal chance of being chosen. Therefore, in this case, even though each subplot's seedling was chosen randomly, the distribution is not random and not necessarily the true age distribution of seedlings on the plot. The greatest problem with this sampling method is: because younger seedlings tend to be smaller than older seedlings, within each plot, subplots with younger seedlings could contain a greater number of seedlings than subplots with older ones. Since only a single random seedling is chosen per subplot younger seedlings could easily be under-represented in the sample.

Age distributions by five-year periods of the randomly selected seedlings for the twelve treated plots are shown in figure 5a-d. Summaries of average ages by plot are shown in table 10. The average age, by treatment, of the randomly selected seedlings was 18, 18.4, and 19.4 years for the light, medium, and heavy thinnings respectively. These differences were not significant. Differences among the four blocks were also insignificant (see table 10).

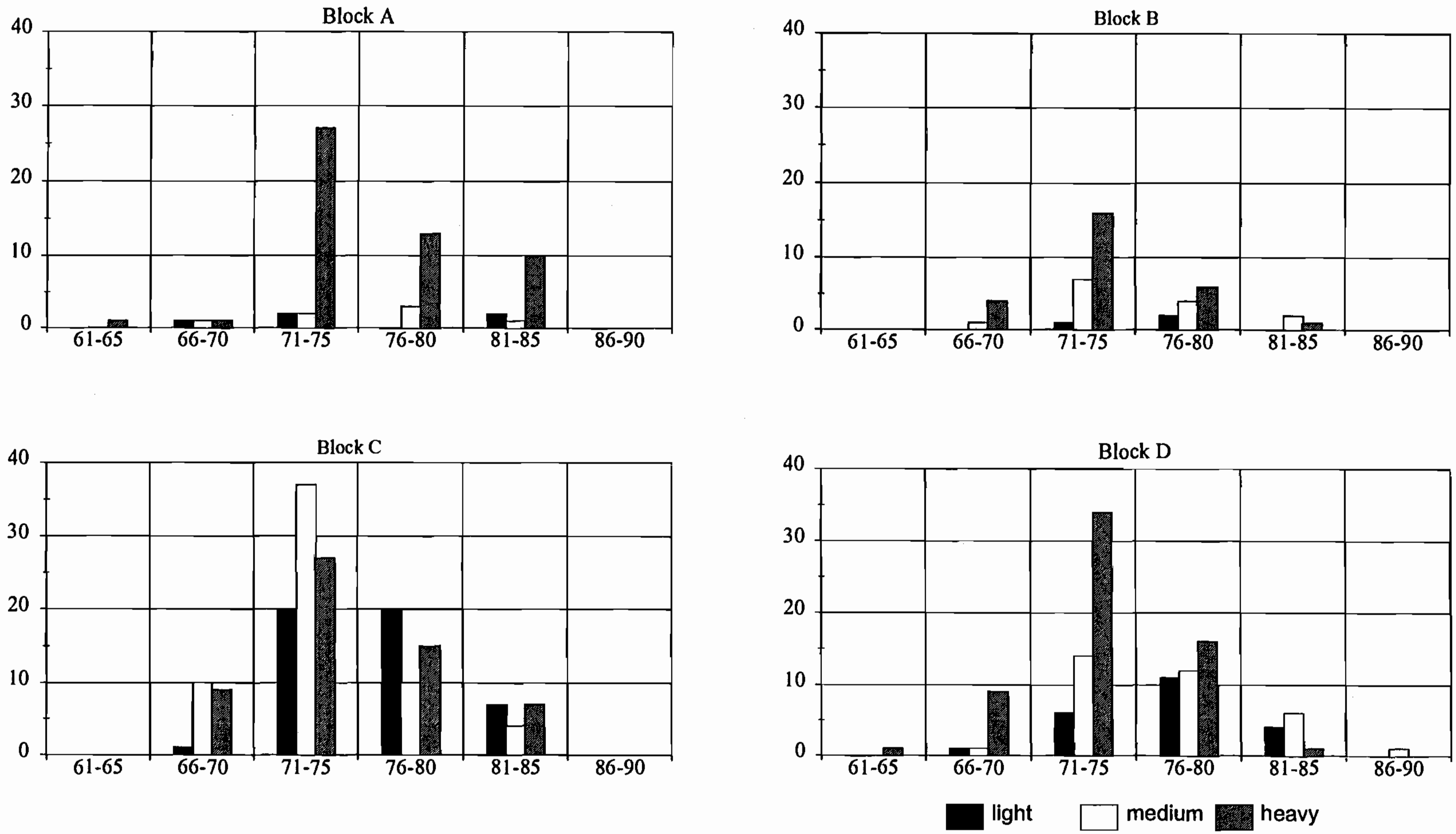


Figure 5a-d, Seedling Germination by Year - The number of the randomly selected seedlings from each plot (**y-axis**) germinating in each five year period from 1961 through 1990 (**x-axis**).

Table 10 - Average Ages of the Randomly Selected Seedlings and of the Tallest Seedlings

plot	treatment	block	randomly selected seedlings	tallest seedlings
29	L	A	19.3	19.7
28	M	A	17.9	18.6
30	H	A	18.4	21.2
25	L	B	18.5	18.5
24	M	B	18.1	18.4
22	H	B	19.7	20.0
34	L	C	17.6	19.2
35	M	C	20.5	23.2
36	H	C	19.2	22.1
40	L	D	16.8	18.1
38	M	D	17.3	19.3
41	H	D	20.3	22.2

Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

L	18.0	18.9
M	18.4	19.9
H	19.4	21.4
p-value	0.3746	0.0826

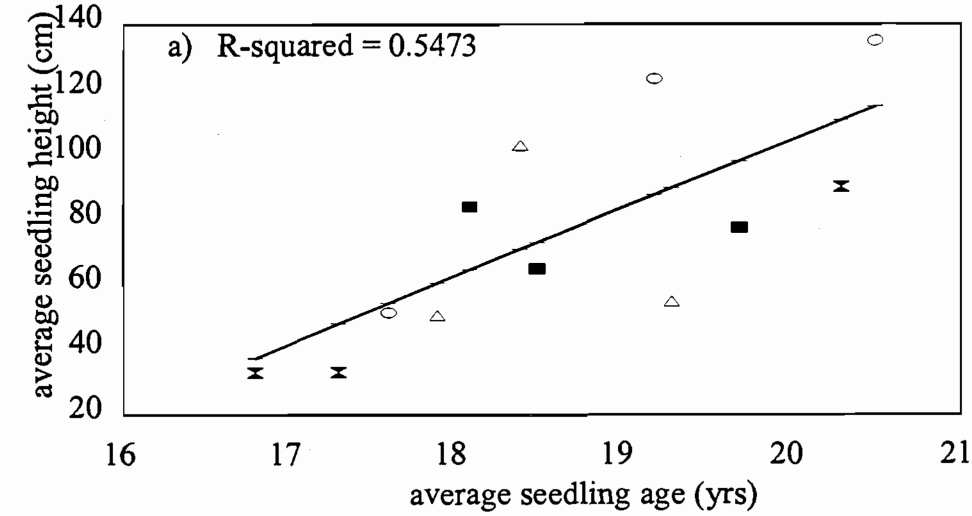
Block Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

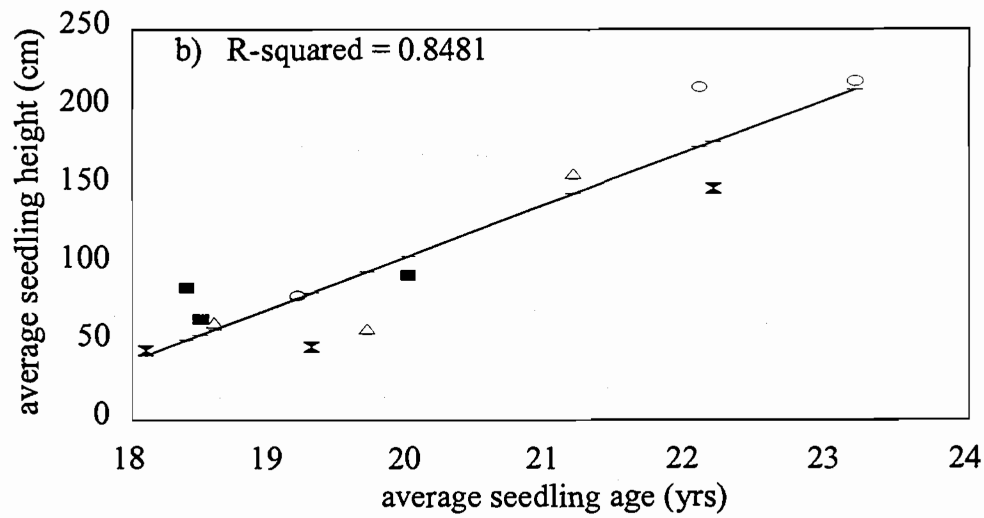
A	18.5	19.8
B	18.8	19.0
C	19.1	21.5
D	18.1	18.7
p-value	0.8251	0.2070

On eleven of the twelve plots seedling germination began between 1967 and 1970 (see figure 5a-d). This occurred regardless of overstory basal area but was presumably in response to the thinning that all twelve plots received in either 1965 or 1966. The exception was plot 25 - the lightly thinned plot on block B - on which seedlings were found on only three of the sixty-four subplots. All three of the randomly selected seedlings germinated between 1974 and 1977.

Among all twelve treated plots only two of the randomly selected seedlings germinated prior to 1966; both of which were found on heavily thinned plots (plots 30 and 41). The oldest seedlings found were thirty-two years old. This agrees with the data of Del Rio (1978), who found that the oldest seedlings in his study germinated between 1962 and 1967 depending upon the plot. Thus, at least some of the seedlings that were on the site in 1977 are still surviving. Germination peaked on most of the plots in the five year period from 1971 through 1975. On ten of the plots seedlings either stopped germinating, or surviving, between 1983 and 1985. The exceptions were plot 25 which, as explained above, had only three randomly selected seedlings of which the last germinated in 1977, and plot 28 (the moderately thinned plot in block A). This plot did stop showing new seedling germination in 1983 but had several new germinants in 1991 and 1992. This may be due to the root rot pocket expanding into the plot's treated buffer and killing several overstory trees on the plot's western edge.

As was stated previously, for individual seedlings height alone did not significantly correlate with age. On a whole plot basis however, significant linear relationships were found between average seedling age and average seedling height (see figure 6a-b). The relationship between the average height of the randomly selected seedlings versus their





△ Block A ■ Block B ○ Block C ⧗ Block D

Figure 6a-b, Average Seedling Height (**y-axis**) vs. Average Seedling Age (**x-axis**). Average height of the randomly selected seedlings from each plot vs. their average age (a). Average height of the tallest seedlings from each plot vs. their average age (b).

average age (figure 6a) was significant ($p \leq 0.0060$) and explained about 55% of the variation in seedling height among plots. The relationship between the average height of the tallest seedlings versus their average age is highly significant ($p \leq 0.0001$) and explains almost 85% of the variation in their average height among plots (figure 6b).

