AN ABSTRACT OF THE THESIS OF

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Title: Conifer Regeneration, Understory Vegetation and Artificially Topped Conifer Responses to Alternative Silvicultural Treatments.

Abstract approved:

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Historically, between 40-60% of the Coast Range of Oregon was comprised of structurally diverse, old forests initiated by disturbances of various spatial scales ranging from thousands of acres (large fires) to the size of a single tree (windthrow). The predominant regeneration method of the past several decades, however, has been clearcutting of units that are at least 8 ha in size followed by burning and/or herbicide application and planting of Douglas-fir (*Pseudotsuga menziesii*) seedlings at high densities. Some question the ability of this regeneration method to provide many of the structural characteristics that existed historically in Pacific Northwest forests. In order to address these concerns, alternative silvicultural practices have been proposed in which green trees and snags are maintained after harvest so that species reliant upon these structures are able to persist through the artificial disturbance. Our research assessed conifer regeneration, understory vegetation, and artificial snag dynamics 16 to 18 years after treatment in clearcuts and two alternative silvicultural regimes: two-story-75% of volume removed resulting in 20 to 30 green trees/ha and group selection-33% of volume removed in 0.2 to 1.0 ha circular, square, or strip-shaped gaps. All harvested areas were planted with Douglas-fir seedlings and competing vegetation was controlled using herbicide. Uncut controls were included in the study and monitored. Concurrent with harvest, 804 mature Douglas-fir trees were topped both with and without retention of live branches in order to create snags and living character trees.

Conifer regeneration growth and survival were greatest in the clearcut treatments, intermediate in the two-story treatment and least in the gaps of the group

selection treatment. Gap size was positively correlated with regeneration growth but had no significant effect on survival.

Understory vegetation communities were generally resilient to disturbance and silvicultural regime had no effect on either total plant cover or tall shrub cover. More disturbed areas had greater species diversity which was driven largely by greater abundance of exotic ruderals. Young stand development may have had a larger impact on vegetation communities than silvicultural treatment.

Twenty-four percent of artificially topped conifers with live branch retention remained living 16 to 18 years after treatment. Only 4% of artificially topped conifers with no live branch retention had broken 16 to 18 years after treatment. DBH of artificially topped conifers was negatively correlated with probability of falling.

Conifer Regeneration, Understory Vegetation and Artificially Topped Conifer Responses to Alternative Silvicultural Treatments.

by
Tristan Huff

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APPROVED:

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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.

Tristan Davis Huff, Author

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CHAPTER 1 – INTRODUCTION

Historically, from 40-60% of the Coast Range of Oregon was comprised of structurally diverse, old forests initiated by disturbances of various spatial scales ranging from thousands of acres, (large fires), to the size of a single tree (windthrow) (Agee 1991, Spies and Cline 1988, Ripple 1994). These historic disturbance types initiated the structurally complex forest stands observed by early European explorers and settlers. The predominant regeneration method of the past several decades, however, has been clearcutting of units that are at least 8 ha in size followed by burning and/or herbicide application and planting of Douglas-fir seedlings at high densities. As part of routine land management, varying amounts of deadwood and live-trees have been retained since the 1970s (Maguire and Chambers 2005).

Some question the ability of this regeneration method to provide many of the structural characteristics that existed historically in Pacific Northwest forests. In order to address these concerns, “New Forestry” practices have been proposed (beginning in the 1980’s) in which green trees, snags, and logs are maintained after harvest so that species that rely on these structures are able to persist through the artificial disturbance (Franklin 1989). Over time, these legacy structures will promote structurally diverse forests that more closely resemble historic conditions while still allowing for commodity production. However, the costs (both ecological and economic) associated with New Forestry methods are significant in some forest types (Niemela et al., 2001) and the long-term outcomes of their implementation are largely untested.

Alternative silviculture vegetation dynamics

Two well-established silvicultural systems that might be utilized to achieve New Forestry goals are irregular shelterwood (or two-story) methods which create two-aged stands, and group selection methods which create uneven-aged stands (Tappeiner et al., 2007, Emmingham 1998). However, Nyland (2003) and Brandeis et al. (2001), highlight the challenge of establishing new cohorts under existing canopies, especially when dealing with shade-intolerant species. In regards to two-aged systems, early growth of both Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (T*suga heterophylla Tsuga heterophylla* (Raf.) Sarg). growing in western Washington decrease as the level of overstory retention increases (Harrington 2006). Five year *survival*, however, was found to be high (>90%) and not significantly affected by levels of overstory retention up to an relative density (RD) of 3.8 ($RD = G/(Dg^{½})$), where G is basal area and Dg is quadratic mean stand diameter; Curtis, 1982).

In the case of group selection, Gray et al. (2002) described how the creation of gaps influence the light, temperature, and soil moisture environments. Malcolm et al. (2001) reviewed how variables such as those considered by Gray et al. are affected by gap size and, ultimately, affect seedling growth. They determined that for species of intermediate shade tolerance, such as Douglas-fir, gaps with diameter/height (d/h) ratios (the diameter of the gap divided by the height of the trees comprising the surrounding matrix) of around 1.5 are required to achieve satisfactory growth.

Partial overstory removal will also affect understory vegetation that competes with regenerating conifers. When trees are removed, available growing space increases and vegetation can rapidly establish. Specifically, Bailey and Tappeiner (1998) found that the density of tall shrubs increases following thinning of Douglas-fir/ western hemlock forests in western Oregon. Because the level of competing vegetation has been found to influence the survival and growth of planted seedlings (Rose and Ketchum 2002, Roth and Newton 1996), understory development as a result of partial overstory removal will likely affect regeneration success. Indeed, Ketchum (1995), Brandeis et al. (2001) and Harrington (2006) all found increased stem volume growth rates and survival (Ketchum 1995 and Brandeis et al. 2001 only) for underplanted conifer seedlings when competing vegetation was controlled.

Of course, the understory vegetation that competes with regenerating conifers is also an important component of old-growth structure and managers may be interested in managing for this structural aspect. Contrary to young, even-aged plantations which contain most of their foliage in the upper canopy, the foliage in an old-growth Douglas-fir forest is distributed from the ground to the top of the canopy (Parker and Brown 2000). One way to encourage the development of understory vegetation communities similar to those found in old-growth forests is to emulate the disturbances that, historically, resulted in their creation (McComb et al. 1993). Differing views, however, exist regarding how forests develop and succeed.

One conceptual forest development model breaks the process into four relatively distinct stages in which the amount of available growing space varies as stand succession progresses (Oliver and Larsen 1996). Immediately following a stand-replacing disturbance, pioneer species quickly occupy the available growing space on a site. Once a site is fully occupied, tree species form a dense canopy which excludes shade-intolerant understory species. During the understory reinitiation stage, gaps in the overstory caused by single-tree mortality allows for the establishment and growth of understory species. An old-growth steady-state results when gap creation from individual tree mortality and small-scale disturbance allows for tree regeneration. Many have described this gap-phase regeneration method as the predominant regeneration process in old-growth forests of many ecosystems (Jones 1945, Runkle 1981, Spies et al. 1990).

However, some evidence suggests that today's old-growth stands didn't develop following this trajectory; it is likely that they developed under relatively open-grown conditions, perhaps at densities as low as 77 to 114 trees/ha (Tappeiner et al. 1997). This suggests that, historically, dense shrub cover may have existed for longer periods of time than under current management regimes.

Character tree and snag dynamics

Standing dead trees (snags), living trees with decay, and hollow trees are all important structural components of Pacific Northwest forest ecosystems. Numerous taxa use snags for nesting, denning, foraging, or as a growth substrate (Thomas et al. 1979). Living trees with decay exhibit structural complexities such as multiple tops and hollow chambers that are used by various canopy dwelling species (Bull et al.

1997). Hollow trees provide nesting, roosting and denning sites for a wide variety of species including Vaux's swifts (*Chaetura vauxi* Townsend), black bears (*Ursus americanus* Pallas) and American martins (*Martes Americana* Turton).

Research has shown, however, that current intensive forestry methods may significantly reduce both the number and quality of snags and living trees with decay in intensively managed forests. Cline et al. (1980) found that managed Coast Range sites in Oregon had fewer and smaller snags than similar unmanaged stands. This reduction in snag quantity and size was hypothesized to be caused by the salvage of sound snags, falling of dangerous snags, and reduced snag recruitment from competition-induced mortality. Wilhere (2003) simulated snag dynamics in a generalized industrial forest and estimated total snag density in managed stands to be only a fifth of that in unmanaged stands. Additionally, his model estimated the density of large snags (63 to 89 cm, DBH) to be only 1% of the density simulated for unmanaged stands.

While uncertainty exists regarding snag dynamics in both managed and unmanaged landscapes, it's clear that routine forest management has reduced snag quality and quantity versus historic levels. In order to address this issue, "New Forestry" practices have been proposed in which snags and structurally complex live trees are maintained through harvest cycles so that these ecosystem components persist through the artificial disturbance (Franklin, 1989). Federal and state regulations have responded to these concerns by requiring some number of snags and green trees to be retained following harvest. In order to retain these structures, however, they must first exist. Wilhere (2003) showed how self-thinning in older stands can result in the creation of large snags, however such snag creation only occurs when there exists competition-induced mortality which is generally minimized through the use of carefully timed thinnings when managing for timber objectives (Tappeiner et al. 2007). Additionally, any naturally-occurring snags can be hazardous to workers if they are left standing during harvest operations (US Department of Labor, 2006).

As an alternative to relying upon naturally-occurring snags to meet the needs of wildlife, some managers turn to artificially created snags. When snags are purposefully created, they can be "placed" at appropriate densities where they will be out of the way of current and future harvest operations. Various methods have been used to kill live trees in order to create snags (Lewis 1998). Trees can be girdled, inoculated with fungus, injected with herbicide, or treated with pheromones in order to encourage insect attack. These methods all retain the tree's full structure and may help encourage heart rot which could increase a snag's value as wildlife habitat (Bull et al. 1997). However, neither girdling, inoculation, herbicide nor insect pheromones guarantee tree death, and snags with an intact top but wounded base may be more susceptible to windthrow than ones which have had their tops removed (Bull and Partridge 1986). Alternatively, trees can also have their crowns fully or partially removed by topping with a chainsaw or dynamite. When all live branches are removed, tree death is guaranteed and rapid, whereas death may be delayed or might not occur at all if some live branches are retained (Bull and Partridge 1986). Hallet et al. (2001) found that snags created by topping were used more by cavity excavating birds than snags that were killed by girdling.

While the decomposition and fall rates of naturally-occurring snags are relatively well understood (Cline et al. 1980, Garber et al. 2005, Chambers and Mast 2005, Russell et al. 2006) the dynamics of artificially-topped conifer trees are not well studied. The fall rate of natural snags is approximated by a sigmoidal pattern where rapid fall rates follow a significant lag time during which newly killed snags decompose and weaken (Cline et al. 1980, Harmon et al. 1986, Garber et al. 2005). However, when healthy live trees are topped and live branches remain, an additional lag time exists between the time the tree is topped and the time the tree dies, if it ever does die. Two other differences exist between natural snags and topped trees: natural snags will generally be taller with correspondingly larger height:diameter ratios, and the cut tops of topped conifers provide an entry point for fungi that intact natural snags lack. Because of these differences, it is important to differentiate between natural snags, fatally-topped trees (FTTs), and non-fatally-topped trees (NFTTs) when studying snag dynamics.

Another poorly studied aspect of snag dynamics is how surrounding forest structure affects a snag's longevity. Garber et al. (2005) considered a stand's silvicultural prescription when modeling natural snag longevity, but differences in stand structure were most likely overridden by the mechanical damage resulting from harvest activities.

Study approach

My study is designed to add to our knowledge of conifer regeneration, understory vegetation, and topped-tree dynamics under alternative silvicultural regimes. I utilize the College of Forestry Integrated Research Project (CFIRP) a research project initiated by OSU's College of Forestry in 1989 and designed to "help our understanding of the tradeoffs associated with a set of alternative management approaches representing a spectrum of conditions: from even-aged with retention to uneven-aged to uncut mature forests" (Maguire and Chambers 2005). This long-term study has been used to test effects of alternative silvicultural regimes on, among other things, harvest efficiency, vertebrate wildlife use, and public acceptance (Maguire and Chambers 2005).

In chapter two, I describe stand-level characteristics of 17 year-old Douglas-fir regeneration (planted and natural) growing under three distinct silvicultural regeneration treatments: group selection, irregular shelterwood (two-story), and clearcut. Additionally, I evaluate how site characteristics and size of group selection openings (gaps) affect the regeneration growing within them. Chapter three assesses understory vegetation communities in each of the three alternative silvicultural regimes discussed above, 16 to 18 years after treatment. I compare percent cover of various functional groups as well as species richness and diversity. In Chapter four I investigated the long-term dynamics of both FTTs and NFTTs (all Douglas-fir) within the context of the same three distinct silvicultural regimes by quantifying the effects of individual stem characteristics and surrounding forest structure on their mortality and fall rates.

CHAPTER 2 – CONIFER REGENERATION RESPONSE TO ALTERNATIVE SILVICULTURAL TREATMENTS

Introduction

Two well established silvicultural systems that might be utilized to achieve alternate goals are irregular shelterwood (or two-story) methods which create two-aged stands, and group selection methods which create uneven-aged stands (Tappeiner et al., 2007, Emmingham 1998). However, Nyland (2003) and Brandeis et al. (2001), highlight the challenge of establishing new cohorts under existing canopies, especially when dealing with shade-intolerant species. In regards to two-aged systems, early growth of both Douglas-fir and western hemlock growing in western Washington decrease as the level of overstory retention increases (Harrington 2006). Five year *survival*, however, was found to be high (>90%) and not significantly affected by levels of overstory retention up to an relative density (RD) of 3.8 (RD = $G/(Dg^{½})$, where G is basal area and Dg is quadratic mean stand diameter; Curtis, 1982).

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Along with changes in understory environment, partial overstory removal will affect understory vegetation that competes with regenerating conifers. When trees are removed, available growing space increases and vegetation can rapidly establish. Specifically, Bailey and Tappeiner (1998) found that the density of tall shrubs increases following thinning of Douglas-fir/ western hemlock forests in western Oregon. Because the level of competing vegetation has been found to influence the survival and growth of planted seedlings (Rose and Ketchum 2002, Roth and Newton 1996), understory development as a result of partial overstory removal will likely affect regeneration success. Indeed, Ketchum (1995), Brandeis et al. (2001) and Harrington (2006) all found increased stem volume growth rates and survival (Ketchum and Brandeis et al. only) for underplanted conifer seedlings when competing vegetation was controlled.

While the studies above generally considered individual variables affecting conifer seedlings growing under various levels of overstory retention, our research utilizes an established experimental study to compare stand-level characteristics of 17 year-old Douglas-fir regeneration (planted and natural) growing under three distinct silvicultural regeneration treatments: group selection, irregular shelterwood (two-story), and clearcut. Additionally, I evaluate how site characteristics and size of group selection openings (gaps) affect the regeneration growing within them.

Specifically, I seek to answer the following research questions:

Stand level- How do (a) median height of the largest trees, (b) median DBH of the largest trees, (c) median H:D ratio of the largest trees, (d) relative stocking and (e) average basal area of 17-year-old Douglas-fir plantations differ by the silvicultural system under which they were planted (clearcut, two-story, group selection)?

Gap level- How are (a) median height of the largest trees, (b) median DBH of the largest trees, (c) median H:D ratio of the largest trees, (d) relative stocking and (e) average basal area of 17 year old Douglas-fir plantations growing in gaps affected by (a) the size of the gap, (b) site productivity and (c) the amount of potential direct incident solar radiation (as determined by slope and aspect)?

Methods

Site Description

I utilize the College of Forestry Integrated Research Project (CFIRP) a research project initiated by OSU's College of Forestry in 1989 and designed to "help our understanding of the tradeoffs associated with a set of alternative management approaches representing a spectrum of conditions: from even-aged with retention to uneven-aged to uncut mature forests" (Maguire and Chambers 2005). The CFIRP study split among three geographically distinct sites in Oregon State University's

4,550-ha McDonald-Dunn Research Forest. The forest is located on the east flank of the Coast Range as it transitions into the Willamette Valley. Elevation across the sites ranges from approximately 120 to 400 m. Slope and aspect both vary by stand. Soils across the three sites are predominantly (93%) comprised of the Dixonville, Jory, Philomath, Price, and Ritner series which are generally deep, well drained silty clay loams derived from basalt parent material. About 7% of the area making up the CFIRP sites is comprised of the Abiqua and Waldo soil series which are alluvial soils associated (on these sites) with terraces and fans of small seasonal streams.

Precipitation averages 104 cm annually with most occurring as rain in the winter and spring (July monthly rainfall averages only 0.1 cm). This is on the low end of the Coast Range's precipitation gradient. Low temperatures in January average 0.5°C while August highs average 27°C (Western Regional Climate Center). Site index (50 year base age) across the sites range from 28 to 40 m (King, 1966)

Study areas occurred within two plant association types: Douglas-fir/hazel/brome-grass (*Pseudotsuga menziesii/Corylus cornuta* var. *californica/Bromus vulgaris*) and Douglas-fir/vine maple/salal (*Pseudotsuga menziesii/Acer circinatum/Gaultheria shallon*) (Franklin and Dyrness 1973). Vegetation was generally similar across sites prior to treatment. Total basal area of stands ranged from 24 to 76 m^2/ha, of which hardwoods comprised between 5 and 26%. Douglas-fir dominated the overstory although there was a small component of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.). Stands ranged in age from 45 to 144 years, and the average height of the 40 largest trees per stand (height top 40) ranged from 29 to 54 m (Maguire and Chambers 2005.

Study Design

Thirty stands comprising 331 ha were designated, each within one of three geographically distinct sites (Saddle, Peavy, or Dunn) as is shown in Figure 2.1. Each of the stands was assigned to one of 3 silvicultural treatments:

Clearcut	1.2 green trees retained per ha.
Two-story	75% of volume removed resulting in 20 to 30 green trees/ha.

Group selection	33% of volume removed in 0.2 to 1.0 ha circular, square, or strip-shaped gaps**.**

The above prescriptions were designed to incorporate New Forestry goals while still being operationally efficient. Treatments were assigned randomly after being stratified in a way such that both cable and ground-based logging would be equally represented in all silvicultural treatments. This method of treatment assignment was not assumed to lead to confounding errors. The number of stands assigned to each treatment is as outlined in Table 2.1.

Stands were harvested between Fall of 1989 and Summer 1991. Stands with a significant portion greater than 30% slope were harvested using a skyline yarder and flatter stands were harvested using a grapple skidder or tractor with winch. Skyline corridors and skid trails were designated by researchers and reviewed by logging contractors (Maguire and Chambers 2005). Planting took place in either the winter of 1990-91 (Saddle site) or the winter of 1991-92 (Peavy and Dunn sites). The harvested areas of all treatments were regenerated using 1-1 or P-1 Douglas-fir seedlings planted at a spacing of 3.4 by 3.4 m to 4 m (625-865 TPH) depending on treatment. Two to five years following planting, all treatments received herbicide applications as needed to control competing vegetation. Planting and vegetation control methods were typical to forest management methods in the region. Specific planting and vegetation management regimes implemented are outlined in Appendix A.

Data Collection

Data on regenerating plantations were collected Fall and Winter of 2007. Remnant overstory trees were not considered in my study. *Two-story* and *clearcut* stands were sampled using 0.008 ha (1/50th acre) fixed radius plots spaced on a grid 90m by 90m (4.5 chains by 4.5 chains). All conifers greater than 1.3m tall (but not pre-harvest remnants) within the plots were tallied and measured for diameter at 1.3m (DBH) and total height. Species and defect were also noted. In *group selection* stands, half of the gaps in each stand were randomly selected for measurement. Within selected gaps, a 6m wide belt transect was installed running from the southern edge of the gap through the center to the north edge of the gap. The length of each transect was recorded for the purpose of per-hectare extrapolation. All conifers within the belt greater than 1.3m (but not pre-harvest remnants) were measured as in the other treatments. Gaps cut in strips or wedges (Dunn site only) were sampled in a similar way except that three belt transects were installed at even intervals perpendicular to the direction of the strip (Figure 2.2)

Analyses

Stand level analysis

From the above sampling procedures, the following variables were calculated for the plantations in each stand (in the case of group selection stands, variables were calculated for each surveyed gap and averaged for the stand):

mHt	Median height of all trees measured in a plantation or in gaps. (in m)
mDBH	Median DBH of all trees measured in a plantation or in gaps (in cm)
mHt(largest)	Median height of all trees measured in a plantation or in gaps when only the tallest Douglas-fir tree in each plot is considered (or in the case of group selection stands, the largest two in each gap) (in m)
mDBH(largest)	Median DBH of all trees measured in a plantation or in gaps when only the largest (DBH) Douglas-fir tree in each plot is considered (or in the case of group selection stands, the largest *two* in each gap) (in cm)
mH:D(largest)	Median H:D ratio of all trees measured in a plantation or in gaps when only the largest (DBH) Douglas-fir tree in each plot is considered (or in the case of group selection stands, the largest *two* in each gap)
RS	Relative stocking calculated as the ratio of current TPH (1.3m and taller) to initial planting density
BA	Average basal area at breast height (in m^2/ha)

The metrics mDBH(largest), mHt(largest) and mH:D(largest), were analyzed because they can be expected to reflect a plantation's productive potential at the time of measurement. Additionally, since it was impossible to distinguish between planted and natural seedlings, by considering only the largest seedings, the chance of tree age confounding the results is greatly reduced. Relative stocking and BA values, however, include all trees over 1.3 m tall and median values of DBH and height including all trees were also analyzed.

In order to test whether there are differences in mHt, mDBH, mHt(largest), mDBH(largest), mH:D(largest), RS or BA among the 16 to 17 year old plantations growing under the above described silvicultural treatments (clearcut, two-story, and group selection), a blocked (by site), one factor analysis of variance (PROC MIXED; SAS institute; 2004) was used separately for each variable. Blocking by site (Saddle, Peavy, and Dunn) should account for variability resulting from site differences as well as by differences in year of plantation initiation. Tukey-Kramer adjustments for multiple comparisons were made where appropriate. Assumptions of normality and equal variance were adequately met in the mDBH, mHt, mDBH(largest) and mHt(largest) data without transformation. BA and RS data were square root-transformed and mH:D(largest) data were log transformed, all in order to correct for higher variance about larger expected values.

Gap-level analysis

Regression analysis (PROC REG; SAS institute; 2004) was used to test for relationships between gap averages (or medians) of the above described dependant variables (mDBH(largest), mHt(largest), mH:D(largest), RS, and BA) and the following gap characteristics:

d/h The ratio of a gap's diameter to the height of the average top $height_{40}$ of the surrounding matrix. This value was calculated using forest inventory and GIS data from OSU College Forests and the following equation:

$$diameter : height = \frac{2\sqrt{PatchArea/\pi}}{TopHeight_{40}}$$

SI 50-year Douglas-fir site index (m) (King, 1966) for the site encompassing the gap as calculated by OSU College Forests.

RAD Potential annual direct incident radiation ($MJ \cdot cm^{-2} \cdot yr^{-1}$) as calculated using OSU College Forests GIS data and the following equation by McCune and Keon (2002):

$$RAD = 0.339 + 0.808 \times \cos(L) \times \cos(S) - 0.196 \times \sin(L) \times \sin(S) - 0.482 \times \cos(A) \times \sin(S)$$

where: L= Latitude (in radians)

S= Slope (in radians)

A= Folded aspect: $= 180 - \left| Aspect - 180 \right|$ (in radians)

Gap d/h ratio was chosen over simple area as an independent variable to describe gap size because it was prevalent in the forest gap literature. Additionally, mature trees in the matrix surrounding gaps spanned a significant height range and I felt this would variably influence microclimate in gaps. Preliminary analyses confirmed this hypothesis. Gap d/h ratio was calculated using a gap's area as defined by the crowns of the matrix trees.

Five separate forward selection processes were conducted in order to determine which of the above three independent variables are significantly related to each of the five previously described dependant variables (mHt(largest), mDBH(largest), mH:D(largest), RS, and BA). Beginning with a random model (no explanatory variables), independent variables were added one at a time with only the most significant (largest t-stat) kept in the model. Additionally, if a variable's parameter estimate was not significant at α=0.90 it was not included. Variables were transformed as deemed appropriate based on graphical analysis.

Results

Stand level results

mHt

The median height of regenerating trees ranged from 5m in a group selection stand to 12m in a clearcut stand (Table 2.2). The effect of silvicultural treatment was found to be statistically significant between any of the treatment groups ($F_{2,4}$ =9.45, P =0.0305). Mean mHt was found to be significantly higher for the clearcut treatment than the group selection treatment (T_4 = 4.33, p =0.0266) but not the two-story treatment (T_4=2.73, p=0.1086) (Figure 2.2). No significant difference was found between the group selection and two-story treatments (T_4 = 1.28, p =0.4746). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

mDBH

The median DBH of regenerating trees ranged from 3.9 cm in a group selection stand to 17 cm in a clearcut stand (Table 2.2). The effect of silvicultural treatment was found to be statistically significant between at least two of the treatment groups ($F_{2,4}$ =13.34, P =0.0170). Mean mDBH was found to be significantly higher for the clearcut treatment than for both the group selection treatment (T_4 = 5.06, p =0.0156) and the two-story treatment (T_4=3.67, p=0.0455) (Figure 2.2). No significant difference was found between the group selection and two-story treatments (T_4 = 0.97, p =0.6289). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

mHt(largest)

The median height of the largest trees in a stand (as described above) ranged from 4.9m in a group selection stand to 15.1m in another group selection stand (Table 2.2). The effect of silvicultural treatment was not found to be statistically significant between any of the treatment groups ($F_{2,4}$ =0.50, P =0.6406). Consequently, no statistical difference was found between the mean mHt(largest) of any treatments (Figure 2.2). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

mDBH(largest)

The median DBH of the largest trees in a stand (as described above) ranged from 7.1 cm in a group selection stand to 23.4 cm in a clearcut stand (Table 2.2). The effect of silvicultural treatment was found to be statistically significant between at least two of the treatment groups ($F_{2,4}$ =7.85, P =0.0412). Mean mDBH(largest) was found to be significantly higher for the clearcut treatment than the group selection treatment (T_4 = 3.90, p =0.0370) but not the two-story treatment (T_4=1.64, p=0.3326) (Figure 2.2). No significant difference was found between the group selection and two-story treatments (T_4 = 2.15, p =0.1950). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

mH:D(largest)

Log transformed mH:D(largest) was used for statistical analyses but all reported results have been back-transformed. The median H:D of the largest trees in a stand (as described above) ranged from 52.44 in a clearcut stand to 88.35 in a group selection stand (Table 2.2). The effect of silvicultural treatment was found to be statistically significant between at least two of the treatment groups ($F_{2,4}$ =12.47, P =0.0191). Median mH:D(largest) was found to be significantly higher for the group selection treatment than the clearcut treatment (T_4 = 4.87, p =0.0179) but not the two-story treatment (T_4=2.29, p=0.1688) (Figure 2.2). No significant difference was found between the clearcut and two-story treatments (T_4=2.11, p=0.2034). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

Relative Stocking

The square roots of RS data were used for statistical analyses but all reported results have been back-transformed. Mean RS ranged from 23% in a group selection stand to 206% in a two-story stand (Table 2.2). The effect of silvicultural treatment was found to be statistically significant between at least two of the treatment groups ($F_{2,4}$ = 7.65, P =0.0430). At α= 0.90, mean RS was found to be significantly lower for the group selection treatment than the clearcut (T_4 = 2.97, p=0.0857) and two-story (T_4=3.40, p=0.0578) treatments (Figure 2.2). No significant difference was found between the clearcut and two-story treatments (T_4=-0.37, p=0.9279). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

Basal Area

The square root of BA data were used for statistical analyses but all reported results have been back-transformed. Mean BA/ha ranged from 0.61 m^2/ha in a group selection stand to 23.90 m^2/ha in a clearcut stand (Table 2.2). The effect of silvicultural treatment was found to be statistically significant between at least two of the treatment groups ($F_{2,4}$ =10.97, P =0.0238). Mean BA was found to be significantly higher for the clearcut treatment than the group selection treatment (T_4 = 4.62, p =0.0214) but not the two-story treatment (T_4=1.83, p=0.2722) (Figure 2.2). No statistically significant difference was found between the group selection and two-story treatments (T_4 = 2.67, p =0.1152). Treatment means and their 95% confidence intervals (Tukey-Kramer adjusted) are shown in Table 2.3.

Gap-level results

Forward selection indicated that Ln(d/h) was the only independent variable with a significant relationship (α=0.90) to any of the five previously described dependant variables (mHt(largest), mDBH(largest), mH:D(largest), RS, and BA). The effect of Ln(d/h) was significant only in models explaining mHt(largest), mDBH(largest) and BA. Ln(d/h) was able to explain 13% of the variation in mHt(largest) data, 43% in mDBH(largest) data and 31% in BA data (Figure 2.3). Estimates of the effects of Ln(d/h) and their associated standard errors are shown in Table 2.4. None of the independent variables considered (d/h, SI, nor RAD) had a significant effect when explaining mH:D(largest) data or RS data. Back-transformation of coefficients yield the following conversations:

1. A doubling of d/h is estimated to result in a 1.9m increase in median height of the tallest two trees in a gap.
2. A doubling of d/h is estimated to result in a 5.3cm increase in median DBH of the largest (DBH) two trees in a gap.
3. A doubling of d/h is estimated to result in a 3.74 m^2/ha increase in a gap's average BA.

Discussion

Growth of seedlings, planted or naturally regenerating, under alternative silvicultural regimes are limited by overstory competition. Growth is most limited in small gaps, intermediate in two-story stands and greatest in clearcuts. This continuum agrees with the findings of Coates (2000) and Harrington (2006) and is to be expected as the amount of available light and water is generally greater in a clearcut versus a gap surrounded by mature trees (Harrington, 2006). Stand-level values were more variable in the group selection treatment than in either the two-story or clearcut treatments. This is likely due to the more variable growing conditions (a factor of varying gap size) across group selections vs. the other two treatments.

The heights of the largest trees didn't differ by treatment although the group selection treatment showed considerably more variability than the others (similar to diameter and, likely, for the same reasons). While Coates (2000) found height growth to be greater in open conditions than in gaps, his metric was mean height of all trees. Alternatively, our analysis utilized the height of the tallest trees in each plantation and this metric has been found to be either independent of planting density (Marshall and Curtis 2002) or to increase with density in the first five years of seedling growth (Cole and Newton 1987, Scott et al. 1998, Woodruff et al. 2002). While the above cited studies dealt with intracohort competition, it is possible to speculate that the intercohort competition between remnant overstory trees and planted seedlings could be expressed in the same way. When I analyzed the median height of all trees measured, values for the clearcut plantations were greater than both two-story and group selection plantations. However, this is likely due to the larger number of young (and consequently smaller) natural regenerated trees in the two-story and group selection treatments which bring down the median values. The same trend was observed in median DBH values.

Since diameters varied by treatment while heights were not significantly affected, it follows that the H:D ratio of the largest trees would be largest in the group selection treatments, intermediate in the two-story and smallest in the clearcut treatment. This is, indeed, what I found. Our results agree with Ketchum's (1995) data on early growth of seedlings on the CFIRP sites which show significantly larger mean H:D ratios in the group selection treatments than in the clearcut and two-story treatments. The differences in H:D ratios are likely to influence relative survival rates into the future as tall, skinny trees have been found to be more susceptible to mechanical damage from ice, snow and wind (Wonn and O'Hara 2001).

Relative stocking was found to be higher in clearcut and two-story treatments than in the group selection treatment (although some individual gaps did show high stocking levels). The high mean RS values of clearcut and two-story treatments suggest that very little mortality occurred or that there was significant natural regeneration (or a combination of the two). Diameter distributions of the clearcut and two-story treatments (averaged across the 6 stands in each treatment type) (Figure. 2.4) suggest that the high mean RS values for the treatments are a result of high survival rates supplemented by some natural regeneration of Douglas-fir and grand fir. Ketchum (1995) found that planted seedling mortality two years after planting on the CFIRP cites averaged 19.7% and 7.3% for the two-story and clearcut treatments, respectively. He also found the amount of natural regeneration to be significantly higher in the two-story vs. the clearcut treatment (1045 vs. 227 TPH respectively) most likely as a result of differing amounts of Douglas-fir seed fall (187,000 vs. 76,000 seeds/ha in two-story and clearcut treatments, respectively). Based on these findings, it seems likely that more natural Douglas-fir regeneration occurred in the two-story treatments than in the clearcut treatments. The diameter distributions suggest roughly equal amounts of grand fir establishment in all treatments. Grand fir seedlings were generally observed in small, dense clumps and could usually be attributed to a nearby remnant grand fir in the overstory.

Since current stocking levels in the group selection gaps are significantly lower than initial planting densities (RS value less than 1), significant mortality must have occurred in many of the gaps. Possible causes of this mortality include competition for light, water, and nutrients both from remnant overstory trees and understory vegetation, breakage from wind, snow and ice due to large H:D ratios, and animal browse. It is likely that all of these factors interacted; for example, dense competing vegetation may induce large H:D ratios in seedlings and, thus, increase mechanical breakage (Tappeiner et al. 2007). Also, slower growth rates caused by shading by the overstory could increase the length of time seedlings take to reach a height at which deer can not browse them. In fact, casual observations indicate that browse damage was much more evident in gaps than in two-story or clearcut treatments presumably due to differing abilities to grow beyond the reach of deer.

It is important to remember that planting density varied by treatment and gap size. This difference in initial seedling density will likely confound differences in individual tree characteristics (due to differences in intracohort competition). However, the results are still useful as similar confounding is likely to occur in a management context.

Regarding competition for light, Mailly and Kimmins (1997) found that when the amount of photosynthetically active radiation (PAR) available (expressed as a percent of full sunlight) was less than 20%, Douglas-fir trees could not survive and at levels less than 40% could not actively grow. Gray et al. (2002) found that at northern middle latitudes, gaps with d/h values of 0.6 only received 34% PAR at their northern edge, 20% in their centers and only 6% at their southern edge. Gaps with d/h values of 1 only received 49% PAR at their northern edge, 43% in their centers and only 9% at their southern edge. More than 70% of the gaps considered in my analysis have d/h ratios less than 1 (Figure 2.5). Thus, it follows that high levels of mortality could be expected. These results are in line with the minimum gap d/h ratio of 1.5 proposed by Malcolm et al. (2001) for Douglas-fir.

That being said, my data showed no strong relationship between a gap's RS and its d/h ratio (Figure 2.6) and some smaller gaps exhibited very high RS rates. The successful regeneration of these small gaps shows that planted seedlings can persist in spite of the environment imposed by the small d/h ratio. Anecdotal evidence suggests that when gap regeneration was unsuccessful, ineffective site preparation and early vegetation control might be to blame. Informal statistical analyses indicate greater growth and survival in the Dunn site gaps where, according to managers, early vegetation control was more effective. These findings are supported by on-the-ground observations which indicate strong associations between failed regeneration in gaps and high percent cover of competing vegetation (see also Figure 3.2)

While the data suggests adequate stocking can be achieved even in small gaps, growth can be significantly retarded when gaps are small and that successful regeneration is not guaranteed. Regression analysis indicated that regeneration diameters, heights and, consequently, BA increase as gap size increases (Figure 1.10). This agrees with the findings of Coates (2000) who also found increasing height and diameter growth rates in conifer seedlings as gap size increased. Differences in site index (SI) and potential annual direct incident radiation (RAD) would be expected to influence the survival and growth of trees growing in gaps but this relationship was not expressed in our data. The inability of these variables to explain variability in a gap's regeneration characteristics is likely an artifact of the study design; there is neither a wide range of site qualities nor a wide range of slope/aspect combinations across the study. While the similarity of these environmental conditions helps reduce variation across the treatments, it disallows a robust regression analysis.

Management Recommendations

Our study shows that, on drier Coast Range sites, both two-story (two-aged) and group selection (uneven-aged) silvicultural systems are viable means by which to regenerate Douglas-fir while retaining legacy structure and increase vertical and horizontal structural heterogeneity as per the objectives of New Forestry. However, important differences exist between plantations growing under the three regimes covered by our study that highlight the need for careful management.

Initial planting densities were more than adequate to fully occupy disturbed areas in all three treatments. Regarding the clearcut and two-story treatments, the large amount of natural regeneration and low mortality have resulted in very dense plantations that will likely require precommercial thinning if rapid tree growth is to be maintained. Gaps were highly variable in their level of stocking and growth rates. Poorly stocked stands seemed to be ones in which competing shrubs dominated, perhaps due to unsuccessful early vegetation control. Relative to traditional clearcuts, more intense vegetation control may be necessary in order to ensure successful regeneration of gaps. This is because the slower growing plantations in gaps will take longer to reach a level of crown closure sufficient to shade out competing vegetation. However, the successful establishment of conifers may not be necessary in all gaps if timber production is not the primary objective. If increased structural heterogeneity is an important objective, the establishment of other types of vegetation such as grasses, forbs and hardwood shrubs and trees in some gaps might be acceptable and even desirable.

While our findings show the ability to successfully regenerate all three treatments, there remain important differences in growth rates of the plantations growing under each regime. It is clear that when overstory trees are retained, growth rates are reduced. Our data shows, however, that the magnitude of this reduction depends, in the case of gaps, on the size of gaps used but that no clear gap size threshold exists at which productivity sharply increases. Additionally, it is unknown how the growth rates of trees growing in these gaps will change in the future. Messier et al. (1999) suggested that there may be a "maximum sustainable height" (caused by a tree reaching its light compensation point) for a given species of tree growing in a given gap size and that this height increases with the size of the gap. Additionally, gap size may decrease over time as the crowns of overstory trees encroach on the gaps (Muth and Bazzaz (2002). It may, therefore, be necessary to either thin the overstory trees in the two-story and group selection treatments or increase the size of gaps in order to maintain present growth rates. Speculations on the future development of these treatments, however, are beyond the scope of our study.

Figure 1.1- Study site locations within McDonald-Dunn Forest, central Coast Range, Oregon.