Seedling Growth

Data on yearly height growth were collected from each subplot from the tallest seedling and from a randomly selected one. Because the light available for growth of the tallest seedlings is limited primarily by the overstory, while the growth response of the randomly selected seedlings also reflects competition for sunlight with other (taller) Douglas-fir seedlings, the focus of the analysis will be on the tallest seedlings.

Average annual growth rates over five year periods for the tallest seedlings are shown in figure 7a-d. Because of the difficulties in identifying the remnants of either bud scale scars or annual whorls, for many seedlings, growth could not be estimated for the first several years. Therefore, especially on those plots with fewer seedlings, growth rates are not necessarily shown for all years in which seedlings existed on the plot. The general trend shown on each of the four blocks is: average annual growth increasing to a maximum in the five year period between either 1975 and 1979 or between 1980 and 1984 and then decreasing.

On three of the four blocks, at the present time, the heavy thinning has the greatest growth rate followed by the medium and light thinnings. The exception is block B where the moderately thinned plot has a slightly greater present growth rate than the heavily thinned plot. A possible reason for this may be that the moderately thinned plot in block

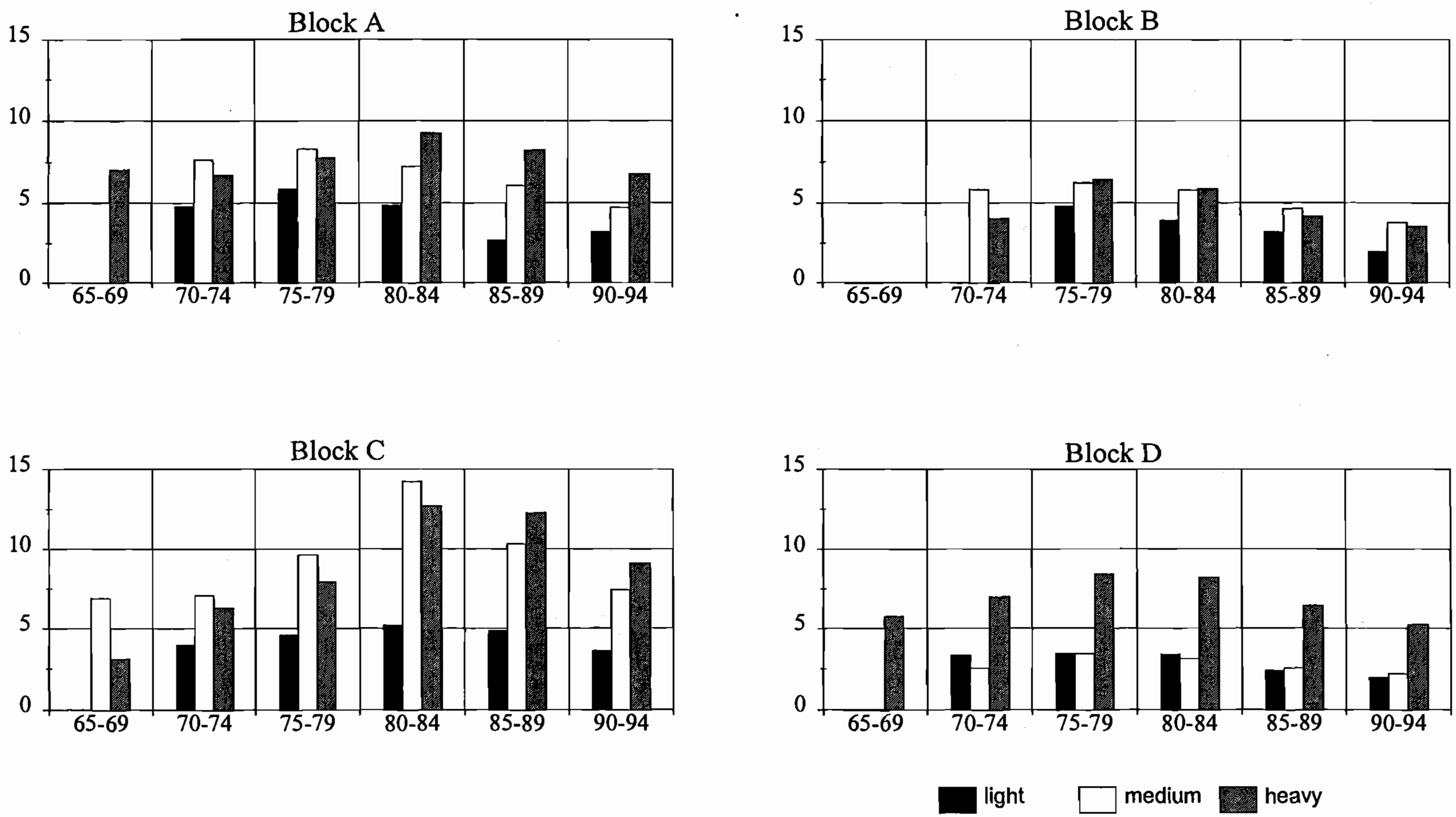


Figure 7a-d, Seedling Growth by Year - Average annual growth rates (cm/yr) of the tallest seedlings in each subplot (**y-axis**) by five year periods from 1965 through 1994 (**x-axis**).

B has a clearcut just south of the plot's treated buffer which may allow the penetration of more light from the side.

Summaries of the overall average annual growth rate as well as the average annual growth rate over the most recent five year period (1990-1994) for both the randomly selected seedlings and the tallest seedlings are given in table 11. Upon analysis several characteristics were noted that confirm what is shown graphically in figures 7a-d. For both the randomly selected seedlings as well as the tallest seedlings:

- There was a positive correlation between thinning intensity and growth rate for both the overall average annual growth rate as well as the average annual growth rate over the most recent five year period.
- The significance of differences, among both treatments and blocks, was greater for the tallest seedlings than for the randomly selected ones.
- The average annual growth rate over the most recent five year period is less than the overall average annual growth rate for individual treatment and block.
- The average annual growth rate over the most recent five year period has the most significant differences among both treatments and blocks.

Among the two open grown seedlings that were examined growth rate has shown a fairly steady increase each year since they were planted. In 1994 one grew 47 centimeters while the other grew 70 centimeters. Their worst height growth in a single year that was able to be identified was ten and twelve centimeters respectively which occurred when they were three and two years-old respectively (Tappeiner & Marshall 1994). By comparison, the greatest height growth by any seedling found in this study was 32 centimeters in a single year. The best growth occurred on the moderately and heavily thinned plots in block C over a period of several years after their most recent thinning in 1977; during this period several of the tallest seedlings showed annual growth rates of over 20 centimeters.

Table 11 - Growth Rate Summary of the Randomly Selected Seedlings and the Tallest Seedlings

	Randomly Selected Seedlings		Tallest Seedlings	
treatment	overall average annual growth rate (cm/yr)	average annual growth rate over the most recent five year period (cm/yr)	overall average annual growth rate (cm/yr)	average annual growth rate over the most recent five year period (cm/yr)
heavy	5.2	4.5 a	7.3 a	6.2 a
medium	4.2	3.4 ab	5.4 ab	4.5 ab
light	3.0	2.4 b	3.5 b	2.7 b
p-value	0.0669	0.0195	0.0286	0.0107

(within a column averages with the same letter are not significantly different from each other)

	Randomly Selected Seedlings		Tallest Seedlings	
block	overall average annual growth rate (cm/yr)	average annual growth rate over the most recent five year period (cm/yr)	overall average annual growth rate (cm/yr)	average annual growth rate over the most recent five year period (cm/yr)
A	4.2	4.0	5.2 ab	4.8 ab
B	4.0	2.9	4.3 a	3.1 a
C	5.5	4.4	8.1 b	6.7 b
D	3.0	2.5	4.0 a	3.1 a
p-value	0.1155	0.0590	0.0468	0.0180

(within a column averages with the same letter are not significantly different from each other)

Herb, Shrub, and Non-Coniferous Tree Characteristics

Low Shrub Cover

Low shrub cover data for 1974 (Wittler 1974) as well as for 1994 are summarized in table 12 and displayed in figure 8a&b. Data used include herbs, shrubs, and non-coniferous tree species less than one meter tall. In 1974 data were not taken from the lightly and moderately thinned plots in block A (plots 29 and 28). Thus, only blocks B, C, and D were analyzed. Also, in order to compare changes in shrub cover between 1974 and 1994 with changes in Douglas-fir seedling density between 1977 and 1994, the data were analyzed both with and without controls (the change in seedling density between 1977 and 1994 does not include controls because the control plots were not investigated in 1977).

Unlike seedling density, low shrub cover showed more of a response to thinning intensity in 1974 than in 1994. In 1974 there was a significant difference among treatments ($p \leq 0.0026$ with controls and 0.0389 without); the light thinnings as well as the controls were each significantly different from all other treatments while the medium and heavy thinnings had similar values (63% and 70% respectively). By 1994 there was no longer any significant difference among any of the four treatments. In the interim the treated plots averaged a decrease while three of the four controls showed an increase. The average increase by the controls is assumed to be the result of a more heterogenous (patchy) overstory on the controls in 1994 as compared to 1974. This patchiness, in turn, is assumed to be the result of the self-thinning of the overstory on the control plots which showed an average reduction in tree density of about 24% during this period.