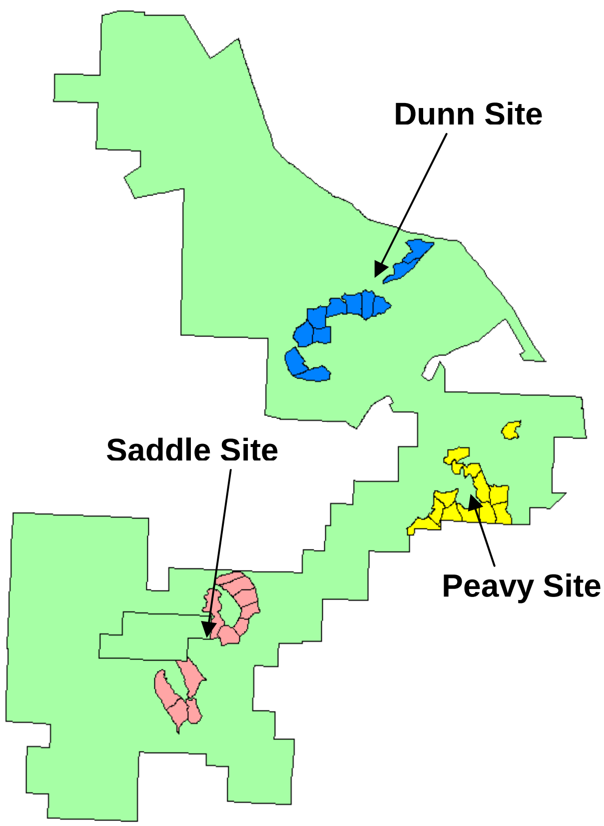


Table 2.1- Number of experimental units assigned to each silvicultural treatment by site

	Saddle	**Peavy**	**Dunn**	*Sum*
Clearcut	2	2	2	6
Two-story	2	2	2	6
Group selection	6	6	6	18
Sum	*10*	*10*	*10*	*30*

Figure 2.1- Belt transect positions in (a) strip-shaped gaps and (b) regular gaps

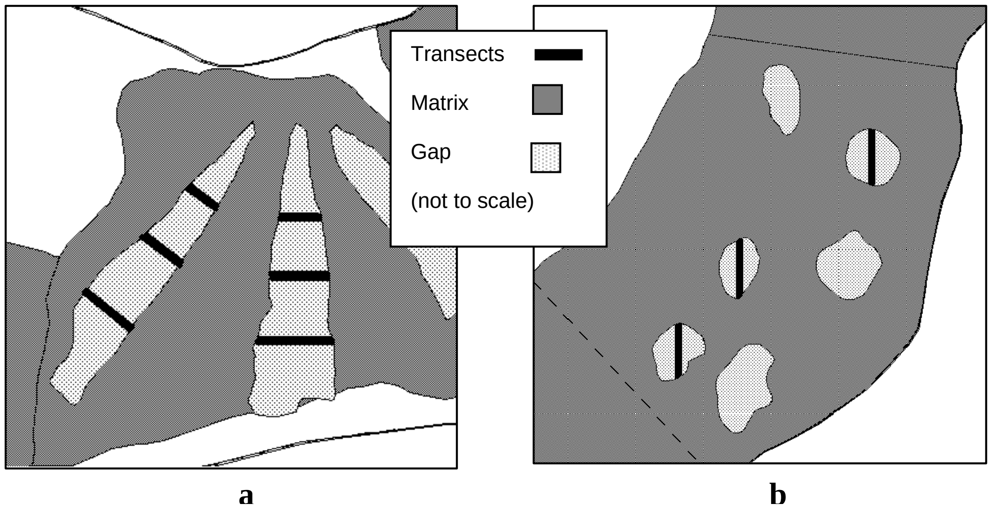
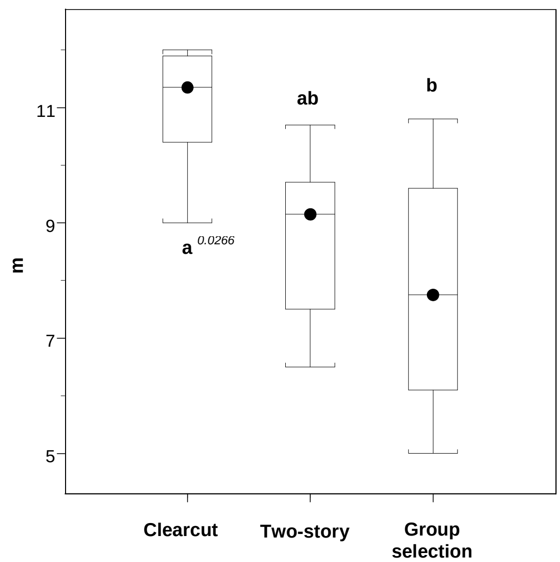
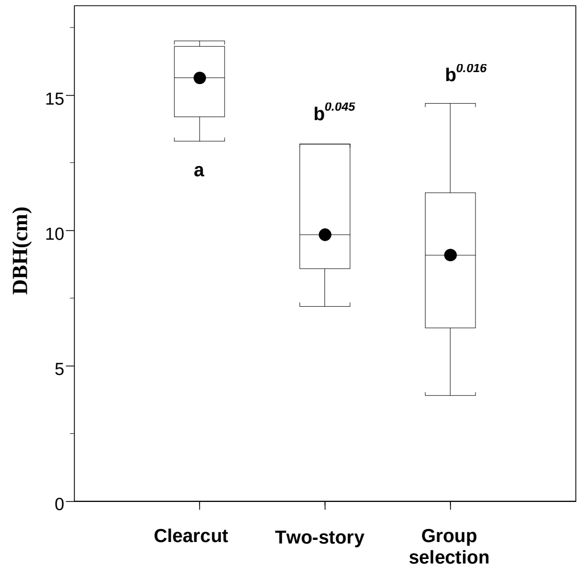


Figure 2.2- Box and whisker plots of stand-level values for 15-16 year-old planted Douglas-fir by treatment of (a) median total height, (b) median DBH, (c) median height (largest), (d) median DBH (largest), (e) median height:diameter ratio (f) relative stocking (ratio of current stocking to initial planting density), (g) basal area. Non-significant differences at α= 0.95 as determined from Tukey-Kramer multiple comparison tests. P-values of comparisons between treatments with non-matching letters are shown in italics.

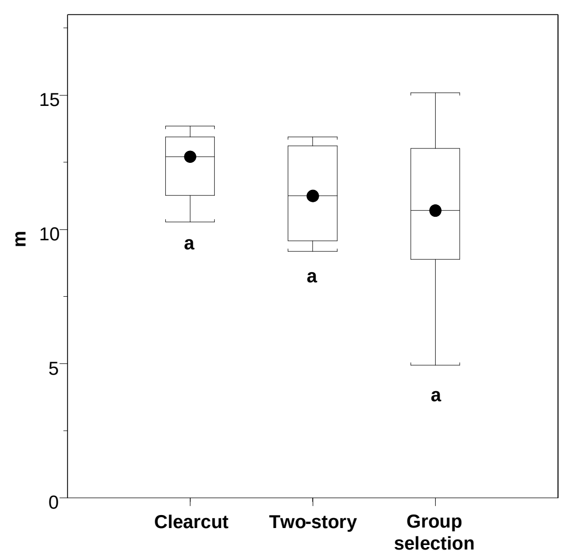
(a) median total height



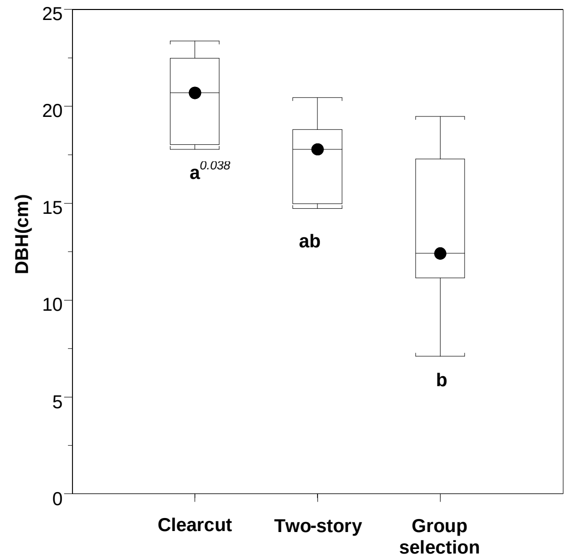
(b) median DBH



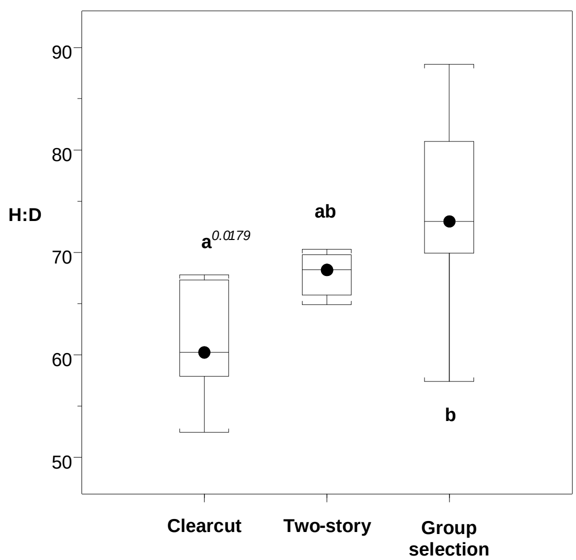
(c) median height (largest)



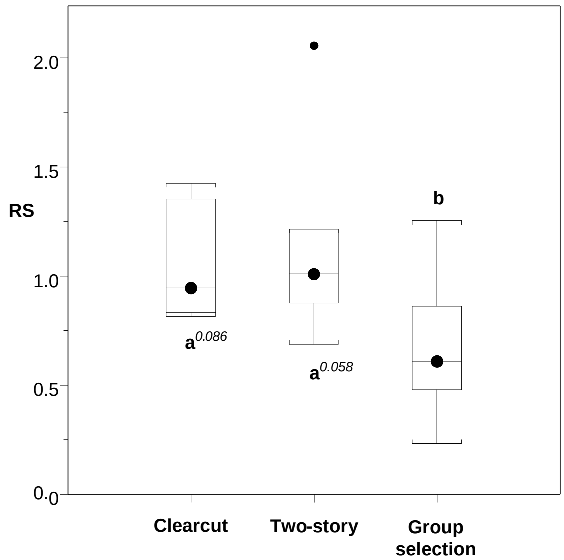
(d) median DBH (largest)



(e) median H:D ratio (largest)



(f) relative stocking



(g) basal area

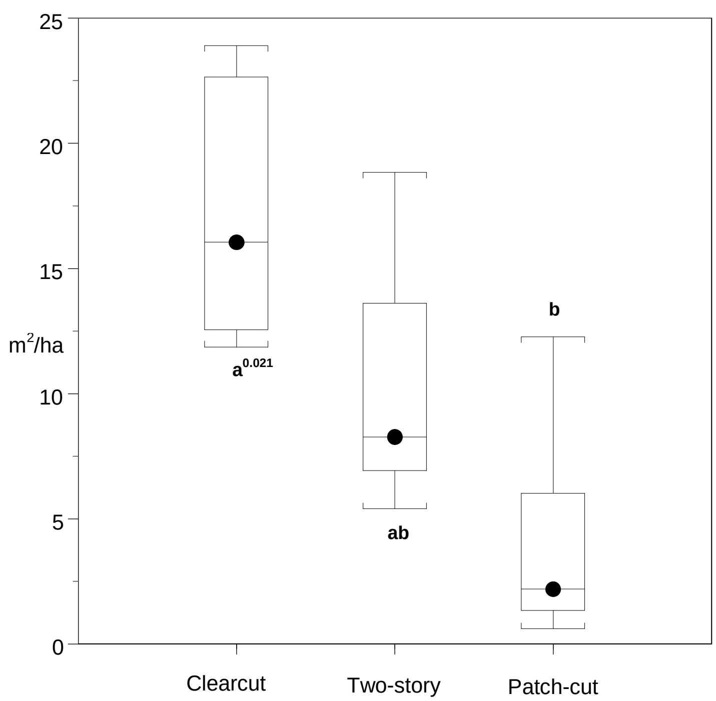


Table 2.2- Stand mean or median values for RS, BA, mDBH, mHt, mDBH(largest), mHt(largest) and mH:D(largest)

Site	Stand	Treatment	RS (%)	BA (m^2/ha)	mDBH (cm)	mHt (cm)	mDBH(largest) (cm)	mHt(largest) (m)	mH:D (largest)
Saddle	S1	Clearcut	143	22.65	15.7	12.0	20.3	13.8	67.81
	S2	Two-story	206	18.84	8.6	9.1	20.4	13.4	68.80
	S3	Group selection	91	2.79	8.1	7.0	11.7	8.9	72.45
	S4	Group selection	86	2.44	6.4	5.0	12.4	10.9	79.63
	S5	Group selection	81	1.19	8.8	7.4	11.4	10.5	84.00
	S6	Group selection	54	0.98	6.1	6.2	11.1	8.1	80.56
	S7	Two-story	122	7.46	8.9	7.5	14.7	9.2	70.30
	S8	Clearcut	100	11.86	13.3	9.0	17.8	10.3	57.92
	S9	Group selection	125	1.70	3.9	5.8	7.8	8.5	84.52
	S10	Group selection	91	1.86	4.3	6.0	10.0	8.0	73.33
Peavy	P2	Clearcut	135	23.90	16.8	11.4	22.5	12.9	52.44
	P3	Group selection	50	1.94	9.9	7.0	12.8	10.9	66.85
	P4	Two-story	97	5.40	7.2	6.5	15.0	9.6	67.80
	P5	Group selection	23	1.33	6.6	5.6	10.7	7.1	80.81
	P6	Group selection	48	1.61	9.9	8.6	12.5	12.6	69.94
	P7	Group selection	58	4.13	9.4	8.9	16.1	13.8	67.60
	P8	Group selection	33	0.91	7.5	8.1	12.3	10.4	57.41
	P9	Group selection	39	0.61	6.0	6.1	7.1	9.5	71.69
	P10	Two-story	69	9.08	13.2	9.2	18.3	11.1	64.88
	P11	Clearcut	89	12.55	14.2	10.4	18.0	11.3	67.33
Dunn	D1	Two-story	88	6.92	10.8	9.7	17.3	11.4	65.84
	D2	Group selection	58	6.13	11.6	9.5	16.4	10.2	67.29
	D3	Clearcut	82	17.81	17.0	11.9	23.4	13.4	61.86
	D4	Group selection	76	8.43	11.3	9.6	19.5	13.0	71.67
	D6	Group selection	61	6.01	11.4	9.6	18.7	12.6	72.74
	D7	Group selection	76	10.87	13.7	10.3	18.6	13.3	80.02
	D8	Two-story	105	13.61	13.2	10.7	18.8	13.1	69.78
	D9	Clearcut	83	14.28	15.6	11.3	21.1	12.5	58.64
	D10	Group selection	98	12.27	14.7	10.8	19.5	14.6	88.34
	D11	Group selection	30	3.37	14.2	10.5	17.2	15.1	86.63

Table 2.3- For 15-16 year old planted Douglas-fir seedlings, stand mean or median values for mHt, mDBH, mHt(largest). mDBH(largest), mH:D(largest), relative stocking (RS) and basal area (BA). Non-significant differences at α= 0.95 as determined from Tukey-Kramer multiple comparison tests are represented by corresponding letters (asterisk denotes non-significance at α= 0.90)

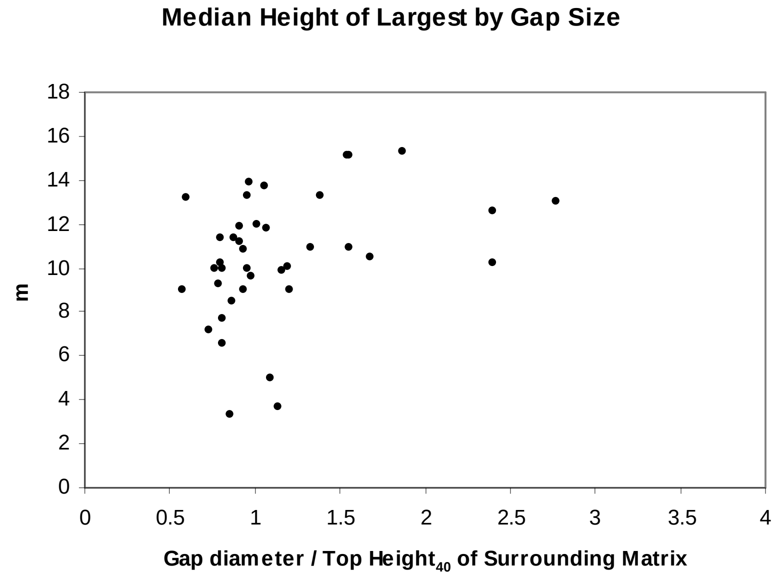
Dependent Variable	**Treatment**	***n***	***Lower C.I.***	**Mean**	***Upper C.I.***
mHt	Clearcut	*6*	*8.42*	10.98 a	*13.54*
(m)	Two-story	*6*	*6.24*	8.80 ab	*11.36*
	Group selection	*18*	*5.52*	7.88 b	*10.24*
mDBH	Clearcut	*6*	*11.23*	15.45 a	*19.68*
(cm)	Two-story	*6*	*6.10*	10.33 b	*14.55*
	Group selection	*18*	*5.24*	9.11 b	*12.98*
mHt(largest)	Clearcut	*6*	*8.43*	11.78 a	*15.12*
(m)	Two-story	*6*	*7.95*	11.30 a	*14.64*
	Group selection	*18*	*7.95*	10.80 a	*13.65*
mDBH(largest)	Clearcut	*6*	*15.69*	20.52 a	*25.34*
(cm)	Two-story	*6*	*12.59*	17.42 ab	*22.24*
	Group selection	*18*	*9.27*	13.66 b	*18.04*
mH:D(largest)	Clearcut	*6*	*53.52*	60.95 a	*68.72*
	Two-story	*6*	*59.74*	68.03 ab	*76.71*
	Group selection	*18*	*68.03*	75.19 b	*82.27*
RS	Clearcut	*6*	*95*	104 a*	*162*
(%)	Two-story	*6*	*64*	111 a*	*170*
	Group selection	*18*	*32*	63 b*	*103*
BA/ha	Clearcut	*6*	*9.29*	16.86 a	*26.65*
(m^2/ha)	Two-story	*6*	*4.26*	9.74 ab	*17.46*
	Group selection	*18*	*0.75*	3.16 b	*7.26*

Table 2.4- Estimates of the effects of Ln(d/h) of a gap on mHt(largest, mDBH(largest) and BA of 16-18 year old conifers in Oregon's Coast Range and their associated standard errors.