Table 12 - Percent Ground Cover of Herbs, Shrubs, and Non-Coniferous Tree Species (0-1 meter tall)

(1974 data are from Wittler, 1974)

plot	treatment	block	1974	1994	% change
27	C	A	40	54	35.0
29	L	A	---	95	---
28	M	A	---	78	---
30	H	A	56	51	-8.9
21	C	B	38	54	42.1
25	L	B	41	41	0
24	M	B	71	94	32.4
22	H	B	79	79	0
37	C	C	8	19	137.5
34	L	C	40	38	-5.0
35	M	C	65	29	-55.4
36	H	C	54	16	-70.4
42-46-50	C	D	14	11	-21.4
40	L	D	32	24	-25.0
38	M	D	52	22	-57.7
41	H	D	78	18	-76.9

Treatment Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

		1994 w/ block A	1994 w/o block A	% change
C	20.0 a	34.5	28.0	52.7
L	37.7 b	49.5	34.3	-10.0
M	63.0 c	56.0	48.3	-26.9
H	70.3 c	41.0	37.7	-49.1
p-value	0.0026	0.3262		

(note: 1974 data and "% change" do not include block A)

Block Averages with Results of Waller-Duncan Multiple Comparisons
(within a column averages with the same letter are not significantly different)

	1974		1994		% change
	w/ controls	w/o controls	w/controls	w/o controls	w/o controls
A	----	----	69.5 a	74.7 a	----
B	57.5	63.7	67.0 a	71.3 a	10.8
C	41.7	53.0	25.5 b	27.7 b	-43.6
D	44.0	54.0	19.0 b	21.3 b	-53.2
p-value	0.1245	0.4372	0.0024	0.0287	

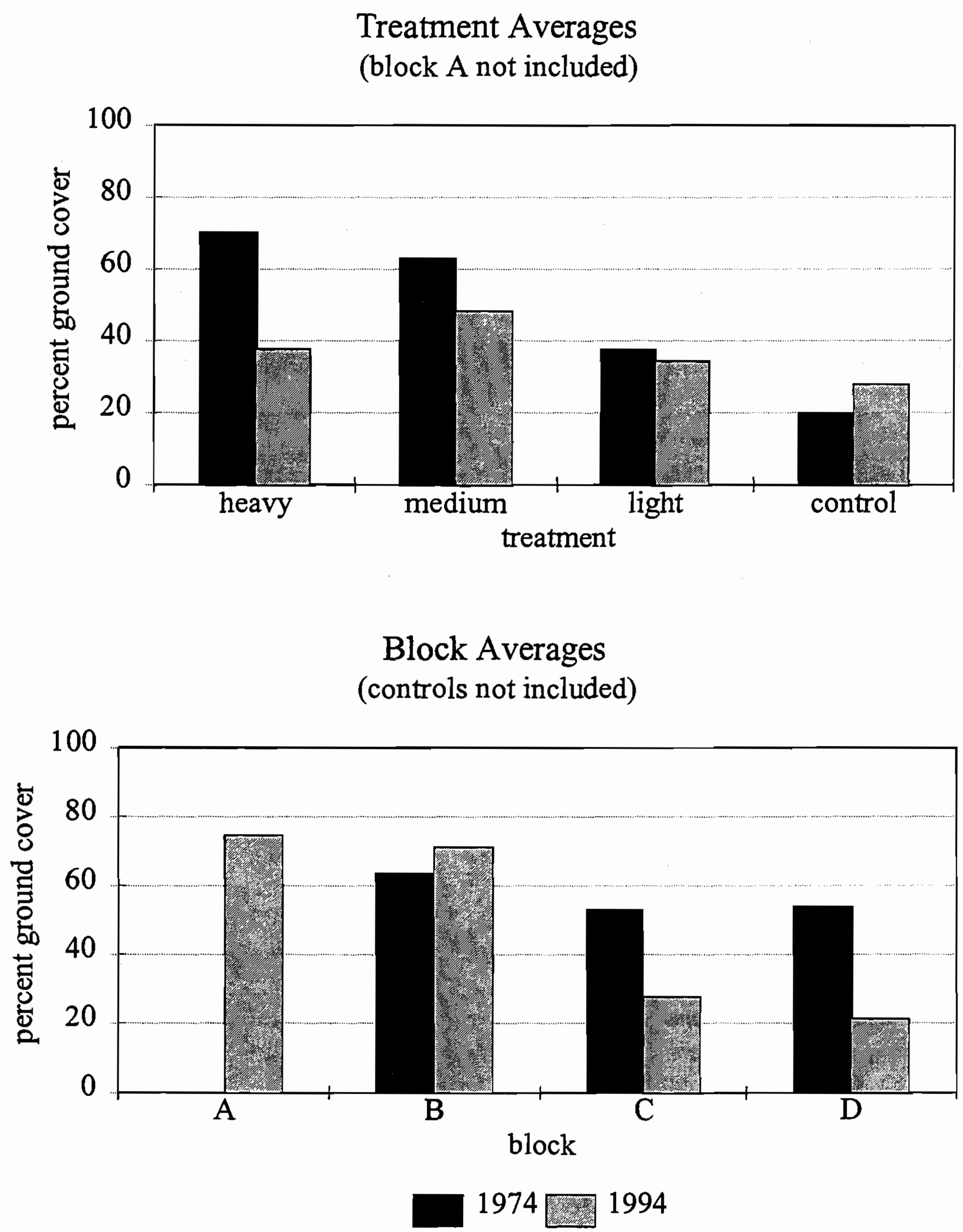


Figure 8a-b, Percent Ground Cover of Low Shrubs (herbs, shrubs, and non-coniferous tree species less than one meter tall) by Treatment (a) and by Block (b) in 1974 and 1994. (Note: because shrub cover was not measured on block A in 1974 treatment averages for 1994 also do not include block A.)

Among blocks, there were no significant differences in 1974. Between 1974 and 1994 the upper two blocks showed large decreases in percent shrub cover while the two lower blocks showed less of a change. Because of these different responses over time, by 1994 differences among blocks had become significant ($p \leq 0.0024$ with controls and 0.0287 without controls). Blocks A and B - the blocks with the least Douglas-fir regeneration - had significantly more shrub cover (75% and 71% respectively) than blocks C and D (25.5% and 19 % respectively). Thus, block differences went from being insignificant in 1974 to being significant in 1994.

In spite of the lack of a significant block effect in 1974, the controls did show the block effect that would exist among all treatments in 1994. The controls on the two lower replications had considerably more low shrub cover in 1974 (40% and 38%) than the controls on the two upper replications (8% and 14%). Thus, undisturbed areas gave an indication of areas of high shrub cover twenty years later.

In explaining current differences in percent shrub cover, among site characteristics, low shrub cover was more highly related to elevation than to either slope or site index. The relationship between percent shrub cover and elevation was negative and after a log transformation of the dependent variable to reduce the larger variance associated with lower elevations, the model had a p-value of 0.0001 with a coefficient of determination of 0.82 (see figure 9). Although soil was not evaluated as part of this study, this relationship between elevation and shrub cover is probably the result of either a soil moisture gradient or other soil characteristic that exhibits differences between the upper replications and the lower ones and not due to any effects from the small differences in elevation itself.

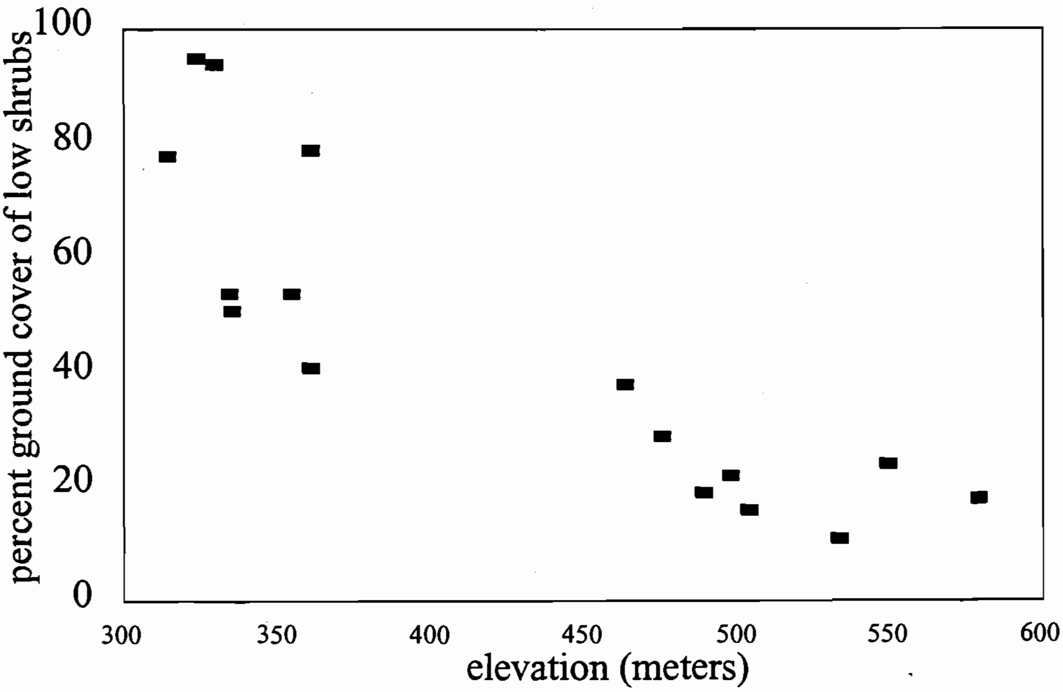


Figure 9, Plot Averages of Percent Ground Cover of Low Shrubs (herbs, shrubs, and non-coniferous tree species less than one meter tall; **y-axis**) vs. Average Plot Elevation (**x-axis**).

Cover of Individual Herb and Shrub Species

The apparent change in low shrub cover over time from a significant difference among treatments but not blocks to a significant difference among blocks but not among treatments seems to be due primarily to the behavior of both bracken fern (Pteridium aquilinum) and Oregon grape (Berberis nervosa). Percent ground cover for the most abundant individual species in both 1974 (Wittler 1974) and in 1994 are summarized in table 13. In 1974, when only fourteen of the sixteen plots were sampled, the most abundant shrub species 0-1 meter tall were bracken fern, Oregon grape, pale blue-bell (Campanula scouleri), and western starflower (Trientalis latifolia) with an average total ground cover per plot of 11.9%, 7.6%, 5.1%, and 3.8% respectively. The non-coniferous species having the greatest percent ground cover in 1994 were: Oregon grape, bracken fern, sword fern (Polystichum munitum), and salal (Gaultheria shallon) with an average cover of 22.9%, 6.3%, 4.9%, and 4.1% respectively. Analysis of both Oregon grape and bracken fern benefitted from square root transformations to create equal variances among the treatments and blocks.

In 1974 and 1994 bracken fern exhibited significant treatment differences ($p \leq 0.0350$ and 0.0441 respectively). At both times the significant differences were between the controls and the medium and heavy thinnings. There were no significant differences among the three thinning levels. Block differences were not significant in either year ($p \leq 0.9779$ in 1974 and 0.4118 in 1994). In both years it was the most abundant herb or shrub species on the two upper blocks C and D). Between 1974 and 1994 bracken fern lost ground cover on most plots (see table 13).

Table 13 - Percent Ground cover of Major Non-Coniferous Species in 1974 and 1994

(Data are presented as percent groundcover 0-1 meter tall in 1974 over percent groundcover 0-1 meter tall in 1994)

plot	Berberis nervosa	Pteridium aquilinum	Polystichum munitum	Gaultheria shallon	Campanula scouleri	Trientalis latifolia	Symphocarpus mollis	Cornus nutalli	all species
27	25/39	1/2	0/2	0/3	0/0	2/0	5/4	1/0	40/54
29	--/50	--/3	--/14	--/12	--/0	--/0	--/6	--/0.3	--/95
28	--/28	--/5	--/3	--/21	--/0	--/0	--/7	--/0	--/78
30	1/17	13/6	1/4	0/3	2/0	6/1	11/11	2/0.6	56/51
21	19/37	2/2	12/11	0/2	0/0	2/0.1	0/0.2	0/0.2	38/54
25	2/21	6/2	0/10	0/2	1/0	9/0	0/0	0/0	41/41
24	18/75	13/7	5/6	0/1	4/0	10/0	0/0.3	0/0.2	71/94
22	26/53	18/12	2/5	2/7	6/0	4/0	0/1	9/0	79/79
37	2/12	1/0.3	0/6	0/0.3	0/0	0/0	0/0	0/0	8/19
34	0/15	21/17	1/3	0/0.2	1/0	0/0	0/1	0/0.1	40/38
35	0/1	24/15	0/2	0/0	13/0	2/0	0/10	0/0	65/29
36	0/2	5/9	0/1	0/0.2	14/0	9/0	0/0.2	0/0	54/16
42-46-50	8/5	0/1	1/4	2/0.4	0/0	0/0	0/0.1	1/0	14/11
40	0/7	9/5	0/1	1/5	4/0	4/0	0/2	5/0	32/24
38	0/3	15/5	4/2	6/8	5/0	3/0	0/0.1	5/0	52/22
41	0/3	39/9	0/3	0/0	22/0	1/0	0/1	0/0	78/18
Avg.	**7.6/22.9**	**11.9/6.3**	**1.9/4.9**	**0.8/8.4**	**5.1/0.0**	**3.8/0.06**	**1.0/2.7**	**1.4/0.1**	**48.1/45.1**
			Treatment Averages (1974 treatments are based on blocks B,C, and D only)						
C	9.7/23.3	1.0/1.6	4.3/5.7	0.7/1.4	0.0/0.0	0.7/0.0	0.0/1.1	0.3/0.1	20.0/34.5
L	0.7/23.3	12.0/6.8	0.3/7.0	0.3/4.8	2.0/0.0	4.3/0.0	0.0/2.2	1.7/0.1	37.7/49.5
M	6.0/26.8	17.3/8.0	3.0/3.3	2.0/7.5	7.3/0.0	5.0/0.0	0.0/4.4	1.7/0.0	58.7/55.7
H	8.7/18.8	20.7/9.0	0.7/3.3	0.7/2.5	14.0/0.0	4.7/0.2	0.0/3.3	3.0/0.2	70.3/41.0
					Block Averages				
A	--/33.5	--/4.0	--/5.7	--/9.7	--/0.0	--/0.3	--/7.0	--/0.2	--/69.5
B	16.3/46.5	9.7/5.7	4.7/8.0	0.5/3.0	2.7/0.0	6.2/0.3	0.0/0.4	2.2/0.1	57.5/67.0
C	0.5/7.5	12.7/10.3	0.3/3.0	0.0/0.2	7.0/0.0	2.7/0.0	0.0/2.8	0.0/0.0	38.5/25.5
D	2.0/4.5	15.7/5.0	1.3/2.5	2.2/3.4	7.2/0.0	2.0/0.0	0.0/0.8	2.7/0.0	44.0/18.8

Oregon grape exhibited no preference for treatment in either 1974 or 1994 ($p \leq 0.2430$ and 0.7828 respectively), but in both 1974 and 1994 it was significantly more prevalent on the lower blocks than on the upper ones ($p \leq 0.0244$ and 0.0032 respectively). Block averages for 1974 were 16.3%, 0.5%, and 2% for blocks B through D while in 1994 they showed increases to 33.5%, 46.5%, 7.5% and 4.5% for blocks A through D. It is unknown to what degree apparent changes over time are due to real changes and to what degree they are due to employing different sampling techniques. Of the fourteen plots that were examined in both 1974 and 1994 Oregon grape appears to have increased in percent ground cover on thirteen and increased more on the lower blocks than on the upper ones (see table 13). Within the two lower blocks Oregon grape represented over half the total shrub cover on six of the eight plots in 1994. One of the two plots on which Oregon grape did not represent over fifty percent of the total shrub cover, was the only plot in the lower two blocks to experience an increase in Douglas-fir seedling density between 1977 and 1994 (plot 30). Within the upper two replications Oregon grape was the most abundant shrub on only three plots of which two were controls and represented over fifty percent of the total shrub cover on only one plot.

Salal, though less abundant than Oregon grape, appeared highly correlated with it (see table 13) and also exhibited a significant block effect in 1994 ($p \leq 0.0471$). Block A, which had the most salal, and block C, which had the least, were significantly different from each other.

Tall Shrubs and Trees

For the 1974 data of percent ground cover of tall shrubs (shrubs and non-coniferous trees 1-6 meters tall), exclusive of Douglas-fir, no significant treatment or block effects were found ($p \leq 0.9888$ and 0.7191 respectively).

The 1994 data on non-coniferous species greater than one meter tall were collected as the number of subplots within each plot that had hardwoods growing on, or over, them. This included trees from one meter up to the overstory canopy. A two-way analysis of variance shows both treatment and block differences to be significant ($p \leq 0.0128$ and 0.0063 respectively). The medium thinnings averaged the greatest number of subplots with hardwoods on or over them (26.75), followed by the heavy thinning (18.75), the light thinning (17.75), and finally the controls (7). The significant difference was between the controls and the medium and heavy thinnings; the three thinning levels did not significantly differ from each other. Among the blocks, averages were 25.5, 25.25, 11.25, and 8.25 for blocks A, B, D, and C respectively; blocks A and B were significantly different from C and D. Thus, the block effect for taller shrubs and trees was the same as it was for low shrub cover.

The major tall shrub and tree species other than Douglas-fir were: Bigleaf maple (Acer macrophyllum) the species appearing over the most subplots, vine maple (Acer circinatum), Pacific dogwood (Cornus nutallii), hazel (Corylus cornuta), and ocean spray (Holodiscus discolor). Among these species none exhibited a significant treatment effect, and neither bigleaf maple nor vine maple showed a significant block effect. The significance of the block effect for the other species ranged from 0.0417 for Pacific dogwood to 0.0116 for ocean spray. In all three cases the block with the most subplots with one of these species over them was either block A or B while the block with the fewest subplots was block C..

Bigleaf Maple

To consider bigleaf maple more specifically, seedlings under one meter and those taller than one meter were combined. Of the 252 subplots used for this portion of the study eighty-four had at least one bigleaf maple seedling. Of these subplots two in plot 28 (medium thinning in block B) had fifty-three and thirty-six seedlings respectively; the next most populated subplot had eighteen seedlings. The average height of the bigleaf maple seedlings on these two subplots was 11 and 10 centimeters respectively while the tallest seedlings on both were 18 centimeters. These two points, which fell on an old skid trail, were considered outliers and dropped from further analysis.

On a whole plot basis the number of seedlings per hectare ranged from zero (a control plot) to 2934 (a lightly thinned plot). No significant treatment or block effects exist for the number of seedlings per hectare ($p \leq 0.8241$ and 0.1694 respectively). The distribution of the number of seedlings per subplot for all of the subplots that were sampled is shown below and shows that two-thirds of the subplots had no bigleaf maple seedlings and only about 11% of the subplots had more than two seedlings.

number of seedlings/subplot	0	1	2	3	4	5	6-10	11-15	16-20
number of subplots	167	34	24	8	5	2	7	4	1

In all, 246 seedlings had their heights recorded. No significant treatment or block effects were found ($p \leq 0.4600$ and 0.4685 respectively). The height distribution among all plots was:

height (cm) (ft)	0-15 0-0.5	16-30 0.5-1	31-45 1-1.5	46-60 1.5-2	61-90 2-3	91-180 3-6	181-270 6-9	271+ 9+
number of seedlings	107	83	19	12	12	10	3	1

Of the eighty-four randomly selected seedlings that were cut for age determination, eight were lost and could not be aged. No seedlings were found less than four years-old. The oldest seedling was at least thirty years-old but it, along with others, showed signs of herbivory which could mean that they are somewhat older. Analysis of variance gave p-values for treatment and block effects of 0.2520 and 0.0790 respectively. The age distribution among all lots was:

age (yrs)	0-5	6-10	11-15	16-20	21-25	26-30
number of seedlings	9	19	10	13	16	9

Determination of Possible Sources of Plot Differences in Seedling Density

Effects of Overstory and Site Characteristics on 1994 Seedling Density

Among the characteristics of the advance regeneration that were examined (i.e. abundance, age, height, and growth rate) the most significant treatment and block effects as well as the greatest plot to plot variability were found for abundance. The results of regressions to see the degree to which each overstory or site characteristic was correlated with differences among the twelve treated plots in 1994 seedling density are given below.

explanatory variable	p-value	R^2
site index	0.1706	0.1790
slope	0.1466	0.1986
elevation	0.0676	0.2957
% canopy closure	0.0323	0.3817
% visible sky	0.3423	0.0904
relative density 1966	0.0085	0.5157
relative density 1977	0.1488	0.1966
relative density 1991	0.7111	0.0143
reduction in relative density 1957-1966	0.0032	0.5985
reduction in relative density 1957-1977	0.0090	0.5111

Data transformations of the dependent variable (seedling density) made little difference in either the significance of the models or in the amount of the total variability that they explained.

The most significant explanatory variables were relative density (the amount of the overstory that remained after thinning) and the cumulative reduction in relative density (the total amount of the overstory that was removed). Relative density in 1966, the year by which each plot had received two thinnings and the year in which much of the present regeneration began appearing, was highly significant ($p \leq 0.0085$) in explaining seedling density in 1994. It explained about 52% of the total variability among treated plots. Relative density in either 1977, the year the last thinnings were done, or in 1991, the most recent year in which the overstory was measured, did not explain a significant portion of the variability in 1994 seedling density. The cumulative reduction in relative density resulting from the first two thinnings (1957-1966) and the cumulative reduction in relative density from all thinnings (1957-1977) were both highly significant in explaining seedling density in 1994 ($p \leq 0.0032$ and 0.0090 respectively). They accounted for about 60% and 51% of the total variability respectively. Graphs showing the relationship between seedling density and either relative density in 1966, 1977, and 1991 or the cumulative reduction in relative density through 1966 and 1977 are shown in figure 10a-e.