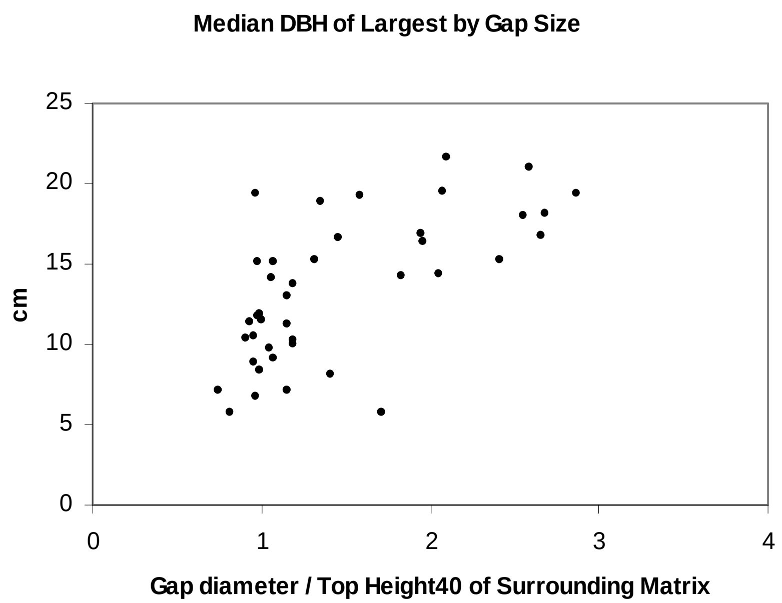
Dependent Variable	*Intercept*/ Dependent Variable	*Parameter Estimate*	Standard Error	T-statistic	P-value	R^2
mHt(largest)	*Intercept*	*10.2845*	*0.44036*	*23.35*	*<0.0001*	
	Ln(d/h)	2.7909	1.2012	2.32	0.0258	0.127
mDBH(largest)	*Intercept*	*10.98*	*0.6893*	*15.93*	*<0.0001*	
	Ln(d/h)	7.7120	1.4184	5.44	<0.0001	0.488
BA	*Intercept*	*1.7450*	*0.6248*	*2.79*	*0.0079*	
	Ln(d/h)	5.3984	1.2563	4.30	0.0001	0.311

Figure 2.3- For all gaps surveyed in my study, gap-level average values for 15-16 year old planted Douglas-fir seedlings of mHt(largest), mDBH(largest), and average BA by gap size.

mHT(largest



mDBH(largest)



BA

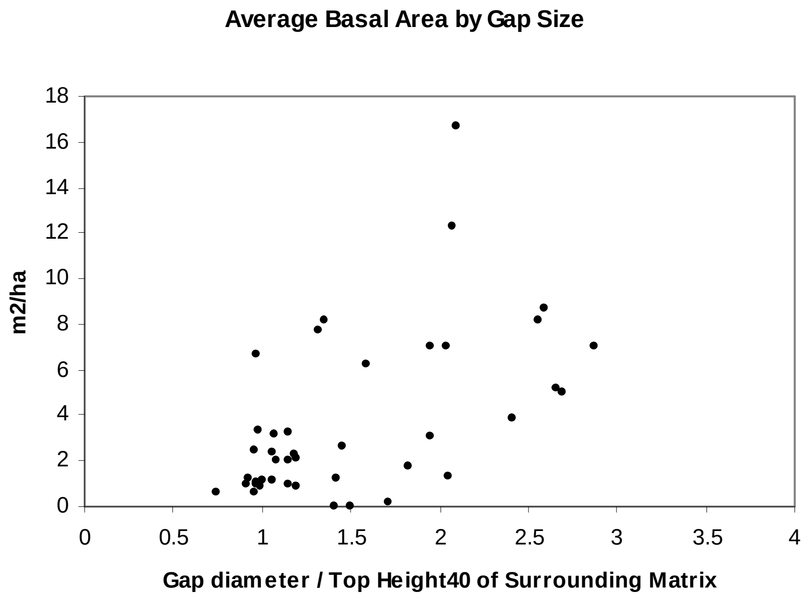

Average Basal Area by Gap Size
m2/ha
18
16
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Gap diameter / Top Height40 of Surrounding Matrix

Figure 2.4- Combined diameter distributions of all planted and natural conifer regeneration 15-16 years after planting stratified by species for each silvicultural treatment

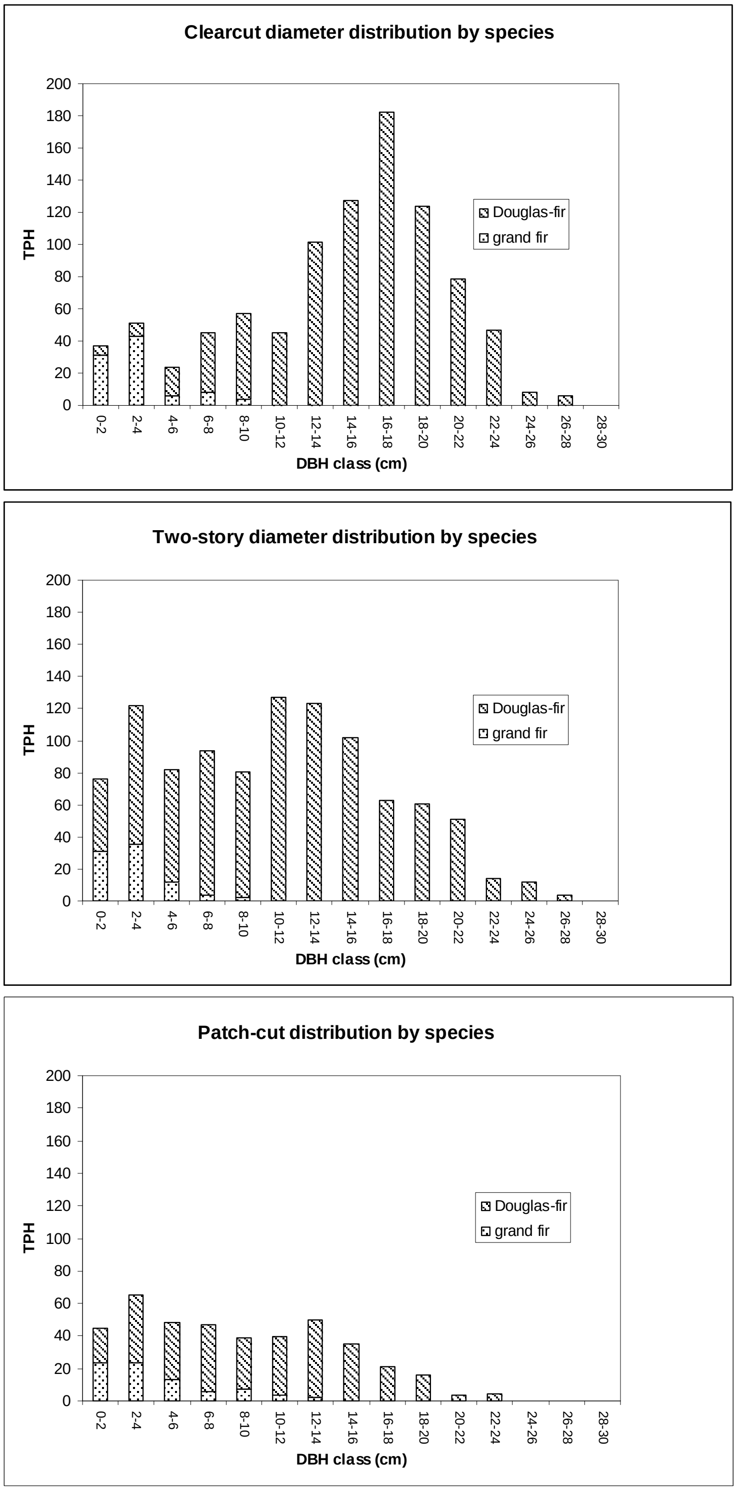


Figure 2.5- Histogram showing the d/h ratios of gaps in the group selection treatment stands (as determined from GIS analysis)

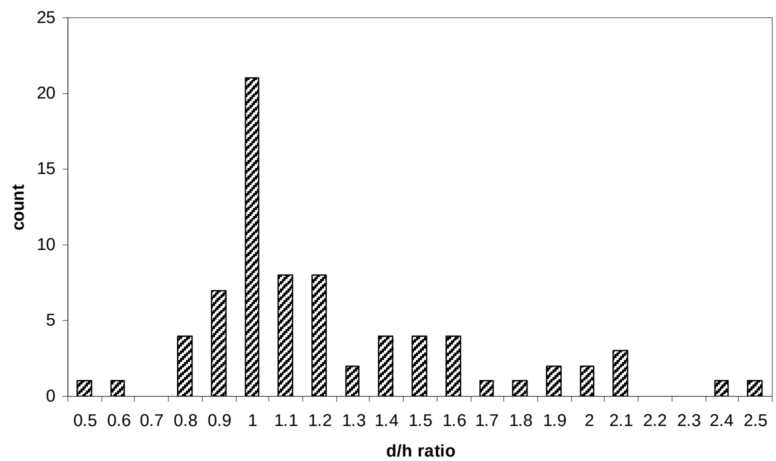
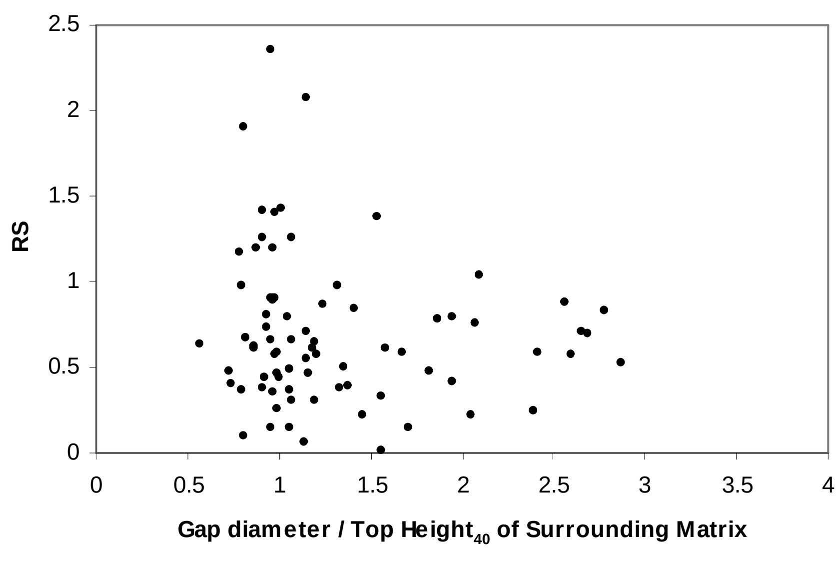


Figure 2.6- Relative stocking of each gap by gap size 15-16 years after planting



CHAPTER 3– UNDERSTORY VEGETATION RESPONSE TO ALTERNATIVE SILVICULTURAL TREATMENTS

Introduction

An important component of old-growth biodiversity and structure is the understory vegetation. Contrary to young, even-aged plantations that contain most of their foliage in the upper canopy, the foliage in an old-growth Douglas-fir forest is continuously distributed from the ground to the top of the canopy (Parker and Brown 2000). One way to encourage the development of understory vegetation communities similar to those found in old-growth forests is to emulate the disturbances that, historically, resulted in their creation (McComb et al. 1993). Differing views, however, exist regarding how these forests develop and succeed.

One conceptual forest development model breaks the process into four relatively distinct stages in which the amount of available growing space varies as stand succession progresses (Oliver and Larsen 1996). Immediately following a stand-replacing disturbance, pioneer species quickly occupy the available growing space on a site. Once a site is fully occupied, tree species form a dense canopy which excludes shade-intolerant understory species. During the understory reinitiation stage, gaps in the overstory caused by single-tree mortality allows for the establishment and growth of understory species. An old-growth steady-state results when gap creation from individual tree mortality and small-scale disturbance allows for tree regeneration. Many have described this gap-phase regeneration method as the predominant regeneration process in old-growth forests of many ecosystems (Jones 1945, Runkle 1981, Spies, et al. 1990).

However, some evidence suggests that today's old-growth stands didn't develop following this trajectory; it is likely that they developed under relatively open-grown conditions, perhaps at densities as low as 77 to 114 trees/ha (Tappeiner et al. 1997). This suggests that, historically, dense shrub cover may have existed for longer periods of time than under current management regimes. Research is needed to assess how silvicultural treatments that emulate the natural disturbance regime at various scales affect understory vegetation communities. Our study strives to accomplish this by assessing understory vegetation communities 16 to 18 years after the implementation of three alternative silvicultural prescriptions to clearcutting.

Methods

Site Description

I utilized the College of Forestry Integrated Research Project (CFIRP), a research project initiated by OSU's College of Forestry in 1989 and designed to "help our understanding of the tradeoffs associated with a set of alternative management approaches representing a spectrum of conditions: from even-aged with retention to uneven-aged to uncut mature forests" (Maguire and Chambers 2005). The CFIRP study was split among three geographically distinct sites in Oregon State University's 4,550-ha McDonald-Dunn Research Forest, located on the east flank of the Coast Range as it transitions into the Willamette Valley. Elevation across the sites ranges from approximately 120 to 400 m. Slope and aspect both vary by stand. Soils across the three sites are predominantly (93%) comprised of the Dixonville, Jory, Philomath, Price, and Ritner series which are generally deep, well drained silty clay loams derived from basalt parent material. About 7% of the area making up the CFIRP sites is comprised of the Abiqua and Waldo soil series which are alluvial soils associated (on these sites) with terraces and fans of small seasonal streams.

Precipitation averages 104 cm annually with most occurring as rain in the winter and spring (July monthly rainfall averages only 0.1 cm). This is on the low end of the Coast Range's precipitation gradient. Low temperatures in January average 0.5°C while August highs average 27°C (Western Regional Climate Center). Site index (50 year base age) across the sites range from 28 to 40 m (King, 1966)

Study areas occurred within two plant association types: Douglas-fir/hazel/brome-grass (Pseudotsuga menziesii/Corylus cornuta var. californica/Bromus vulgaris) and Douglas-fir/vine maple/salal (Pseudotsuga menziesii/Acer circinatum/Gaultheria shallon) (Franklin and Dyrness 1973). Vegetation was generally similar across sites prior to treatment. Total basal area of stands ranged from 24 to 76 m^2/ha, of which hardwoods comprised between 5 and 26%. Douglas-fir dominated the overstory although there was a small component of grand fir (*Abies grandis*). Stands ranged in age from 45 to 144 years, and the average height of the 40 largest trees per stand (height top 40) ranged from 29 to 54 m (Maguire and Chambers 2005.

Study Design

Thirty-three stands comprising 331 ha were designated, each within one of three geographically distinct sites (Saddle, Peavy, or Dunn) as is shown in Figure 2.1. Each of the stands was assigned to one of 4 silvicultural treatments:

Clearcut (CC)	1.2 green trees retained per ha.
Two-story (TS)	75% of volume removed resulting in 20 to 30 green trees/ha.
Group selection (PCG, PCM)	33% of volume removed in 0.2 to 1.0 ha circular, square, or strip-shaped gaps**.**
Control (C)	No harvest activity

The above prescriptions were designed to incorporate New Forestry goals while still being operationally efficient. Treatments were assigned randomly after being stratified in a way such that both cable and ground-based logging would be equally represented in all silvicultural treatments. The number of stands assigned to each treatment is as outlined in table 2.1.

Stands were harvested between Fall of 1989 and Summer 1991. Stands with a significant portion greater than 30% slope were harvested using a skyline yarder and flatter stands were harvested using a grapple skidder or tractor with winch. Skyline corridors and skid trails were designated by researchers and reviewed by logging contractors (Maguire and Chambers 2005). Planting took place in either the winter of 1990-91 (Saddle site) or the winter of 1991-92 (Peavy and Dunn sites). The harvested areas of all treatments were regenerated using 1-1 or P-1 Douglas-fir seedlings planted at a spacing of 3.4 by 3.4 m to 4 m (625 to 865 TPH) depending on treatment. Two to five years following planting, all treatments received herbicide applications as needed to control competing vegetation. Planting and vegetation control methods were typical to forest management methods in the region. Specific planting and vegetation management regimes implemented are outlined in Appendix A.

Data Collection

Understory vegetation sampling took place in each of the 33 stands during summer 2007 using 1 x 2 m rectangular plots. Within each plot I ocularly estimated percent cover of each species or group listed in Table 3.1 stratified by height class:

Class	Height Range (m)
1	0-0.25
2	0.25-1
3	1-2
4	2-5
5	5+

Cover estimates were recorded as Braun-Blanquet (1965) cover classes:

Class	Cover Percent	Midpoint
1	0-5	2.5%
2	6-25	15.5%
3	26-50	38%
4	51-75	63%
5	76-100	88%

Braun-Blanquet class midpoints were used for analyses. Within the gaps of group selection stands (PCG), transects were oriented in a crosshair fashion running south to north and east to west, beginning and ending directly underneath the canopy edge of the bordering trees. Plots were placed along the transects at 5 m intervals. This sampling intensity resulted in about 160 plots in gaps for each group selection stand (depending on the size and number of gaps). Within CC, TS, and C treatments, transects were located along the straight-line route between plots used for regeneration assessment (chapter 2); in the matrix of group selection stands (PCM), transects were placed along the straight-line route between gaps (beginning and ending 10m from a gap's edge). In CC, TS, C and PCM treatments, plots were placed along transects at a variable spacing that result in 50 plots per stand. Since percent cover was stratified by species (or group) and height, total cover could exceed 100%. Percent cover of the species and groups in table 3.1 were aggregated in order to calculate the following stand-level metrics:

Total Cover	Summed cover of all vascular plants
Tall Shrub	Summed % cover over 1 meter tall of: *Acer circinatum*, *Corylus cornuta*, *Symphoricarpos albus*, *Rhamnus purshiana*,, *Cornus nuttallii*, *Sambucus spp.*, *Rubus spectabilis*, *Oenothera brachycarpa*
Exotic Ruderal Species	Summed % cover of *Rubus discolor*, *Cirsium spp.*, *Tanacetum spp.*
Forbs	Total forb cover
Shannon's Diversity Index	$H = -\sum_{i=1}^{s} p_i \ln p_i$ where: H= Shannon's diversity index s =number of species considered *p*= proportion of S comprised of the i^{th} species
Species Richness	Total number of species (or groups) from the above list encountered in a stand (adjusted for sample size using rarefacation)

When calculating species richness, rarefaction was used to adjust the large sample size in the PCMs (average n= 160 plots per stand) to match the smaller sample size in the CC, TS, PCM and C treatments (n=50 plots per stand) (Hurlburt 1971). Shannon's diversity indices were not compared for PCG treatments because of the unequal sample size.

Analyses

Six individual blocked (by site), one factor analysis of variance (PROC MIXED; SAS institute; 2004) were used to test for between-treatment differences in each of the above variables between clearcuts (CC), two-story (TS), group selection gaps (PCG) and group selection matrix (PCM). Due to the issue with unequal sample size discussed above, comparisons of Shannon's diversity index were not made with PCGs. Blocking by site (Saddle, Peavy, and Dunn) should account for variability resulting from site differences as well as by differences in year of plantation initiation. Tukey-Kramer adjustments for multiple comparisons were made where appropriate. Assumptions of normality and equal variance were adequately met in the ruderal % cover, Shannon's diversity index and species richness, data without transformation. Total % cover, tall shrub % cover, and forb % cover were square root-transformed.

Regression analysis was used to test for a relationship between the average BA/ha of regenerating Douglas-fir in a stand with its percent cover of Himalaya blackberry. Percent cover was log transformed in order to adjust for unequal variance.

Results

Percent cover of all vascular plants, tall shrubs, ruderal species, and forbs as well as Shannon's diversity index and species richness for each stand are summarized in Table 3.2. Treatment means and 95% confidence intervals for the same variables are shown in Table 3.3. No statistically significant difference was found between treatment means of total cover, tall shrub cover, or species richness (Figure 3.1). Concerning ruderals, the TS treatment had marginally higher cover than both the PCM and C treatments (P-values of 0.068 and 0.044 respectively). Forb cover was significantly higher in C treatments than in the PCG treatments (P-value of 0.040). Shannon's diversity index was found to be significantly greater in the TS treatments than in the PCM treatments. Significant differences between treatment groups are summarized in Table 3.4.

Basal area of young plantations in a meaningful predictor of Himalaya blackberry cover ($P<0.001$). For each 1 m^2/ha increase in a young plantation's BA, median Himalaya blackberry cover can be expected to decrease by 11% proportionally (+/- 4%, 95% CI); and regeneration basal area explains 53% of the variation in the natural log of RUDI cover (Figure 3.2).

Discussion

Shrub cover responses to these three silvicultural treatments have been minor for 16 to 18 years. Ketchum (1995) surveyed vegetation response to the CFIRP treatments 1 to 2 years after treatment and found no significant trend in shrub cover despite surveying relatively soon after treatment. Following harvest, herbicides were used in order to ensure equally low levels of competition from the regenerating shrubs (Appendix A). Thus, similar amounts of shrub cover can be expected in all the harvested treatments. However, shrubs were not excluded from the site and many shrub species were able to persist despite herbicide treatments and, later, competition from Douglas-fir regeneration. Similarly low shrub covers were observed in both the PCM and C treatments despite their lack of vegetation control. Shrub cover in these mature, relatively dense stands is likely regulated by the overstory density (Alaback 1982, Bailey and Tappeiner 1998).

Greatest plant diversity was observed in the most disturbed treatments of our study. Others have observed this same relationship as disturbance is likely to increase the suitability of a site for ruderals (Selmants and Knight 2005, Bailey et al. 1998). Indeed, I also found this increased diversity to be driven by ruderal invasion as trends in ruderal cover closely follow trends in species diversity. Ruderal cover and species diversity were both somewhat lower in the CC treatments than in the TS treatments.

This is a result of the interplay between conifer regeneration and invasive pioneer species dominance as is evidenced by our regression analysis (Figure 3.3). Currently, 16 to 18 years following regeneration, many of the CC treatments have entered into the stem exclusion stage of stand development (Oliver and Larsen 1996). The planted Douglas-fir trees have grown large enough to achieve crown closure and effectively exclude shade intolerant invasives such as Himalaya blackberry. Douglas-fir trees in the TS treatments, however, have not grown as fast and, consequently, have not yet reached the stem exclusion stage of stand development. Consequently, ruderal invasives continue to occupy large areas of the TS treatments.

While disturbance encourages invasion by exotic ruderals, it is important to note that a vigorous plantation of conifers can quickly outcompete these ruderals and exclude them from a site; Puettmann and Berger (2006) found similar results in their study of understory vegetation in young Douglas-fir stands. However, not all important invasives follow this pattern; false-brome (*Brachypodium sylvaticum* [Huds] Beauv.) is an important exotic invasive grass that is adapted to low-light understory environments. None of the stands in our study were devoid of this grass, and percent cover didn’t differ by silvicultural treatment. It is likely that this plant is less reliant upon disturbance than ruderal exotics such as Himalaya blackberry, and is, instead, more influenced by things such as availability of propagules.

Forbs exhibited a negative response to disturbance; at this point in succession, forb cover was greatest in mature forests and lowest in harvested treatments. This same trend was shown by Alaback (1982) in coastal spruce-hemlock forests. He concluded that low forb cover following disturbance was a result of competition from woody plants. It is likely that the same process is occurring in our study with shrubs and ruderals, along with conifer regeneration, out-competing the forbs.

Overall, however, understory vegetation communities have shown high resilience in the face of disturbance. This is to be expected as many other researchers have found little or no long-term changes in vegetation communities following harvest (Halpern 1988, Halpern and Spies 1995, Bailey et al. 1998, Selmants and Knight

2005). This resilience suggests that the silvicultural treatments utilized in this study are not severe enough to extirpate native Coast Range plant communities.

Generally, all of the dependent variables considered in our study exhibited high variability. This is to be expected in such a large, replicated experiment. Silvicultural treatments were designed to be operationally efficient and, consequently, some variability likely existed in the execution of each treatment. Additionally, while all the stands in the CFIRP study began as mature forests, they spanned a range of structural conditions. This variability within treatments and sites adds greatly to the inferential power of the study and also lends credence to the consistent responses seen in our data.

Management implications

New Forestry management methods incorporating ecological objectives are increasingly being embraced by land managers. Because the diversity of plant species is found to be correlated with diversity in other taxa, especially insects (Murdoch et al. 1972, Hagar 1996) increasing plant species diversity is a likely goal for some foresters. Utilizing two-story and group selection regeneration methods in which regeneration crown closure is not immediately achieved will increase the timeframe during which a site's plant diversity is maximized although some of this diversity will be comprised of invasive ruderals.

Timber harvest is not likely to permanently alter understory shrub communities nor does it increase a site's likelihood of being invaded by shade-tolerant species like false-brome. Therefore, when managing the spread of this invasive grass, other factors not considered in our study (such as availability of propagules) need to be considered.

Table 3.1- Percent cover was assessed for each species or species group listed.

Code	**Common Name**	**Scientific Name**
MOSS	Moss	(bryophytes)
BRAC	false-brome	*Bracipodium sylvaticum*
RUUR	trailing blackberry	*Rubus urisinus*
RUPA	Thimbleberry	*Rubus purshiana*
FORB	all forbs	n/a
PTAQ	bracken fern	*Pteridium aquilinum*
ROSA	Rose	*Rosa spp.*
HODI	ocean spray	*Holodiscus discolor*
POMU	sword fern	*Polystichum munitum*
ACCI	vine maple	*Acer circinatum*
COCO	Hazel	*Corylus cornuta*
ACMA	bigleaf maple	*Acer macrophylla*
QUGA	white oak	*Quercus garryana*
SYAL	Snowberry	*Symphoricarpos albus*
RHPU	Cascara	*Rhamnus purshiana*
CONU	Dogwood	*Cornus nuttallii*
RUDI	Himilaya blackberry	*Rubus discolor*
BENE	Oregon grape	*Mahonia aquifolium*
GRASS	all graminoids besides BRSY	n/a
RULA	evergreen blackberry	*Rubus laciniatus*
THIS	bull, milk and Canadian thistles	n/a
TANS	tansy	*Tanacetum vulgare*
GASH	salal	*Gaultheria shallon*
SAMB	elderberry	*Sambucus spp.*
RHDI	poison oak	*Toxicodendron diversilobum*
VETC	vetch	*Vicia spp*
TABR	Pacific yew	*Taxus brevifolila*
RUSP	Salmonberry	*Rubus spectabilis*
PRUN	bitter cherry	*Prunus spp.*
ARME	Pacific madrone	*Arbutus menziesii*
OECE	Indian plum	*Oemleria cerasiformis*
ILAQ	English holly	*Ilex aquifolium*

Table 3.2- Percent cover of all vascular plants, tall shrubs, ruderal species, and forbs and Shannon's diversity index and species richness for all CFIRP study stands organized by block and silvicultural treatment 15 to 16 years after treatment.

Block	**Stand**	**Treatment**	**Total Cover (%)**	**Tall Shrub Cover (%)**	**Ruderal Cover (%)**	**Forb Cover (%)**	**Shannon's DI**	**Species Richness**
d	1	ts	102	12	60	5	2.01	22
d	2	pcg	179	30	55	8	n/a	20
d	2	pcm	157	10	46	9	1.83	18
d	3	cc	121	7	21	5	1.62	16
d	4	pcg	110	17	41	5	n/a	18
d	4	pcm	121	10	38	12	1.30	15
d	5	c	164	30	27	20	2.02	21
d	6	pcg	163	24	59	8	n/a	16
d	6	pcm	138	21	27	7	1.90	18
d	7	pcg	106	21	35	2	n/a	13
d	7	pcm	105	25	17	1	1.50	19
d	8	ts	91	16	40	5	1.96	16
d	9	cc	71	23	16	9	1.79	14
d	10	pcg	118	27	6	1	n/a	17
d	10	pcm	203	58	46	14	1.87	17
d	11	pcg	153	20	19	3	n/a	18
d	11	pcm	213	36	39	5	1.64	16
p	1	c	153	18	0	35	1.18	13
p	2	cc	70	28	5	5	1.74	16
p	3	pcg	134	10	50	1	n/a	13
p	3	pcm	149	8	0	5	0.89	16
p	4	ts	166	31	84	19	2.11	26
p	5	pcg	158	48	45	6	n/a	18
p	5	pcm	135	67	15	4	1.68	19
p	6	pcg	148	30	29	2	n/a	20
p	6	pcm	136	6	2	10	0.91	18
p	7	pcg	131	15	73	0	n/a	14
p	7	pcm	146	17	15	2	1.73	19
p	8	pcg	149	46	19	2	n/a	19
p	9	pcg	144	42	36	1	n/a	17
p	9	pcm	167	38	9	23	1.32	18
p	10	ts	152	32	70	12	2.27	24
p	11	cc	138	33	51	19	2.10	26
s	1	cc	188	14	81	7	2.04	23
s	2	ts	181	25	58	10	2.53	25
s	3	pcg	166	34	53	12	n/a	18
s	3	pcm	210	72	7	44	1.96	17
s	4	pcg	195	52	57	24	n/a	20
s	4	pcm	154	76	10	18	2.29	21
s	5	pcg	157	20	63	5	n/a	22

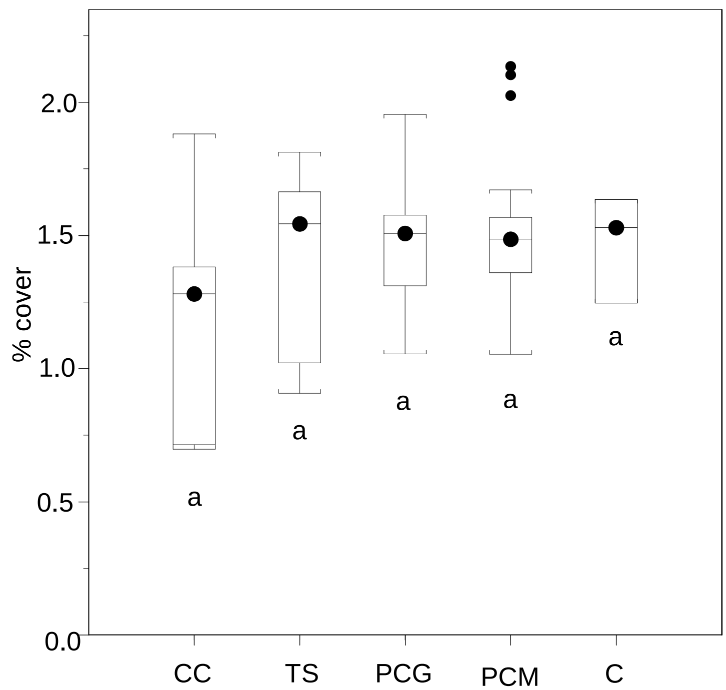
s	5	pcm	147	21	25	15	1.88	17
s	6	pcg	153	23	72	8	n/a	20
s	6	pcm	157	46	30	16	2.25	22
s	7	ts	157	51	51	11	2.52	22
s	8	cc	135	32	44	12	2.39	25
s	9	pcg	155	28	44	4	n/a	19
s	9	pcm	154	38	14	12	1.75	21
s	10	pcg	107	50	23	8	n/a	19
s	10	pcm	106	93	0	12	1.39	17
s	11	c	125	7	13	16	1.88	16

Table 3.3- Treatment means and 95% confidence intervals (Tukey-Kramer adjusted) for total cover, tall shrub cover, invasive ruderal cover, Shannon's diversity index and species richness for each treatment 15 to 16 years after treatment. Non-significant differences at α= 0.95 as determined from Tukey-Kramer multiple comparison tests are represented by corresponding letters. (asterisk denotes non-significance at α= 0.90)

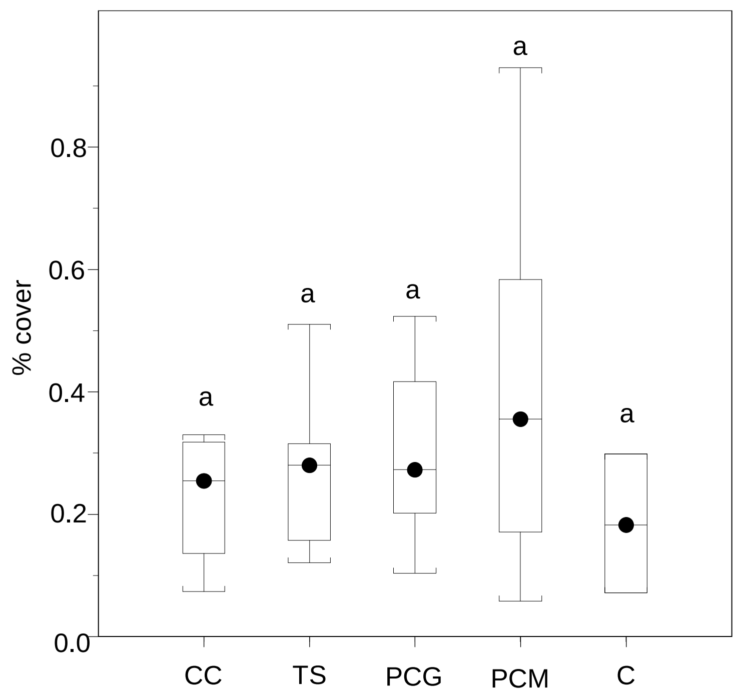
Dependent Variable	**Treatment**	***Lower C.I.***	**Mean**	***Upper C.I.***
Total Cover	CC	*0.97*	1.04 a	*1.10*
	TS	*1.02*	1.09 a	*1.14*
	PCG	*1.06*	1.1 a	*1.14*
	PCM	*1.07*	1.1 a	*1.14*
	C	*1.01*	1.1 a	*1.18*
Tall Shrub Cover	CC	*0.54*	0.68 a	*0.80*
	TS	*0.58*	0.71 a	*0.83*
	PCG	*0.64*	0.73 a	*0.81*
	PCM	*0.66*	0.75 a	*0.84*
	C	*0.44*	0.64 a	*0.80*
Ruderal Cover	CC	*0.19*	0.36 ab	*0.57*
	TS	*0.26*	0.61 a	*0.82*
	PCG	*0.03*	0.42 ab	*0.59*
	PCM	*0.15*	0.20 b*	*0.36*
	C	*0.00*	0.13 b	*0.40*
Forb Cover	CC	*0.42*	0.55 ab	*0.65*
	TS	*0.45*	0.57 ab	*0.66*
	PCG	*0.36*	0.46 a	*0.54*
	PCM	*0.47*	0.56 ab	*0.62*
	C	*0.57*	0.69 b	*0.80*
Shannon's DI	CC	*1.50*	1.95 ab	*2.40*
	TS	*1.78*	2.23 a	*2.68*
	PCG	*N/A*	N/A	*N/A*
	PCM	*1.25*	1.64 b	*2.03*
	C	*1.15*	1.69 ab	*2.23*
Richness	CC	*16.2*	20.0 a	*23.8*
	TS	*18.7*	22.5 a	*26.3*
	PCG	*14.6*	17.8 a	*21.1*
	PCM	*14.8*	18.1 a	*21.4*
	C	*12.2*	16.7 a	*21.1*

Figure 3.1- Percent cover of (a) all vascular plants (b) tall shrubs (c) ruderal species, (d) forbs and (e) Shannon's diversity index and (f) species richness by silvicultural treatment (CC=clearcut, TS= two-story, PCG= gaps group-selection, PCM= matrix of group-selection, C= control) 15 to 16 years after treatment. P-values (Tukey-Kramer adjusted) of comparisons between treatments with non-matching letters are shown in italics (if less than 0.1).