Each of the above-mentioned overstory and site characteristics was substituted as a covariate in place of "block", and analyses of covariance were done. The square root of seedling density, which is what was used in the original two-way analysis of variance, was the dependent variable. The results, showing the significance of the covariate, were:

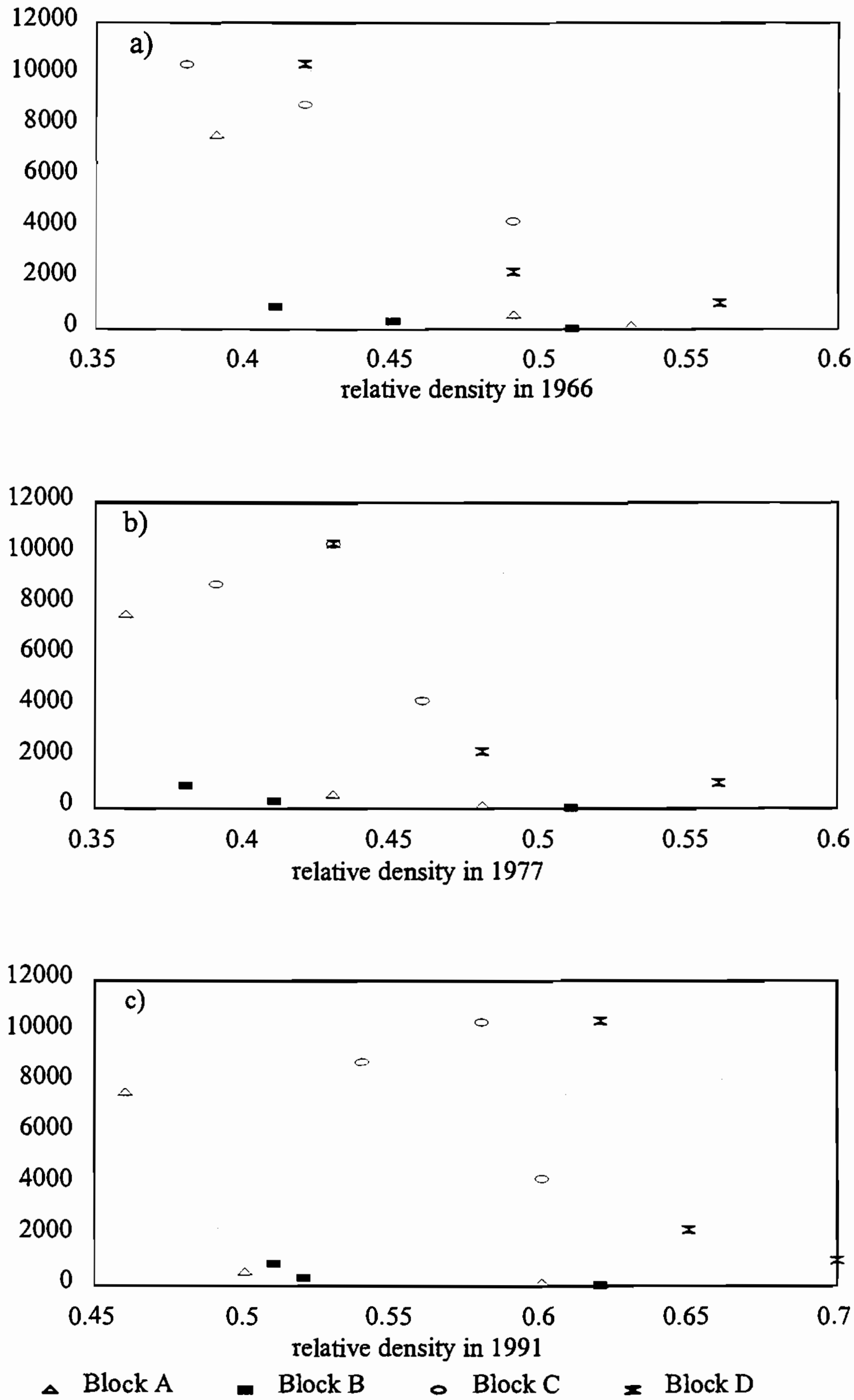


Figure 10a-c, Seedling Density in 1994 (number of Douglas-fir seedlings/hectare; **y-axis**) vs. Relative Density (**x-axis**) in a)1966, b)1977, and c)1991.

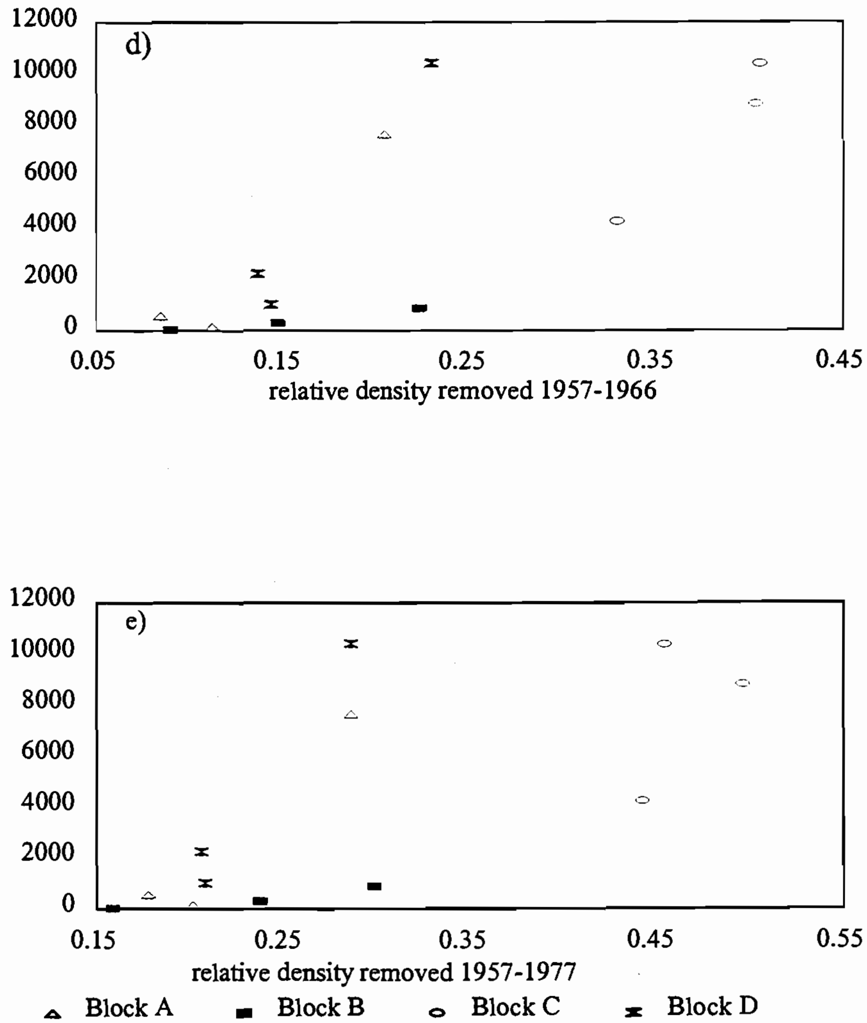


Figure 10d-e, Seedling Density in 1994 (number of Douglas-fir seedlings/hectare; **y-axis**) vs. Cumulative Reduction in Relative Density (**x-axis**) from 1957 through d)1966 and e)1977.

covariate substituted in place of "block"	p-value
slope	0.4501
site index	0.4784
elevation	0.2634
% canopy closure	0.7334
%visible sky	0.1683
relative density in 1966	0.4710
relative density in 1977	0.8959
relative density in 1991	0.7850
reduction in relative density 1957-1966	0.0953
reduction in relative density 1957-1977	0.1256

At the 95% significance level none of the variables could explain a significant portion of the variability that was not already explained by the treatment effect. The cumulative reduction in relative density through 1966, however, would be considered significant at the 90% significance level.

When "block" was reinserted in the analysis and those overstory characteristics that showed significant treatment differences were each substituted as a covariate in place of "treatment" the results (shown below) tended to be more significant.

covariate substituted in place of "treatment"	p-value
% canopy closure	0.0687
% visible sky	0.6034
relative density in 1966	0.0070
relative density in 1977	0.0763
relative density in 1991	0.2298
reduction in relative density 1957-1966	0.0234
reduction in relative density 1957-1977	0.0645

The most significant covariates were relative density in 1966 and the cumulative reduction in relative density up through 1966. At the 95% confidence level each explained a significant amount of the present variability in seedling density among the twelve thinned plots that was not explained by the block effect.

Effects of the Overstory on 1977 Seedling Density

Although treatment differences were not nearly as great as they were in 1994, seedling density in 1977 was also regressed against relative density in either 1966 or 1972 or against the cumulative reduction in relative density through 1966 or 1972. Overstory conditions for 1972 rather than for 1977 were used because 1977 seedling densities were measured prior the 1977 thinning. The results, which are given below, show that, as was the case with 1994 seedling levels, 1966 overstory conditions explained 1977 seedling densities better than more recent conditions. Unlike 1994 seedling density, 1977 seedling levels were much better explained by the cumulative reduction in relative density than by relative density. None of these parameters explained as much of the variation among the thinned plots in seedling density in 1977 as they did in 1994.

explanatory variable	p-value	R^2
relative density 1966	0.1608	0.1866
relative density 1972	0.7068	0.0148
reduction in relative density 1957-1966	0.0164	0.4534
reduction in relative density 1957-1972	0.0263	0.4043

Effect of the Overstory on 1994 Seedling Frequency

Results of regressions of seedling frequency in 1994 versus relative density or the cumulative reduction in relative density (shown below) indicate that it was also related more to 1966 differences than to those in 1977 or in 1991 (see figure 11a-b), and the reduction in relative density was a better explanatory variable than was relative density.