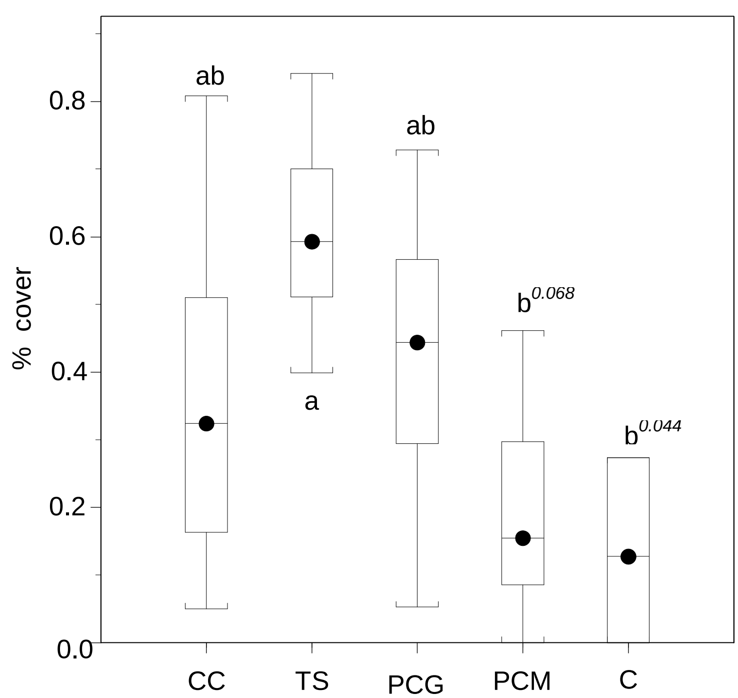
a) Total cover



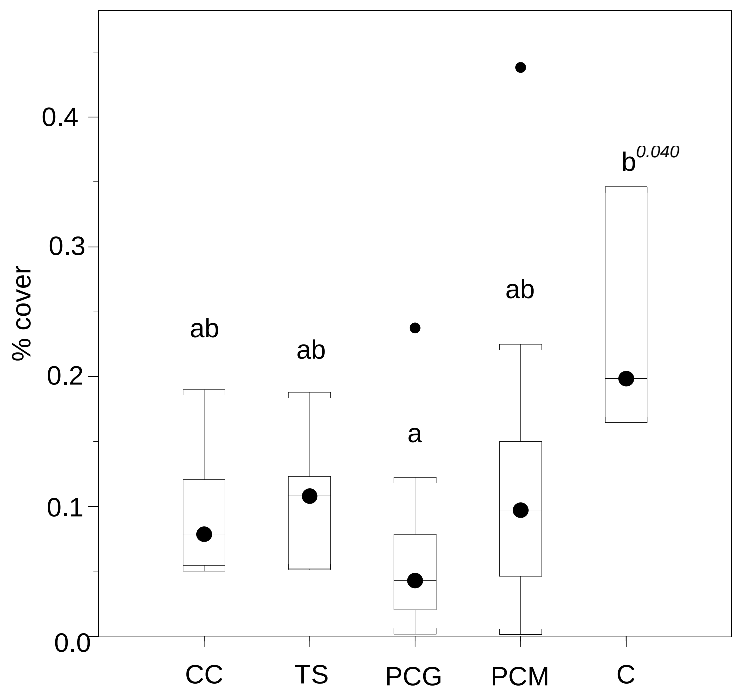
b) Tall shrubs



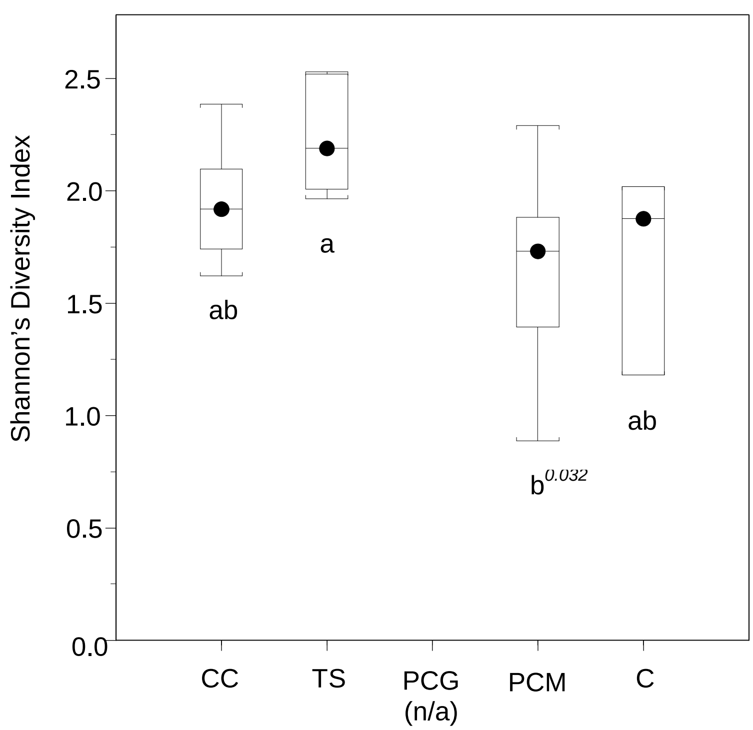
c) Ruderals



d) Forbs



e) Shannon's diversity index



f) Species richness

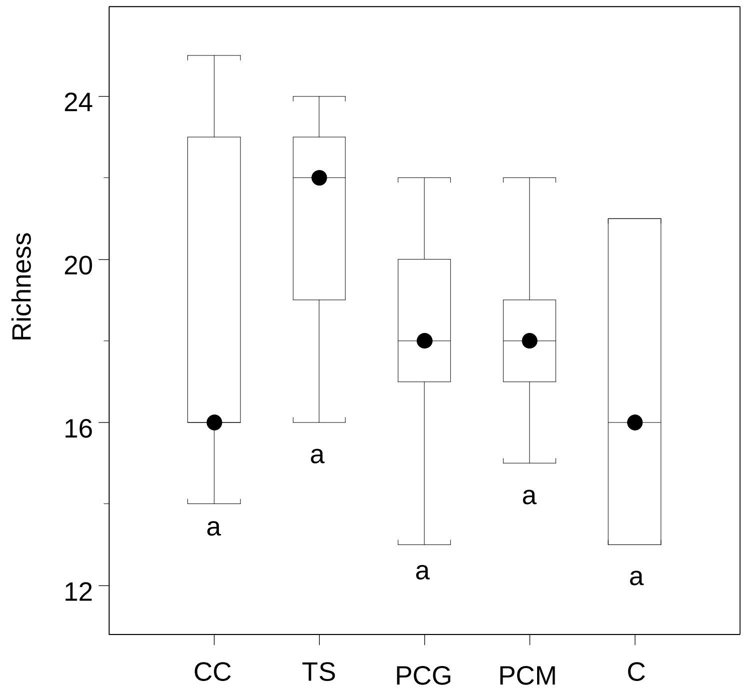
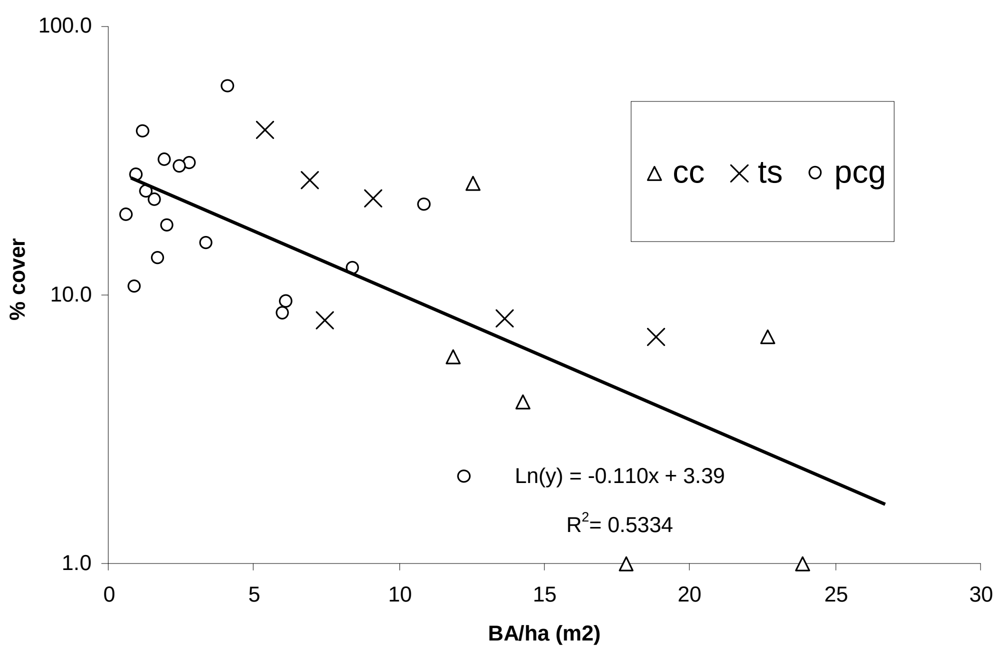


Table 3.4- Significant treatment differences in group covers and diversity. P-values and confidence intervals are Tukey-Kramer adjusted for multiple comparisons.

Dependent Variable	**Treatment Comparison**	**d.f.**	**T-stat**	**P-value**	***Lower C.I.***	**Mean**	***Upper C.I.***
Ruderal Cover	TS vs. PCM	8	3.54	0.068	*-0.01*	0.41	*0.81*
	TS vs. C	8	3.23	0.044	*0.03*	0.47	*0.98*
Forb Cover	C vs PCG	8	3.61	0.040	*0.01*	0.18	*0.35*
Shannon's DI	TS vs. PCM	6	3.86	0.032	*0.06*	0.59	*1.13*
Total Cover	No significant differences						
Tall Shrub Cover	No significant differences						
Richness	No significant differences						

Figure 3.2- Himalaya blackberry percent cover vs. regenerating Douglas-fir BA by treatment in all harvest areas of the CFIRP study 16-18 years after harvest.



CHAPTER 4 – ARTIFICIALLY-TOPPED DOUGLAS-FIR DYNAMICS IN THREE ALTERNATIVE SILVICULTURAL TREATMENTS

Introduction

Standing dead trees (snags), living trees with decay, and hollow trees are all important structural components of Pacific Northwest forest ecosystems. Numerous taxa use snags for nesting, denning, foraging, or as a growth substrate (Thomas et al. 1979). Living trees with decay exhibit structural complexities such as multiple tops and hollow chambers that are used by various canopy dwelling species (Bull et al. 1997). Hollow trees provide nesting, roosting and denning sites for Vaux's swifts (*Chaetura vauxi* Townsend) black bears (*Ursus americanus* Pallas) and American martins (*Martes Americana* Turton).

Research has shown, however, that current intensive forestry methods may significantly reduce both the number and quality of snags and living trees with decay in intensively managed forests. Cline et al. (1980) found that managed Coast Range sites in Oregon had fewer and smaller snags than similar unmanaged stands. This reduction in snag quantity and size was hypothesized to be caused by the salvage of sound snags, falling of dangerous snags, and reduced snag recruitment from competition-induced mortality. Wilhere (2003) simulated snag dynamics in a generalized industrial forest and estimated total snag density in managed stands to be only a fifth of that in unmanaged stands. Additionally, his model estimated the density of large snags (63 to 89 cm, DBH) to be only 1% of the density simulated for unmanaged stands.

While uncertainty exists regarding snag dynamics in both managed and unmanaged landscapes, it's clear that routine forest management has reduced snag quality and quantity versus historic levels. In order to address this issue, "New Forestry" practices have been proposed in which snags and structurally complex live trees are maintained through harvest cycles so that these ecosystem components persist through the artificial disturbance (Franklin, 1989). Federal and state regulations have responded to these concerns by requiring some number of snags and green trees to be retained following harvest. In order to retain these structures, however, they must first exist. Wilhere (2003) showed how self-thinning in older stands can result in the creation of large snags, however such snag creation only occurs when there exists competition-induced mortality which is generally minimized through the use of carefully timed thinnings when managing for timber objectives (Tappeiner et al. 2007). Additionally, any naturally-occurring snags can be hazardous to workers if they are left standing during harvest operations (US Department of Labor, 2006).

As an alternative to relying upon naturally-occurring snags to meet the needs of wildlife, some managers turn to artificially created snags. When snags are purposefully created, they can be "placed" at appropriate densities where they will be out of the way of current and future harvest operations. Various methods have been used to kill live trees in order to create snags (Lewis 1998). Trees can be girdled, inoculated with fungus, injected with herbicide, or treated with pheromones in order to encourage insect attack. These methods all retain the tree's full structure and may help encourage heart rot which could increase a snag's value as wildlife habitat (Bull et al. 1997). However, neither girdling, inoculation, herbicide nor insect pheromones guarantee tree death, and furthermore, snags with an intact top but wounded base may be more susceptible to windthrow than ones which have had their tops removed (Bull and Partridge 1986). Alternatively, trees can also have their crowns fully or partially removed by topping with a chainsaw or dynamite. When all live branches are removed, tree death is guaranteed and rapid, whereas death may be delayed or might not occur at all if some live branches are retained (Bull and Partridge 1986). Hallet et al. (2001) found that snags created by topping were used more by cavity excavating birds than snags that were killed by girdling.

While the decomposition and fall rates of naturally-occurring snags are relatively well understood (Cline et al. 1980, Garber et al. 2005, Chambers and Mast 2005, Russell et al. 2006) the dynamics of artificially-topped conifer trees are not well studied. The fall rate of natural snags is approximated by a sigmoidal pattern where rapid fall rates follow a significant lag time during which newly killed snags decompose and weaken (Cline et al. 1980, Harmon et al. 1986, Garber et al. 2005). However, when healthy live trees are topped and live branches remain, an additional lag time exists between the time the tree is topped and the time the tree dies, if it ever does die. Two other differences exist between natural snags and topped trees: natural snags will generally be taller with correspondingly larger height:diameter ratios, and the cut tops of topped conifers provide an entry point for fungi that intact natural snags lack. Because of these differences, it is important to differentiate between natural snags, fatally-topped trees (FTTs), and non-fatally-topped trees (NFTTs) when studying snag dynamics. FTTs, for the purpose of this study, are trees that retain live branches after topping and NFTTs are topped trees which have all live branches removed.

Another poorly studied aspect of snag dynamics is how surrounding forest structure affects a snag's longevity. Garber et al. (2005) considered a stand's silvicultural prescription when modeling natural snag longevity, but differences in stand structure were most likely overridden by the mechanical damage resulting from harvest activities.

Our study investigated the long-term dynamics of both FTTs and NFTTs (all Douglas-fir) within the context of three distinct silvicultural regimes. Specifically, I sought to quantify the effects of individual stem characteristics and surrounding forest structure [clearcut (CC), two-story (TS), or mature forest matrix of group selection stands (PCM)] on the mortality rates and fall rates of fatally- and non-fatally-topped Douglas-fir trees 16 to 18 years after their creation in the Coast Range of Oregon.

Methods

Site Description

FTTs and NFTTs were created within the context of the College of Forestry Integrated Research Project (CFIRP) initiated by OSU's College of Forestry in 1989 and designed to "help our understanding of the tradeoffs associated with a set of alternative management approaches representing a spectrum of conditions: from even-aged with retention to uneven-aged to uncut mature forests" (Maguire and Chambers 2005). The CFIRP study is split among three geographically distinct sites in Oregon State University's 4,550-ha McDonald-Dunn Research Forest. The forest is located on the east flank of the Coast Range as it transitions into the Willamette Valley. Elevation across the sites ranges from approximately 120 to 400 m. Slope and aspect both vary by stand. Soils across the three sites are predominantly (93%) comprised of the Dixonville, Jory, Philomath, Price, and Ritner series which are generally deep, well drained silty clay loams derived from basalt parent material. About 7% of the area making up the CFIRP sites is comprised of the Abiqua and Waldo soil series which are alluvial soils associated (on these sites) with terraces and fans of small seasonal streams.

Precipitation averages 104 cm annually with most occurring as rain in the winter and spring (July monthly rainfall averages only 0.1 cm). This is on the low end of the Coast Range's precipitation gradient. Low temperatures in January average 0.5°C while August highs average 27°C (Western Regional Climate Center). Site index (50 year base age) across the sites range from 28 to 40 m (King, 1966).

Study areas occur within two plant association types: Douglas-fir/hazel/brome-grass (Pseudotsuga menziesii/Corylus cornuta var. californica/Bromus vulgaris) and Douglas-fir/vine maple/salal (Pseudotsuga menziesii/Acer circinatum/Gaultheria shallon) (Franklin and Dyrness 1973). Vegetation was generally similar across sites prior to treatment. Total basal area of stands ranged from 24 to 76 m^2/ha,of which hardwoods comprised between 5 and 26%. Douglas-fir dominated the overstory although there was a small component of grand fir (Abies grandis). Stands ranged in age from 45 to 144 year, and the average height of the 40 largest tress per stand ranged from 29 to 54 m (Maguire and Chambers 2005).

Study Design

Thirty stands comprising 297 ha were designated, each within one of three geographically distinct sites (Saddle, Peavy, or Dunn) as is shown in Figure 2.1. Each of the stands was assigned to one of 3 silvicultural treatments:

Clearcut	1.2 green trees retained per ha.
Two-story	75% of volume removed resulting in 20 to 30 green trees/ha.
Group selection	33% of volume removed in 0.2 to 1.0 ha circular, square, or strip-shaped gaps**.**

Stands were harvested between Fall of 1989 and Summer 1991 and all harvested areas were planted with Douglas-fir seedlings. The above prescriptions were designed to incorporate New Forestry goals while still being operationally efficient. Treatment assignments by stand are outlined in Table 4.1.

Concurrent with the harvesting, both FTTs and NFTTs were created by a climber using a chainsaw. Cutters were instructed to keep live branches on the trees as convenient. A total of 804 Douglas-fir trees were topped (288 non-fatally and 516 fatally), and the resulting topped trees had a mean height of 16.9 m (range of 12.2 to 23.5 m) and a mean dbh of 86 cm (range of 33 to 198 cm). Topped trees were created in two spatial arrangement treatments: (1) Clumped – created in groups of 8 to 12 or (2) Scattered – spaced evenly throughout the stand. Each of the 30 CFIRP stands was randomly assigned one of the spatial arrangement treatments (Table 4.1). In the group selection treatments, all topped trees were created within the mature forest matrix. Topped trees were individually numbered using aluminum tags and their locations were recorded using a GPS receiver. Additionally, the following measurements were taken on each topped tree after being cut: DBH, height, percent lean, and slope of ground.

Data Collection

Topped trees (both NFTTs and FTTs) were revisited during the winter of 2007-8, 16 to 18 years after their creation. If they were still alive, then they were recorded as such and assessed for relative vigor: declining, intermediate, or vigorous. “Declining” trees had sparse crowns and appeared to be declining in health. Trees marked as “vigorous” had a well-developed crown that showed signs of growth since the tree was topped. “Intermediate” trees showed signs of growth since treatment but had less dense crowns then the “well” trees. Dead NFTTs and FTTs were marked as either standing or broken. Standing topped trees retained their original flat-cut top while broken topped trees were ones that had either been uprooted or were missing their cut top. Broken topped trees were measured for height; a value of zero was assigned to trees which uprooted or broke at the base. Twenty-six topped trees could not be located due to missing GIS data and were removed from consideration in the analyses. Additionally, 34 topped trees were missing initial assessment data and were also not analyzed leaving a total sample size of 744.

Analyses

Separate analyses were conducted for NFTTs and FTTs. For each group, logistic regression was used to test for effects of stem and site variables on the proportion of topped trees that, 16 to 18 years after topping, were: 1) alive (in the case of NFTT group only) and 2) broken.

TREATMENT	Silvicultural system topped tree is in (CC, TS or PCM)
ARRANGEMENT	Clumped vs. scattered spatial arrangement
CREATEYEAR	Year the tree was topped (covaries with site)
HEIGHT	Height of the stem after topping
DBH	Diameter at breast height of stem
SLOPE	Percent slope of the ground at the topped tree (only in FTT group)
LEAN	Percent lean from vertical of the topped tree (only in FTT group)
SDI	Stand Density Index (Reineke 1933) of the stand prior to silvicultural treatment and tree topping (only in NFTT group)

Three separate stepwise selection processes were conducted in order to determine which of the above seven independent variables were significantly related to the two previously described dependant variables (proportion alive and proportion broken) for both fatally- and non-fatally-topped trees. Beginning with a random model (no explanatory variables), independent variables were added one at a time with only the most significant (largest t-stat) kept in the model. Additionally, if a variable's parameter estimate was not significant at α=0.95 it was not included and if, after the inclusion of other variables, a parameter estimate was not significant at α=0.90 it was removed from the model. Final models were checked for interactions between dependant variables.

Results

Non-fatally-topped trees

Two hundred and six of the 262 revisited NFTTs (76.7%) died at some time in the 16 to 18 years since they were created. Of the 61 that remain living, 50% were classified as "vigorous", 37% as "intermediate" and only 13% were classified as "declining" (Figure 4.1). Percent survival by silvicultural treatment, spatial arrangement and creation year as well, as mean values of the above described tree and site characteristics for living and dead NFTTs are all shown in Table 4.2. I identified TREATMENT, CREATEYEAR, and DBH as being significant when explaining the probability of non-fatally-topped Douglas-fir trees surviving 16 to 18 years after being topped (Table 4.3). The odds of survival for a NFTT created within a mature, closed-canopy stand are estimated to be 2.5 times (95% CI: 1.0 to 6.9 times) the odds of survival for NFTTs in a clearcut and 3.3 times (95% CI: 1.3 to 8.2 times) the odds for NFTTs in a very low density stand (two-story treatment). For each 10 cm increase in DBH, the odds of dying within 16 to 18 years of creation for FTTs are increased by 20% (95% CI =4% to 39%). Test statistics and odds ratios for all model variables and comparisons within the groups of each are summarized in Table 4.4.

Only eight of the 262 revisited non-fatally-topped Douglas-fir trees (3.1%) were broken (i.e. did not retain their full height) (Table 4.2); consequently, logistic regression on the proportion with breakage was not feasible with the NFTT group.

Fatally-topped trees

Nineteen of the 482 revisited fatally-topped Douglas-fir trees (3.9%) were broken 16 to 18 year after topping. I identified DBH as the only significant variable when explaining the probability of fatally-topped Douglas-fir trees breaking within 16 to 18 years of being topped (Wald χ^2, 1 df = 14.39, p-value =0.0001). For each 10 cm increase in DBH, the odds of breaking within 16 to 18 years of creation for FTTs are decreased by 80% (95% CI =33% to 144%).

Discussion

Death is not guaranteed when Douglas-fir trees are topped in such a way that a portion of their live crown is retained; 23% of all NFTTs have survived 16 to 18 years, and half of those that have survived remain vigorous with considerable diameter and height growth (Figures 4.2 and 4.3). Additionally, the uppermost branches in many surviving NFTTs were observed to convert to leaders, thus creating a candelabra structure (Figure 4.4). This growth pattern results in large diameter branches that can be used as nesting platforms by, for example, the federally listed marbled murrelet (*Brachyramphus marmoratus* Gmelin) (Baker et al. 2006).

NFTTs created within a mature, closed-canopy stand are significantly more likely to survive long enough to develop candelabra structures useful to wildlife than NFTTs in clearcuts or very low density (shelterwood-like) stands. Topped trees created in a matrix are more sheltered from the wind and, thus, are able to retain more of their live branches following topping relative to the trees topped in more open settings (Schmid et al. 1985). Additionally, the lower level foliage that remains after topping is comprised of shade needles, and these shade needles experience fatal sunscald in the open conditions following harvest in the clearcut and two-story treatments. This effect is similar to the thinning shock described by Harrington and Reukema (1983). These speculations on the cause of survival differences, however, are speculative and beyond the scope of our study. The odds of a NFTT surviving are decreased by 20% for each 10 cm increase in DBH. It is unclear why smaller diameter NFTTs would be more likely to survive than larger diameter individuals. This effect, however, is fairly small and statistical significance may be an artifact of the high statistical strength afforded by the large sample size.

Generally, topped trees are very unlikely to break within the first 16 to 18 years after their creation. When both NFTTs and FTTs are considered only 3.6% experienced any form of height reduction and of those 32 only 4 are currently too short (less then 1.8 m) to meet the needs of birds for nesting (Thomas et al. 1979) (Figure 4.5. This very low rate of breakage agrees with the findings of Cline et al. (1980) who found that for larger Douglas-fir natural snags, the lag time before snags begin to fall is around 20 years. Our finding that larger stem diameter resulted in lower rates of breakage also agree with the findings of past studies of natural snags. Cline et al. (1980) found that with natural Douglas-fir snags, fall rate lag time increases with increasing diameter. In a review of natural snag fall rate studies, 8 out of the 10 studies considered found that natural snags stand longer as their diameters increase; the other two studies didn't detect a significant relationship (Cluck and Smith 2007).

Management implications

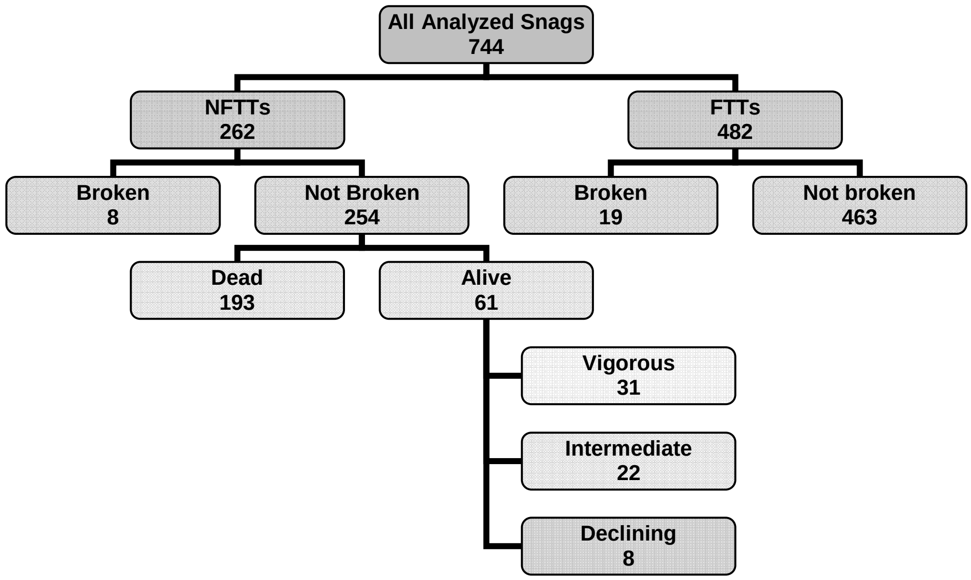
1) Topping trees, both fatally and non-fatally, is an effective was to create snags where they are lacking in stands or landscapes. When topping trees for the purpose of snag creation, large diameter trees should be selected in order to ensure a long useful life.

2) Non-fatal topping of live Douglas-fir trees is a viable way to create structurally complex, candelabra crown structures where management objectives dictate such a need. When the creation of these complex structures is an objective, NFTTs should be created in mature stands in order to ensure relatively high levels of survival.

Table 4.1- General characteristics and silvicultural and topped tree arrangement treatment assignments for CFIRP stands.

Stand Number by Block	*Area (ha)*	*Average Age*	*Regeneration Treatment*	*Snag Treatment*
Saddle Block				
1	6.9	119	Clearcut	Scattered
2	11.6	119	Two-story	Scattered
3	9.6	119	Group selection	Scattered
4	7.6	96	Group selection	Scattered
5	6.1	73	Group selection	Scattered
6	10.4	108	Group selection	Clumped
7	17.8	117	Two-story	Clumped
8	15	144	Clearcut	Clumped
9	8	95	Group selection	Clumped
10	12.5	136	Group selection	Clumped
Peavy Block				
2	9.7	134	Clearcut	Scattered
3	11.1	130	Group selection	Scattered
4	10.3	111	Two-story	Scattered
5	9.6	109	Group selection	Scattered
6	9.8	109	Group selection	Scattered
7	9.9	104	Group selection	Clumped
8	8.1	114	Group selection	Clumped
9	8.4	127	Group selection	Clumped
10	7.8	124	Two-story	Clumped
11	5.5	118	Clearcut	Clumped
Dunn Block				
1	16.1	77	Two-story	Clumped
2	11.4	70	Group selection	Clumped
3	10.7	124	Clearcut	Clumped
4	7.9	76	Group selection	Clumped
6	7.3	67	Group selection	Scattered
7	11.7	59	Group selection	Scattered
8	9	58	Two-story	Scattered
9	6.7	45	Clearcut	Scattered
10	9.8	58	Group selection	Scattered
11	10.9	60	Group selection	Clumped
Totals: 30	***297***			

Figure 4.1- Fates of all analyzed NFTTs and FTTs displayed by count in hierarchical form 16 to 18 years after treatment in Oregon's Coast Range. Accompanying pie chart shows the same data proportionally.



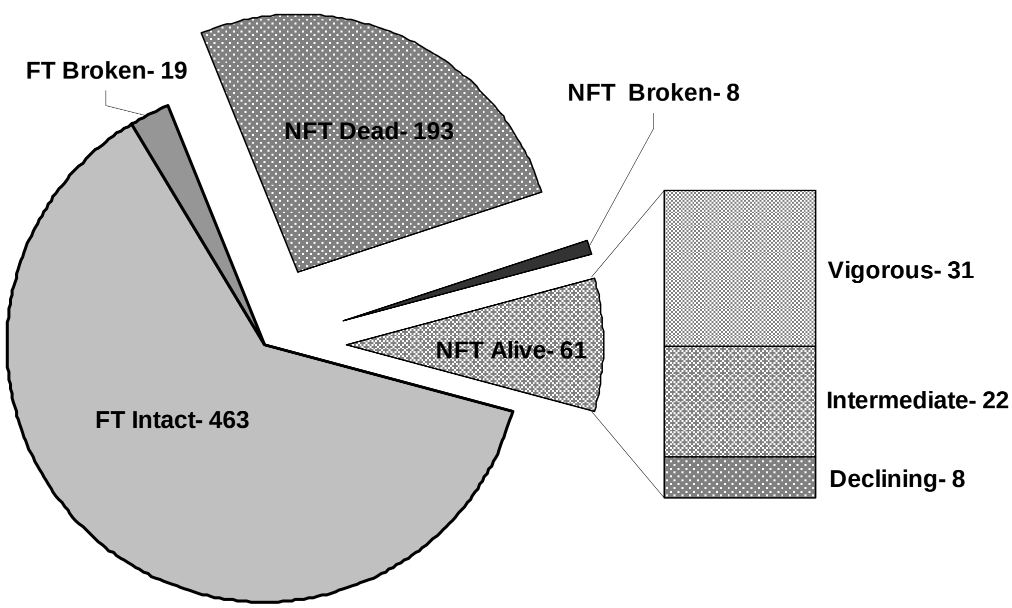


Table 4.2- Percent living and percent broken of both fatally- and non-fatally-topped trees by treatment, creation year and spatial arrangement 16 to 18 years after treatment in Oregon's Coast Range. Also, mean values of height, DBH, H:D ratio, percent slope, percent lean, and SDI of the stand prior to harvest and (in parentheses) each mean's standard deviation.

		Silvicultural treatment (% in each treatment)			Creation year (% in each treatment)			Spatial arrangement (% in each treatment)							
	2007 Status	CC	TS	PCM	'89	'90	'91	Clumped	Scattered	Ht (m)	DBH (cm)	H:D	Slope (%)	Lean (%)	SDI of stand prior to harvest
Non-Fatally-Topped	Dead	86.3%	90.1%	66.4%	74.4%	91.8%	70.3%	71.4%	82.2%	16.9 (±1.5)	89 (±30)	0.21 (±0.07)	N/A	N/A	423 (±76)
	Alive	13.7%	9.9%	33.6%	25.6%	8.2%	29.7%	28.6%	17.8%	16.7 (±1.8)	72 (±27)	0.26 (±0.08)	N/A	N/A	457 (±88)
	Broken	3.9%	4.2%	2.1%	2.2%	3.3%	3.6%	2.3%	3.9%	17.5 (±0.4)	80 (±29)	0.24 (±0.07)	N/A	N/A	N/A
	Not broken	96.1%	95.8%	97.9%	97.8%	96.7%	96.4%	97.7%	96.1%	16.8 (±1.4)	85 (±30)	0.22 (±0.07)	N/A	N/A	N/A
Fatally-Topped	Broken	5.8%	1.6%	4.2%	5.1%	3.1%	4.2%	4.1%	3.7%	16.7 (±1.4)	87 (±28)	0.3 (±0.09)	25 (±16)	1.5 (±1.8)	N/A
	Not broken	94.2%	98.4%	95.8%	94.9%	96.9%	95.8%	95.9%	96.3%	17 (±1.4)	62.1 (±28)	0.21 (±0.06)	28 (±15)	1.9 (±2.3)	N/A

Figure 4.2- Core from a vigorous live topped Douglas-fir within the matrix of a groups selection stand in Oregon's Coast Range 18 years after treatment exhibiting decreased, but still significant, diameter growth. Arrow indicates the age at time of topping.

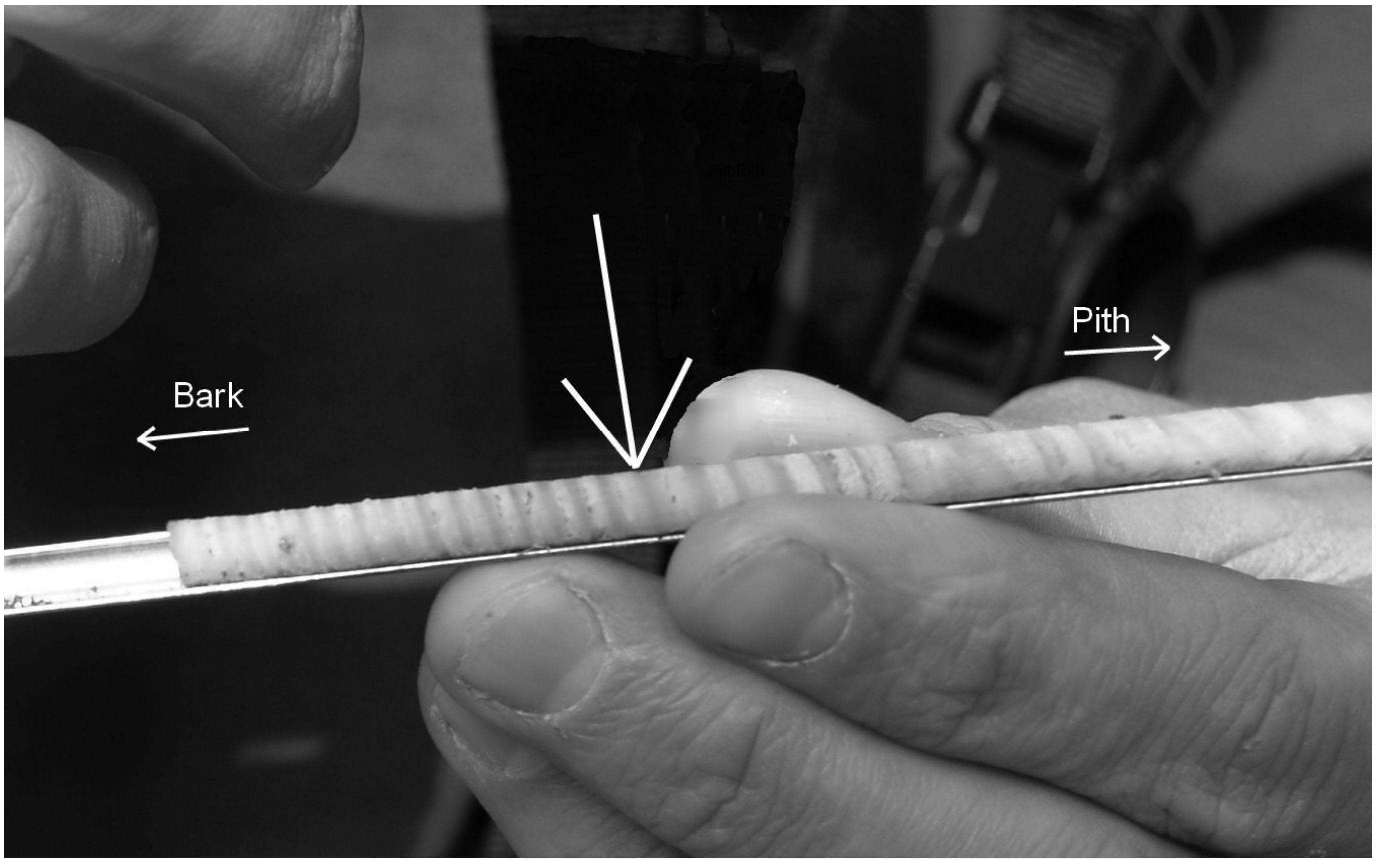


Table 4.3- Test statistics and p-values for significance of treatment effects in explaining Logit(survival) of non-fatally topped trees in Oregon's Coast Range 16-18 years after topping.

Effect	df	Wald chi-square	P-value
TREATMENT	2	9.317	0.0095
CREATEYEAR	2	8.212	0.0165
DBH	1	6.357	0.0117

Table 4.4- Test statistics and odds ratios for survival of non-fatally topped trees 16-18 years after treatment (with Wald 95% CI) for contrasts between treatment types and years topped. Also, the odds ratio of survival for an increase in stem DBH of 10 cm.

Effect	Contrast	df	Wald chi-square	P-value	Odds Ratio	95% Wald Confidence Intervals Lower	Upper
Treatment	TS vs.CC	1	0.175	0.675	0.78	*0.24*	*2.50*
	CC vs. PCM	1	3.503	0.061	0.29	*0.14*	*1.04*
	TS vs. PCM	1	6.627	0.010	0.30	*0.12*	*0.75*
Year Topped (covarying by site)	1990 vs. 1989	1	7.708	0.006	0.19	*0.06*	*0.57*
	1990 vs. 1991	1	8.805	0.003	0.23	*0.08*	*0.65*
	1991 vs. 1989	1	0.340	0.560	0.81	*0.41*	*1.63*
DBH (increase of 10cm)	-	1	6.357	0.012	0.83	*0.72*	*0.96*

Figure 4.5- Distribution of breaking heights of all topped trees that broke within 16 to 18 years in the CFIRP study.

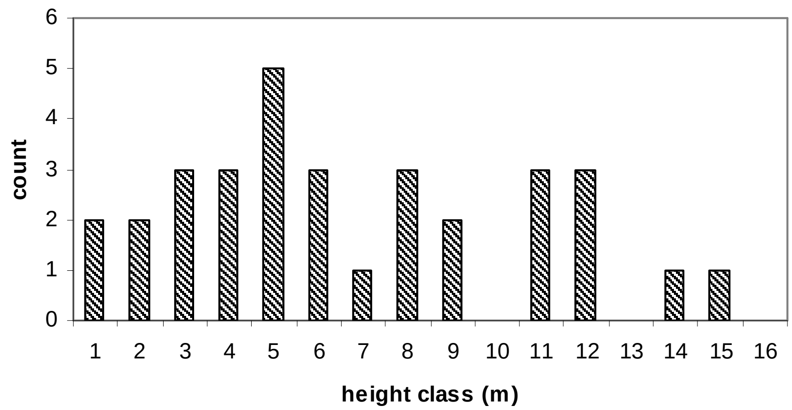


Figure 4.3- Vigorous live topped conifer exhibiting considerable height growth since treatment.