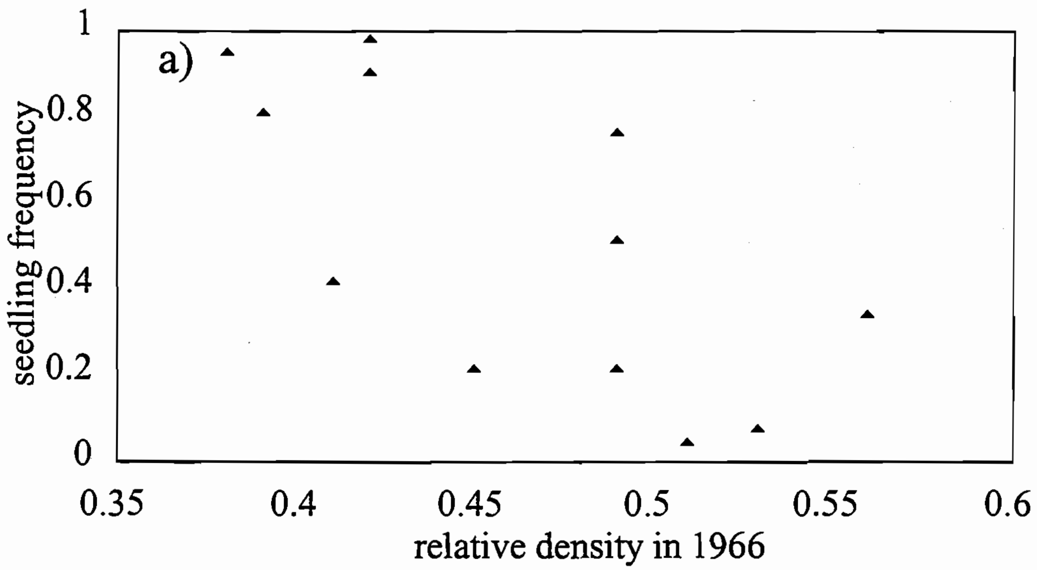
explanatory variable	p-value	R^2
relative density 1966	0.0122	0.4825
relative density 1977	0.1349	0.2092
relative density 1991	0.7549	0.0102
reduction in relative density 1957-1966	0.0008	0.6923
reduction in relative density 1957-1977	0.0021	0.6289

Effect of Shrub Cover on Seedling Density

To determine the effect that shrub cover had on 1994 seedling density the following explanatory variables from 1974 (Wittler 1974) and 1994 were evaluated.

explanatory variable	p-value	R^2
1974 percent ground cover of all herbs, shrubs, and non-coniferous trees ≤ one meter	0.4168	0.0961
1974 percent ground cover of Oregon grape and salal	0.0992	0.3030
1974 percent ground cover of Oregon grape	0.1423	0.2487
1994 percent ground cover of all herbs, shrubs, and non-coniferous trees ≤ one meter	0.0317	0.3836
1994 percent ground cover of Oregon grape and salal	0.0101	0.5001
1994 percent ground cover of Oregon grape	0.0278	0.3980

When these measures of shrub competition were the only variables used to explain 1994 seedling density, the 1994 values, which were collected from all twelve treated



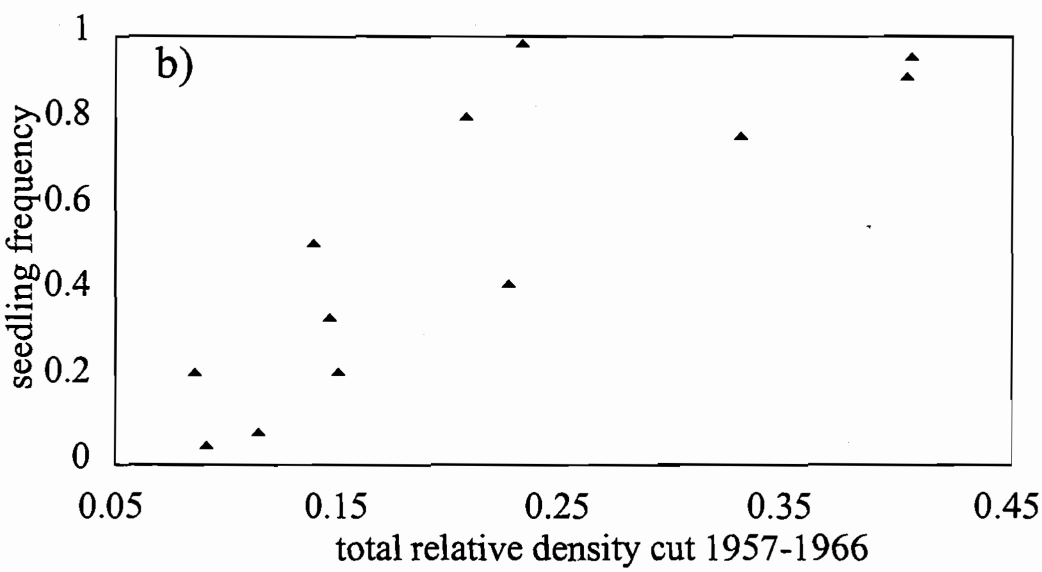


Figure 11a-b, Seedling Frequency vs. Relative Density in 1966 (a) or Cumulative Reduction in Relative Density 1957-1966 (b).

plots, were better than the 1974 values, which were collected from only ten of the treated plots. For both 1974 and 1994 the percent ground cover of Oregon grape and salal was the best explanatory variable.

As with overstory and site characteristics, the percent ground cover of Oregon grape and salal in 1974 and 1994 were each substituted as a covariate in place of "block" in the analysis of variance. The square root of 1994 seedling density was the dependent variable. Both were significant, though the percent ground cover of Oregon grape and salal in1974 was a more significant covariate than it was in 1994 ($p \le 0.0068$ and 0.0481 respectively), and therefore seems to better account for block differences in seedling density.

When two-variable regressions were evaluated, the combined percent ground cover of Oregon grape and salal in 1974 or 1994 was used as the first explanatory variable and either relative density or the cumulative reduction in relative density was used as the second. The results are shown below.

	% ground cover of Oregon grape and salal in 1974		% ground cover of Oregon grape and salal in 1994	
	p-value	adjusted-R^2	p-value	adjusted-R^2
relative density 1966	0.0003	0.8706	0.0001	0.8360
relative density 1977	0.0066	0.6940	0.0003	0.7953
relative density 1991	0.0752	0.3861	0.0035	0.6529
reduction in relative density 1957-1966	0.0216	0.5701	0.0033	0.6561
reduction in relative density 1957-1977	0.0402	0.4868	0.0053	0.6192

Comparisons of the regression containing the percent ground cover of Oregon grape and salal in 1974 versus 1994 show that, as before, 1966 values of relative density, or its cumulative reduction, were better explanatory variables than those in 1977 or 1991. The cumulative reduction in relative density from 1957 to 1966 explained almost 60% of the total variation in seedling density among plots when it was the only explanatory variable. The addition of the percent ground cover of Oregon grape and salal in 1994 increased the total variation explained by only about 6 percentage points. The addition of the percent ground cover of Oregon grape and salal in 1974 slightly decreased the total variation that was explained.

When relative density in 1966 was the only explanatory variable it explained about 52% of the variability in 1994 seedling density. The addition to the regression of the percent ground cover of Oregon grape and salal in either 1974 or 1994 increased the total variability that was explained by 35 and 32 percentage points respectively and were the best models obtained. The coefficients of both these models are given below. The significance level (p-value) of each term in the model is given in brackets beneath the term.

seedling density in 1994 = 32354 - 57616(relative density in 1966)
[0.0001] [0.0004]

- 302.4(percent ground cover of Oregon grape and salal in 1974)
[0.0008]

$p \leq 0.0003$ adjusted $R^2 = 0.8706$

seedling density in 1994 = 27203 - 44685(relative density in 1966)
[0.0001] [0.0008]

- 95.7(percent ground cover of Oregon grape and salal in 1994)
[0.0009]

$p \leq 0.0001$ adjusted $R^2 = 0.8360$

Figure 12 shows graphically the relationship among seedling density in 1994, relative density in 1966, and the percent ground cover of Oregon grape and salal in 1994.

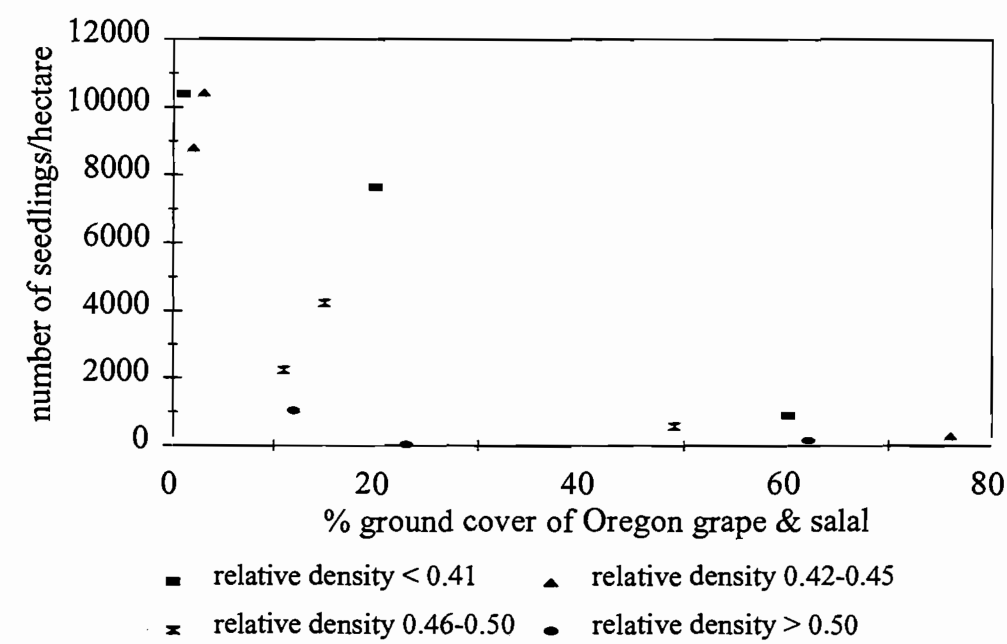


Figure 12, Douglas-fir Seedling Density in 1994 (**y-axis**) vs. Percent Ground Cover of Oregon Grape and Salal in 1994 (**x-axis**) and Overstory Relative Density in 1966.

Determination of Possible Sources of Plot Differences in Seedling Height

Effects of Overstory Characteristics

In addition to being highly correlated with seedling density, differences in average seedling height in 1994 were also highly correlated with overstory conditions. A summary of the results of regressing the average height of all seedlings against either relative density or the cumulative reduction in relative density are shown below. In all cases the response was linear.

explanatory variable	p-value	R^2
relative density 1966	0.0003	0.7503
relative density 1977	0.0360	0.3696
relative density 1991	0.2109	0.1516
relative density removed 1957-1966	0.0022	0.6251
relative density removed 1957-1977	0.0065	0.5401

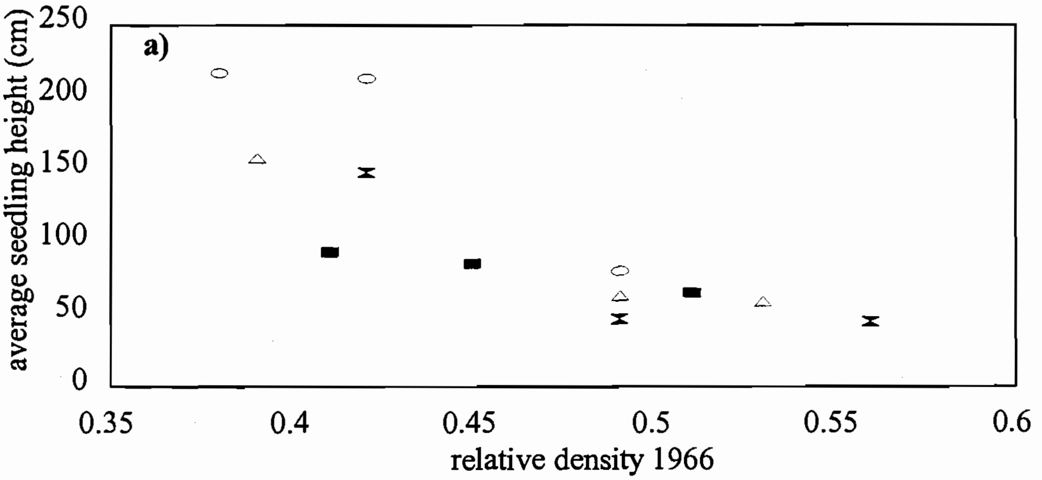
In the case of the average height of the tallest seedlings linear responses were obtained with the following:

explanatory variable	p-value	R^2
ln(relative density 1966)	0.0001	0.7803
ln(relative density 1977)	0.0096	0.5046
ln(relative density 1991)	0.1182	0.2261
relative density removed 1957-1966	0.0010	0.6756
relative density removed 1957-1977	0.0030	0.6023

As with seedling density overstory conditions in 1966 were the best explanatory variables. Unlike seedling density, the amount of the overstory that was left was better than the amount of the overstory that was removed. The relationship between the average height of the tallest seedlings and relative density in 1966 is shown in figure 12a while that of the average height of the tallest seedlings and the cumulative reduction in relative density through 1966 is shown in figure 12b.