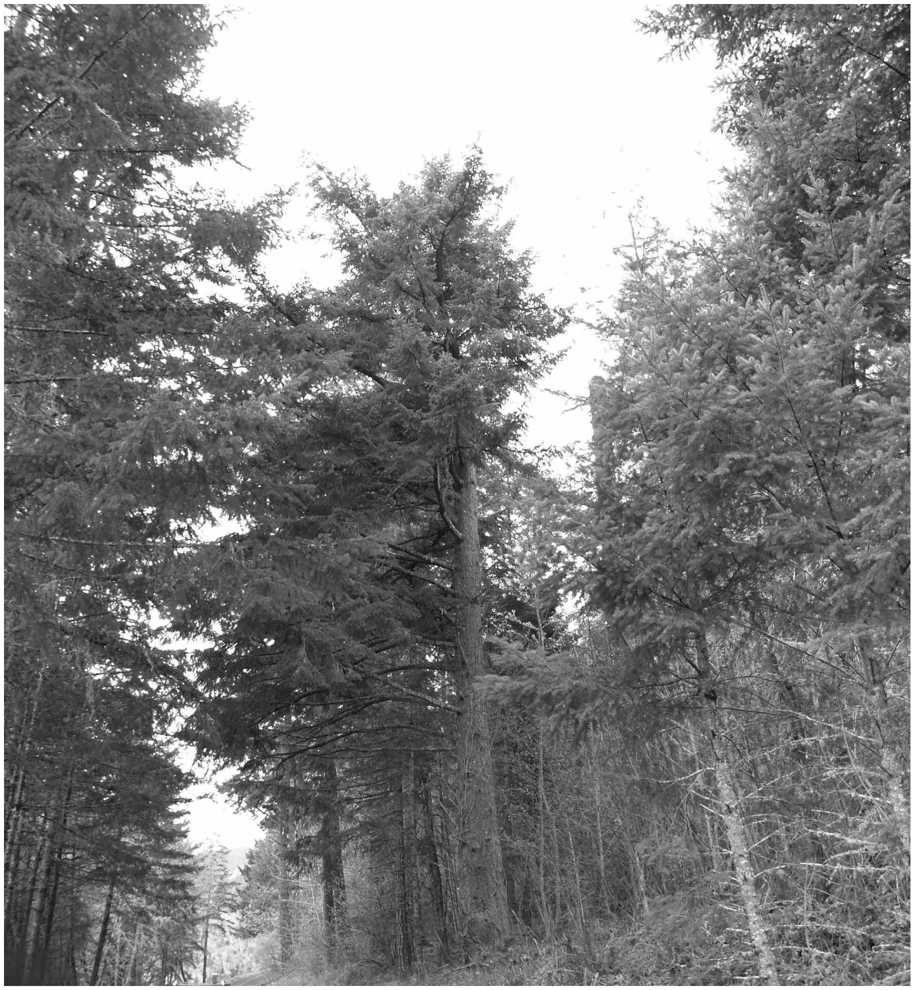
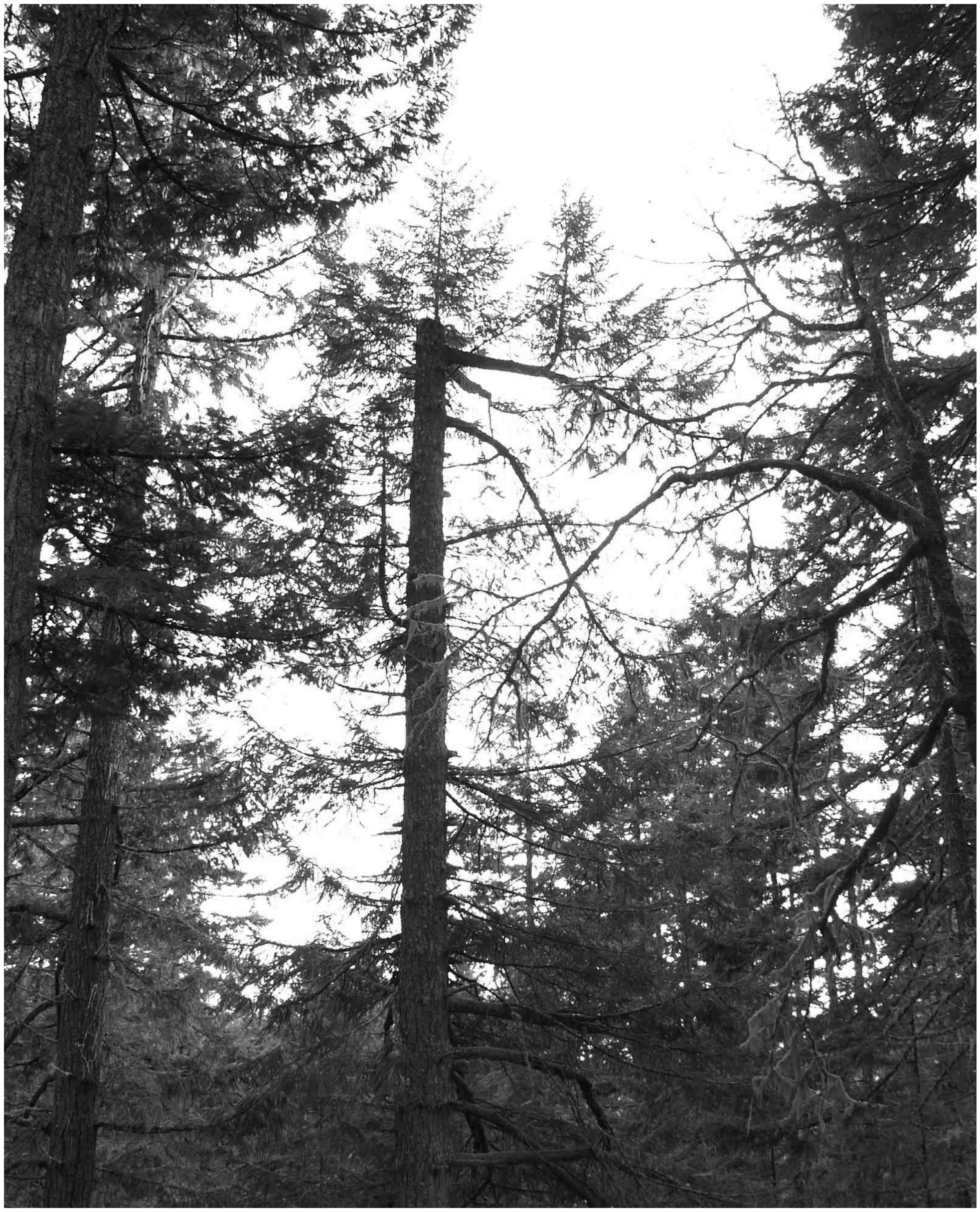


Figure 4.4- Candelabra-shaped crown created when the branches of a live topped conifer converted into leaders



CHAPTER 5- CONCLUSION

Historically, Coast Range foresters have drawn from a relatively small subset of the available silvicultural tools when managing forests. This simplistic management has been a result of relatively simple objectives based on timber production. Recently, however, foresters have been asked to manage for a broader array of objectives including biodiversity, recreation, aesthetics, carbon sequestration and water quality, often concurrently with timber production. While alternative silvicultural treatments would likely be useful in solving complex multiple-use forest management problems, foresters might be reluctant to utilize them due to the fact that they remain largely untested on an operational level. Our study has answered some of the questions managers could have regarding the outcomes of alternative silvicultural treatments.

Growth of regenerating Douglas-fir is regulated by overstory density. Thus, there is a trade-off between green-tree retention and growth rates of the newly regenerated cohort. Although growth rates may be reduced, plantation establishment is possible using two-story or group selection regeneration methods if competing vegetation is sufficiently controlled. When using group selection, larger gaps will result in greater growth rates of regeneration.

Plant community responses to harvest are driven largely by successional trends rather than differences in silvicultural treatments. Shrub communities are very resilient and are not greatly affected by either partial or complete harvest. Forb cover is reduced somewhat during the first two decades of stand development but forbs were not extirpated in any of the treatments considered. Furthermore, other research suggests forb cover will rebound in later successional stages (Alaback 1982, Halpern and Spies 1995).

Topping trees, both fatally and non-fatally, is an effective was to create snags where they are lacking in stands or landscapes. When topping trees for the purpose of snag creation, large diameter trees should be selected in order to ensure a long useful life. Non-fatal-topping of live Douglas-fir trees is a viable way to create structurally complex, candelabra crown structures where management objectives dictate such a need. When the creation of these complex structures is an objective, NFTTs should be created in mature stands in order to ensure relatively high levels of survival. While topping trees, both fatally and non-fatally, is relatively inexpensive, there is a significant opportunity cost of reduced timber revenue and available growing space (Maguire and Chambers 2005, Bull and Partridge 1986).

There are clear tradeoffs whenever a single stand is asked to provide multiple values. Objectives, and scale dependencies related to those objectives, need to be considered when planning management in order to maximize a forest's output of whatever qualities one is interested in. For example,

Our study benefits from being a part of the long-term CFIRP study. While our findings are limited in that it only considers one point in successional lifespan of stands, I am able to build upon the findings of past researchers. Future research is needed in order to assess longer-term treatment responses. Additionally, this study would likely benefit from additional manipulative entries; as an operational study, treatments should emulate prescriptions that land forest managers are likely to follow. Many of the CFIRP stands would benefit from silvicultural treatments such as pre-commercial thinning, vegetation control, planting and/or further overstory removal in order to meet the New Forestry objectives outlined at the inception of the study. As long as these further treatments are applied uniformly across replicates, I will be able to continue making strong inferences on the long-term effects of operational New Forestry methods.

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APPENDICES

Appendix A- Specific planting and vegetation control activities conducted after harvest for the CFIRP stands

Block/ Stand	Silvicultural Treatment	Date	Planting (all Douglas-fir)	Date	Vegetation Control
Dunn 1	Two-story	1/92	1-1, P-1, and 2-0 seedlings @ 11.5' spacing	7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
		1/93	1280 1-1 seedlings interplanted	9/93	Spot-sprayed within 4 ft of seedlings with 1% Accord, 1% Garlon4 and 1% MorAct
				9/24	Broadcast Sprayed using hose and reel with 0.75% Garlon 4
				10/96	Hardwoods and Shrubs treated with 1% Arsenal, 2% Accord and 2% Entry II
Dunn 2	Group selection	12/91	1-1 seedlings @ 11.5' spacing	3/92	Broadcast Sprayed using hose and reel with4.4 lbs. Atrazine and 1.5 qt. 2.4-6
		1/94	500 1-1 seedlings interplanted	4/93	Broadcast Sprayed using hose and reel with 2.66 oz. Oust
		3/95	1-1 seedings interplanted	7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
				9/93	Broadcast Sprayed using hose and reel with 1.5 qt. Accord and 10 oz Entry II

				4/94	Broadcast Sprayed using hose and reel with 2 qt. Velpar and 2 oz oust
				4/95	Spot-sprayed within 4 ft of seedlings with 15. oz./gal Velpar
Dunn 3	Clearcut	1/92	P-1, and 2-0 seedlings @ 11' spacing	3/92	Broadcast Sprayed using helicopter with 4 lbs. Atrazine and 1.5 qt. 2.4-6 in water
		12/93	1620 2-1 seedlings interplanted	4/93	Broadcast Sprayed using helicopter with 2.66 oz Oust
				12/93	Foliar application of Arsenal
				4/94	Broadcast Sprayed using helicopter with 4.4 lbs. Atrazine and 1.5 qt. 2,4-6
				8/94	Broadcast Sprayed using helicopter with 1.5 qts Accord and 10 oz Entry II
Dunn 4	Group selection	1/92	1-1 seedlings @ 11' spacing	3/92	Broadcast Sprayed using helicopter with 4 lbs. Atrazine and 1.5 qt. 2.4-6 in water
		12/93	interplanted with 2-1 seedlings	4/93	Broadcast Sprayed using helicopter with 2.66 oz Oust
				7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
				9/93	Spot-sprayed within 4 ft of seedlings with 1% Accord, 3/4% Garlon4 and 1% MorAct

Dunn 6	Group selection	1/92	1-1 seedlings @ 11' spacing	3/92	Broadcast Sprayed using helicopter with 4.4 lbs. Atrazine and 1.5 qt. 2.4-6 in water
		1/94	interplanted with 2-1 seedlings	4/93	Broadcast Sprayed using helicopter with 2.66 oz Oust
				7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
				9/93	Spot-sprayed within 4 ft of seedlings with 1% Accord, 3/4% Garlon4 and 1% MorAct
				8/94	Broadcast Sprayed using helicopter with 1.5 qts Accord and 10 oz Entry II
Dunn 7	Group selection	12/91	1-1 seedlings @ 12' spacing	3/92	Backpack Spayed with 4.4 lb. Atrazine and 1.5 qt. 2,4-6
				3/93	Spot-sprayed within 4 ft of seedlings with 14qt. Velpar
				7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
				10/96	Spot-sprayed with 1% Arsenal, 2% Accord, and 2% Entry II
Dunn 8	Two-story	1/92	P-1 seedlings @ 11' spacing	3/92	Broadcast Sprayed using helicopter with 20 lbs Pronone 10G
		3/93	interplanted with P-1and 1-1 seedlings	4/93	Spot-sprayed within 4 ft of seedlings with 4 qts Velpar

				7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
				10/93	Spot-sprayed within 4 ft of seedlings with 1% Accord, 1% Garlon4 and 1% MorAct
				9/97	8 acres spot sprayed with 2% Accord, 1% Arsenal, and 2% LI 700
				9/98	Spot sprayed with 2% Accord, 1% Arsenal, and 2% LI 700
Dunn 9	Clearcut	1/92	P-1 and 2-0 seedlings @ 11' spacing	3/92	Broadcast Sprayed using helicopter with 4 lbs. Atrazine and 1.5 qt. 2.4-6 in water
		3/93	Eastern 5 acres interplanted with 1-1 seedlings	8/92	Broadcast Sprayed using helicopter with 1.5 qt. Accord amd 10 oz. Entry II
		1/96	Eastern 3 acres interplanted with 1-1 seedlings	4/93	Broadcast Sprayed using helicopter 2.66 oz of Oust
				7/93	Foliar application of 2.5% Arsenal & 0.5% R-11
				10/93	Spot-sprayed within 4 ft of seedlings with 1% Accord and 1% Entry II
				3/96	Eastern 3 acres treated using hose and reel with 2 oz Oust and 2 qt. Velpar in 10 Gal. Water
				4/98	Broadcast sprayed using hose and reel with 2% arsenal and 0.5-1% surfactant

Dunn 10	Group selection	1/92	1-1 seedlings @ 11.5' spacing	3/92	Broadcast sprayed using hose and reel with 4.4lb atrazine and 1.5 qt 2,4-D
		1/94	220 2-1 seedlings interplanted	3/93	Broadcast sprayed using hose and reel with 1.5 qt Accord and 10 oz. Entry II
				8/92	Broadcast sprayed using hose and reel with 2.66 oz Oust
				7/93	Foliar application of 2.5% Arsenal & 0.5% Entry II
				9/93	Spot-sprayed within 4 ft of seedlings with 1% Garlon 4 and 1% MorAct
				9/94	Portions broadcast sprayed using hose and reel with 3/4% Garlon 4
Dunn 11	Group selection	12/91	1-1 seedlings @ 13.5' spacing	3/92	4 qt. Velpar or 4.4 lbs. Atrazine and 1.5 qts. 2,4-D in water
		1/94	2-1 seedlings interplanted	8/92	Broadcast sprayed using hose and reel with 1.5 qt Accord and 10 oz. Entry II
				3/93	Spot-sprayed within 4 ft of seedlings with 4 qt. Velpar
				7/93	Foliar application of 2.5% Arsenal & 0.5% Entry II
				4/94	2 qt. Velpar and 2 Oz Oust

				9/94	Broadcast sprayed using hose and reel with 3/4% Garlon 4
Peavy 2	Clearcut	12/91	1-1 seedlings @ 11.5' spacing	6/91	Hack and Squirt with Garlon 3A
		1-93	interplanted with 1-1 seedlings	3/92	Broadcast Sprayed using helicopter with 4 lbs. Atrazine and 1.5 qt. 2.4-6 in water
				8/92	Broadcast Sprayed using helicopter with 1.5 qt. Accord and 10 oz. Entry II
				4/93	Broadcast Sprayed using helicopter 2.66 oz of Oust
				8/94	Spot foliar application of 2.5% Arsenal & 0.5% R-11
				3/96	West half of stand treated using hose and reel with 2 oz Oust and 2 qt. Velpar in 10 gal water
Peavy 3	Group selection	12/91	1-1 seedlings @ 13.5' spacing	6/91	Hack and Squirt with Garlon 3A
		3/93	interplanted with 1-1 and 2-0 seedlings	3/92	Unknown chemical treatment
				9/92	Foliar spot spray using 2.5% Arsenal and 0.5% R-11
				9/93	Spot Sprayed with 3/4% Garlon 4

Peavy 4	Two-story	1/92	1-1 seedlings @ 11.5' spacing	1/96	Basal spray of hardwoods using 12% Garlon 4 in crop oil
				3/92	Broadcast Sprayed using helicopter with 20 lbs Pronone 10G
				8/92	Spot foliar application of 2.5% Arsenal & 0.5% R-11
				9/92	Spot-sprayed within 4 ft of seedlings with 1% Accord and 1% Entry II
				9/93	Spot-sprayed within 4 ft of seedlings with 1% Accord, 1% Garlon4 and 1% MorAct
				8/94	Spot foliar application of 2.5% Arsenal & 0.5% R-11
Peavy 6,7,8,9	Group selection	12/91	P-1 seedlings @ 13.5' spacing	3/92	4.4 lbs Atrazine amd 15 oz Entry II
				8/92	Broadcast sprayed using hose and reel with 1.5 qt Accord and 15 oz. Entry II
				9/93	Spot Sprayed with 3/4% Garlon 4
				4/94	Spot sprayed with 4 qts Velpar
				8/94	Foliar application of 2.5% Arsenal & 0.5% R-11

				1/96	Basal spray of hardwoods using 12% Garlon 4 in crop oil
Peavy 9	Group selection	12/91	P-1 seedlings @ 13.5' spacing	3/92	4.4 lbs Atrazine amd 1.5 qt 2,4-D
				8/92	Spot sprayed with unknown chemical
				9/92	Foliar application of 2.5% Arsenal & 0.5% R-11
				9/93	Spot Sprayed with 1% Accord, 3/4% Garlon 4, and 1% MorAct
				1/96	Basal spray of hardwoods using 12% Garlon 4 in crop oil
Peavy 10 & Peavy 11	Two-story and Clearcut	1/92	1-1 and 2-0 seedlings at 11.5	3/92	Broadcast Sprayed using helicopter with 20 lbs Pronone 10G
		12/93	Interplanted with 2945 2-1 seedlings	8/92	Spot foliar application of 2.5% Arsenal & 0.5% R-11
				9/92	Spot-sprayed within 4 ft of seedlings with 1% Accord and 1% Entry II
				9/93	Spot Sprayed with 1% Accord, 3/4% Garlon 4, and 1% MorAct
				8/94	Maple clumps treated with foliar application of 2.5% Arsenal & 0.5% R-11
				9/94	Broadcast sprayed using hose and reel with 1.5 qt Accord and 10 oz. Entry II
				1/96	Basal spray of hardwoods using 12% Garlon 4 in crop oil
Saddle 1, 8	Clearcut	12/90	1-1 seedlings @ 11' spacing	3/91	Broadcast Sprayed using helicopter with 4 lbs Atrazine and 1.5 qt 2,4-D
				4/91	Broadcast Sprayed using helicopter with 4 lbs Atrazine and 1.5 qt 2,4-D

				8/91	Broadcast Sprayed using helicopter with 1.5 qt. Accord amd 15 oz. Entry II
				10/95	Foliar application of 1% Arsenal and 2% Accord in water
Saddle 2	Two-story	1/91	1-1 seedlings @ 15' x 9' spacing	4/91	Broadcast Sprayed using helicopter with 20 lbs Pronone 10G
				6/92	Spot-sprayed within 4 ft of seedlings with 2% Arsenal and 1% Entry II and Accord
				10/95	Foliar application of 1% Arsenal and 2% Accord and LI700in water
Saddle 3,4,5,6,	Parch-cut	12/90	1-1 seedlings @ 13.5' spacing	3/91	Broadcast spray of 4 lbs Atrazine and 1.5 qt 2,4-D in water using hose and reel
		4/93	P-1 seedlings planted in some gaps	7/91	Spot sprayed with 3/4% Garlon 4, 1% Round-up and 1% Moract
				3/92	Treated with either 4.4 lbs Atrazine and 1.5 qts 2,4-D or 4 quarts Velpar.
				8/92	Broadcast spray of 1.5 qt. Accord and 10 oz. Entry II using hose and reel
				9/93	Backpack broadcast sprayed with 3/4% Garlon 4, 1%Accord and 1% Moract
				10/97	Spot treatment of hardwoods and shrubs using 2% Accord, 1% Arsenal, and 2% LI700
				3/98	Broadcast spray of 2 oz. Oust and 1.33 lns Velpar using hose and reel
Saddle 7	Two-story	2/91	P-1 seedlings @ 11.5' spacing	4/91	Broadcast Sprayed using helicopter with 20 lbs Pronone 10G
		12/93	Interplanted with 2-1 seedlings	9/91	Arsenal Treatment (details unknown)
				9/93	Spot-sprayed within 4 ft of seedlings with 1% Accord 1% Garlon 4 and 1% MorAct
				9/93	Broadcast spray of 1.5% Accord and Entry II using hose and reel

				10/95	Backpack foliar treatment
Saddle 9, 10	Group selection	12/90	1-1 seedlings @ 13.5' spacing	3/91	Broadcast spray of 4 qt. Velpar in water using hose and reel
		2/92	interplanted with P-1and 1-1 seedlings	3/92	Treated with either 4.4 lbs Atrazine and 1.5 qts 2,4-D or 4 quarts Velpar.
				9/93	Spot-sprayed within 4 ft of seedlings with 1% Accord 3/4% Garlon 4 and 1% MorAct
				4/94	Spot-sprayed within 4 ft of seedlings with Velpar
				3/98	Broadcast spray of 2 oz. Oust and 1.33 lns Velpar using hose and reel