Effect of Shrub Cover on Seedling Height

Unlike seedling density, the addition of the percent ground cover of Oregon grape and salal to the regression did not greatly improve the amount of the variation in average height that was explained. When relative density in 1966 and the percent ground cover of Oregon grape and salal in 1994 were the explanatory variables the adjusted-R^2 value for explaining the average height of all seedlings improved from 0.7503 to only 0.7828 while for explaining the natural logarithm of the average height of the tallest seedlings it improved from 0.7803 to only 0.7949. When the cumulative reduction in relative density through 1966 and the 1994 percent ground cover of Oregon grape and salal were the explanatory variables the adjusted-R^2 value for explaining the average height of all seedlings and the average height of the tallest seedlings declined from 0.6251 and 0.6756 to 0.5420 and 0.6057 respectively.



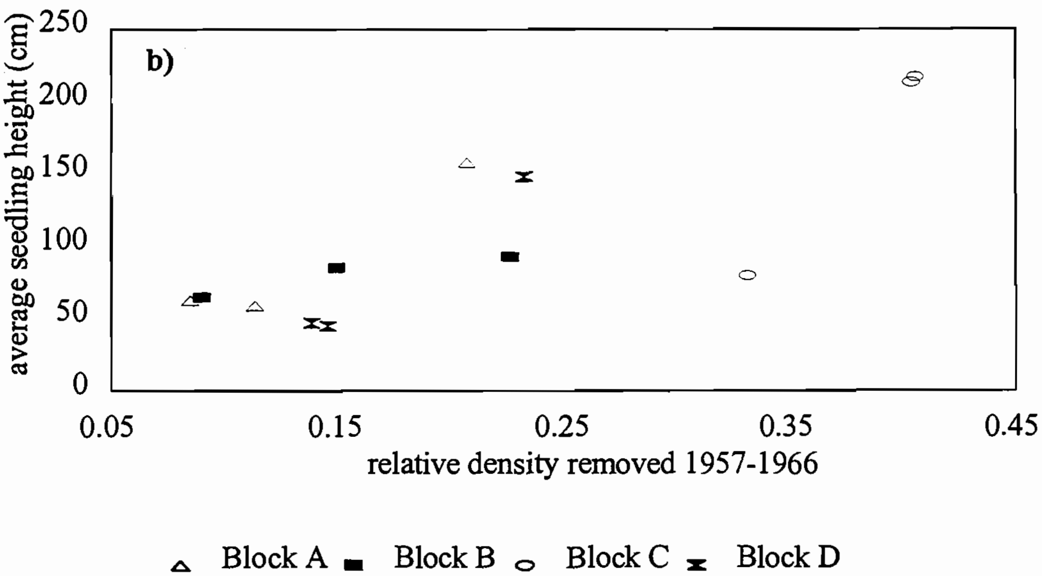


Figure 13a-b, Average Height of the Tallest Seedlings per Plot **(y-axis)** vs. Relative Density in 1966 (a) or Cumulative Reduction in Relative Density 1957-1966 (b).

DISCUSSION

The major results concerning the presence and growth of advance regeneration Douglas-fir at this site are:

- In 1994, among the treated plots, the heavy thinnings averaged the most, tallest, fastest growing, and oldest seedlings while the light thinnings averaged the fewest, shortest, slowest growing and youngest. This coincides with the findings of others who also found a correspondence between thinning intensity and the abundance and growth of advance regeneration of either Douglas-fir (Bailey 1996, McDonald 1976, Oliver and Dolph 1992) or other conifer species (Deal and Farr 1994, Bassman et al. 1992).

- After a square root transformation a significant treatment effect in seedling density was found though not among all three thinning levels. Differences in seedling density among the three treatments have increased with time. In 1977, when overstory differences among treatments were greater, treatment differences were not significant. Between 1977 and 1994 the lightly thinned plots averaged a greater loss of seedlings than the moderately thinned ones. The heavily thinned plots averaged an increase and their range of change was the largest of the three treatments. Seedling frequency, the proportion of subplots per plot that contained at least one seedling, was highly correlated with seedling density.

- Overall average age of seedlings was about nineteen years, and differences that exist among treatments were not significant. On almost all of the treated plots germination of those seedlings that are currently alive began, peaked, and ended at about the same time. The cessation in germination and/or survival between 1983 and 1985 occurred despite large differences among plots in seedling density, overstory conditions, and shrub cover. The drop in seedling density on most of the plots between 1977 and 1994 combined with the germination of many seedlings after 1977 indicates that prior to 1985 new seedlings were germinating even as older seedlings were dying. The oldest seedlings are the same ones that were present when advance regeneration was first examined seventeen years before this study (Del Rio 1978).

- Average seedling height was significantly correlated with both average seedling density and average seedling age. The average heights of the tallest seedlings showed more significant treatment differences than did the average height of all measured seedlings. Relatively few seedlings were found greater than 2.4 meters, and on most of the plots most of the seedlings were less than one meter tall.

- As with seedling height, the tallest seedlings better reflected growth rate differences among treatments and blocks than did the randomly selected ones. As thinning intensity increased, growth rate increased, indicating that height differences among treatments are due to growth differences and not solely to differences in average age among the treatments. Growth rates are decreasing. As growth rates have slowed differences among treatments and blocks have increased. This shows that growth rates among treatments are becoming more different while overstory treatment differences are becoming less distinct. In general and regardless of treatment, growth rates continued to increase until about ten to thirteen years after their most recent thinning. At no time have even the tallest seedlings on the heavily thinned plots, shown growth rates that were comparable to those of planted seedlings from an adjacent clearcut which are about ten years younger than much of the advance regeneration.

- Unlike the treatment differences, significant block differences in seedling density have existed since regeneration was first examined in 1977. Present differences among blocks account for more of the total variation among plots than do differences among treatments; density was the only seedling characteristic whose block differences were greater than its treatment differences. Of the seedling characteristics examined in 1994 seedling density showed the greatest plot to plot variability as measured by its coefficient of variation (standard deviation/mean) which was 1.0 versus 0.2 to 0.6 for height, age and the various measured aspects of height growth.

The major results concerning understory species other than Douglas-fir regeneration are:

- Of the various individual understory species that were examined, Douglas-fir was the only one whose abundance showed a significant treatment effect in 1994.

- In 1974 total shrub cover, though the difference was not significant, tended to be greater on the lower two blocks than on the upper two. The lack of significance was probably due to shrub cover not being measured on all of the plots in block A. In 1994 the difference in total shrub cover between the lower blocks and the upper ones was highly significant. Among the control plots, which have been undisturbed, the two from the lower blocks had considerably more shrub cover in both 1974 and 1994 than the two from the upper blocks. Block preferences of individual non-coniferous tree species greater than one meter tall, when they existed, were also in favor of the lower blocks.

- The principal shrub species on the lower two blocks in both 1974 and 1994 was Oregon grape, and between 1974 and 1994 its percent ground cover appears to have increased on all blocks. In 1974 and in 1994 the dominant shrub species on the upper two blocks was bracken fern whose abundance has decreased.

- Bigleaf maple, the species other than Douglas-fir that was studied in some depth, behaved very differently from both Douglas-fir as well as from most of the other trees and shrub species. Unlike Douglas-fir it showed no preference for either treatment or block. Height differences among treatments and blocks were also insignificant. Additionally, the oldest bigleaf maple seedlings tended to be about as old as the oldest Douglas-fir seedlings, but in contrast to Douglas-fir, bigleaf maple seedlings are still germinating and surviving.

The major results from the examinations of the overstory, which were done for 1966 (the year by which all treated plots had been thinned twice), 1977 (the year in which the last block received its final thinning), and 1991 (the most recent year in which overstory data were collected) were:

- Average relative density differences among all four treatments did not significantly differ until 1977. By 1991 treatment differences had begun to diminish. Block differences in relative density have steadily increased. By 1991 each block was significantly different from at least one other block.

- The cumulative reduction in overstory relative density through 1966 and through 1977 showed significant treatment differences at both times. Due to different initial relative densities, there was also a significant block effect through both 1966 and 1977.

The variability among plots in seedling density was best explained by the relative density of the overstory in 1966 or the cumulative reduction in relative density from 1957 to 1966. These explanatory variables were each better than relative density in either 1977 or 1991 or the cumulative reduction in relative density from 1957 to 1977 respectively.

This may indicate that present plot to plot differences in seedling density are affected more by past overstory conditions than by more recent ones. It is also possible that present seedling density differences may be most strongly related to the time at which plot to plot overstory differences were greatest, whether this occurred after the first, an intermediate, or final thinning or at the present time. Examination of the overstory shows that relative density in 1966 has about the same plot to plot variability, as measured by the standard deviation, as relative density in 1977 or in 1991 (0.058 versus 0.058 and 0.070 respectively). The standard deviation of the cumulative reduction in relative density through 1966 and through 1977 are also similar to each other (0.114 and 0.116 respectively). Therefore, the greater correlation between 1994 seedling density and overstory conditions in 1966, versus those in 1977 or 1991, probably exists because present differences in understory conditions are indeed more affected by older thinnings than by either more recent ones or present conditions.

Past levels of percent canopy closure and percent visible sky, had they been measured, may also have explained more of the variation in 1994 seedling density than present values did.

Analysis of covariance indicated that the cumulative reduction in relative density from 1957 to 1966 may have been explaining some of the block differences in seedling density. But, it, along with the other overstory or site characteristics, even when they exhibited significant block differences, seemed to explain differences among treatments in seedling density more than differences among blocks.

Seedling density in 1977, even though it did not show the degree of differentiation among treatments that 1994 seedling density did, also correlated more with 1966 overstory conditions than with overstory conditions after the most recent thinning at that time (1972).

Differences among treatments and blocks in seedling height were not as significant as those in seedling density but were also more significantly related to 1966 levels of both relative density and cumulative relative density removed than to 1977 or 1991 levels.

The fact that the cumulative relative density removed was as successful as relative density in explaining regeneration characteristics would be expected if initial (1957) overstory conditions had been similar throughout the site. In such a case the two parameters would be describing the same phenomenon. Initial overstory conditions, however, were not the same throughout the site (see figure 1). Both parameters explained differences among treatments in regeneration. It also seems likely that the cumulative reduction in relative density explained some aspects of the differences among blocks. As a covariate substituted in place of "block" it would be considered significant at the 90% confidence level. Specifically, it may explain the higher levels of regeneration and greater seedling height on block C relative to the other blocks. Due to its higher initial basal area, block C required the removal of a significantly higher proportion of its overstory in order that residual basal area on its plots approached the target levels for each treatment. Through both 1966 and 1977 block C had about twice as much of its relative density removed than the other blocks did (see table 4).

The reason for this being a possible reason for the better regeneration is that, within a given treatment, even though basal areas after a thinning may be equivalent, a larger initial basal area would mean that the percentage of a closed canopy that was removed during thinning would have been greater and the canopy closure of the residual stand would then be less. The first thinnings on the other three blocks may not have removed enough of the overstory to have as great an impact on canopy closure. This assumes that differences among blocks in either canopy closure or the percent of visible sky, which are now insignificant, were probably greater and more significant in the past during the thinnings.

The larger overstory removal would also probably mean increased soil disturbance from logging, which would mean a better seedbed for Douglas-fir regeneration. Additionally, Reukema (1982) found that thinnings in a Douglas-fir stand had little effect on the amount of seed produced in poor seed years but "did have a substantial effect on the amount of seed produced in some of the better seed years" and that thinning intensity and seed production were directly related. An examination of seed production at Black Rock from 1956 to 1977 found that, relative to other years, 1956, 1959, 1965, 1968, 1971, and 1972 were either good or excellent years (Berg 1978). The large overstory removal in 1966 on block C may have increased seed production on its plots, relative to the plots on the other blocks, in the seed years 1968, 1971, and 1972. Therefore, a greater overstory removal could mean more Douglas-fir regeneration due to a combination of more seed, a better seedbed, and more light for germination and growth.

Alternatively, it can be argued that the greater height and abundance of Douglas-fir seedlings in 1994 on block C could be due to its having received its last thinning later

(1977) than the three other blocks (1969-1971). Even though the 1977 thinning only brought block C's plots into line with the respective treatments on the other blocks and did not reduce them to their target basal areas, it would still represent an opening of the canopy. However, the 1977 seedling density measurements, which were done prior to this last thinning, also show a higher correlation to 1966 overstory conditions than to 1972 conditions. Additionally, in 1977 block C had more and only slightly shorter seedlings, as compared with the other blocks. At that time, it had received only two thinnings, as compared to three or four on the other blocks, and it had been eleven years since its previous thinning as compared with four or five on the other blocks.

Block differences appear to be correlated more with competing understory shrubs than with any aspect of the overstory or of the site itself. In general, the blocks could be said to be divided into two groups: the upper two blocks and the lower two blocks. The lower two blocks (A and B) averaged less Douglas-fir regeneration as well as more herb and shrub cover and non-coniferous trees than the two upper ones. On the two upper blocks it does not appear that the greater abundance of Douglas-fir regeneration is due to its being able to out-compete shrubs. Rather, it appears that on these two blocks competition with other species was not a factor. On the lightly thinned plots from both upper blocks and on the moderately thinned plot in block D there was considerable space covered with neither Douglas-fir seedlings nor other species. Additionally, the controls, which show almost no Douglas-fir regeneration on any of the four blocks, showed, in both 1974 and 1994, considerably less low shrub cover on blocks C and D than on blocks A and B. And, all herb, shrub, and non-coniferous tree species that showed any preference for blocks were more common on the lower blocks (A and B) than on the upper ones. Although it is not possible to definitively state a cause and effect relationship, it is assumed that it was the abundance of the competing species on the lower two blocks that is the cause of their lower levels of Douglas-fir regeneration.

The herb and shrub species that appear to affect Douglas-fir seedling density the most are Oregon grape and salal. Their combined percent ground cover in both 1974 and 1994 appears to explain the significant block differences in seedling density. And, when each was combined with relative density in 1966 the resulting regressions explained as much of the variation in seedling density among the treated plots as was explained by the original two-way analysis of variance.

When the cumulative reduction in relative density was combined with the percent ground cover of Oregon grape and salal in both 1974 and 1994 the resulting regressions did not explain much more of the total variation in seedling density than the cumulative reduction in relative density did by itself. This implies that, to some degree, they are explaining different aspects of the block effect. The cumulative reduction in relative density may explain why the plots making up block C had higher than average seedling densities for their respective treatments while the levels of Oregon grape and salal explain why most of the plots in blocks A and B had low seedling densities. This suggests that seedling density on the plots making up blocks C and D seems to be explained largely by past overstory conditions while on blocks A and B it is explained by present and past shrub competition as well as by past overstory conditions.

Shrub competition, when combined with past overstory conditions, did not explain significantly more of the plot to plot variation in seedling height than was explained by past overstory conditions alone. This indicates that height may be less affected than density by herb and shrub competition.

The direct relationship between average height and average seedling density has also been noted for Douglas-fir seedlings grown in the open; after seven to nine years seedlings planted at higher densities were taller than those planted at lower densities (Scott et al. 1992). However, the reasons for this similarity between understory and open-grown seedlings may be somewhat different. At Black Rock, plots with more and taller seedlings are the plots that probably received more sunlight in the past. In open-grown seedlings all plots receive equivalent amounts of sunlight. The greater height associated with higher densities in open-grown seedlings is probably due to seedlings allocating more resources to height growth due to an inability to grow as much laterally as seedlings planted at wider spacings.

CONCLUSIONS

The small number of replications, the number of confounding factors, and that it was implemented on a single site make the following conclusions of both tentative and limited.

- Thinning intensity affects both the abundance and size of Douglas-fir regeneration in the understory. Regeneration is related not only to the amount of the overstory that is left (relative density) but also to the amount of the overstory that is removed (cumulative reduction in relative density) and is probably best explained by a combination of both.

- Among abundance, age, height, and growth rate, abundance is not only the most affected by thinning intensity but is also the most affected by shrub competition. Shrub competition, specifically Oregon grape and salal, strongly negatively impacts the abundance, but not the height, of advance regeneration. Seedling abundance is most satisfactorily explicable in terms of both overstory and understory conditions while seedling height, at this site, is largely explicable in terms of the overstory alone.

- Treatment differences in the abundance and growth of advance regeneration increase after the cessation of thinnings even as overstory treatment differences, actual seedling numbers, and seedling growth rates decrease. In the absence of further thinnings, it is presumed that the significance of differences among treatments and blocks in the growth and abundance of advance regeneration Douglas-fir will probably continue to increase even as actual growth and abundance decline on all plots.

- To a large degree differences in height and abundance created by the first thinnings maintain themselves through later thinnings and up to the present. This may indicate that the later thinnings, even though they reduced overstory basal area on each plot to the same target levels as before, were probably not sufficiently heavy to have as large an impact as the initial thinnings on the advance regeneration. This in turn may indicate that as seedlings grow they need more light than they do when they are small. It may also mean that as the overstory ages, thinnings reducing the overstory to the same residual basal area as before may not open the canopy as much as they do when the overstory is younger.

- Whether seedling height growth is increasing or decreasing prior to release has been shown to strongly affects its growth after release. Because, on these plots, regardless of treatment, decline in growth started ten to thirteen years after the final thinning, thinnings designed to foster natural regeneration should probably not be spaced more than ten years apart.

These findings show that, at the thinning levels examined in this study, advance Douglas-fir regeneration can establish and maintain itself in the understory for many years but will never grow at rates comparable to seedlings grown in the open. If thinnings are done for the purpose of encouraging natural regeneration and have it grow to become part of the mid-story, these findings suggest the following management guidelines. In terms of site selection, overstocked stands that may have been conditioned through light thinnings to support the removal of a large portion of the overstory while still remaining wind-firm and that have little potential for shrub competition, should be preferred sites. In terms of management actions, multiple thinnings that are progressively heavier and spaced no more than about ten years apart are probably necessary.

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Plot/Tree Data Card

Plot Number 1-4	Tree Number 5-7	Tree Count 8-13	Tree History 14	Species 15-17	DBH 18-21	Diameter Inc. 22-24	Total Height 25-27	Ht. to Topkill 28-30	Height Inc. 31-34	Cwn Ratio Code 35	Damage Code 36-37	Severity Code 38-39	Damage Code 40-41	Severity Code 42-43	Tree Value Class 48	Cut/Leave Code 49	Slope (%) 50-51	Aspect (deg) 52-54	Habitat Type 55-57	Topo. Position 58	Site Prep. 59

Data form for Suppose, Data Translator and FVS (Ver.6.x)

Stand Data Card

Project: ______________________ **Crew:** ______________________

Data file name: ______________________ **Date** ______________________

Nearest National Forest ________	Colv=621; Kanik=113; Koot=114; Okan=608; Wen=617; GP=603
Habitat Type ________	Contact FRIS for appropriate guides.
Stand Origin year ________	Used to give starting age to stand projection
Aspect (deg.) ________	
Slope (%) ________	
Elevation (x 100) ________	Elevation in 100's of feet, e.g., 3,500'=35
BAF ________	For trees > or = to breakpoint DBH, use only one BAF per stand.
Inverse of fixed plot size ________	FRIS standard, for trees < breakpoint DBH. See table for plot size.
Break-point DBH ________	Usually 5.5", FRIS standard. Sets DBH boundary between variable radius (BAF) and fixed plot methods
No. plots taken ________	Total number plots, includes non stockable plots
No. Non-stockable plots ________	Plots incapable of supporting trees. NOTE: Data translator expects # of stockable plots.
Diam.-growth translation code ________	0=increment core data, FRIS standard
Diam.-growth msmt. period ________	Usually 10 years, FRIS standard
Ht.-growth translation code ________	0=direct measurement of ht. growth
Ht.-growth msmt. period ________	usually 5 years
Mortality msmt. period ________	usually 2 years, FRIS standard