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The response to various levels of stand density by natural Douglas-fir regeneration, shrub and sprouting hardwood species was studied in the mixed-evergreen-forests of southwest Oregon. Partial-cut old growth (harvested 22-31 years prior) and thinned even-aged (harvested 9-17 years prior) stand types were used as surrogates for intentionally managed uneven-aged stand types, which were not available for this study. A lower number of clearcut and uncut stands were also sampled in order to capture the full range of overstory densities.

Harvest preceded the establishment of: >95% of seedlings (trees 15-140 cm height) in thinned (970 seedlings/ha) and partial-cut (1300 seedlings/ha) stand types and, 82% of saplings (trees 1.4-5.0 m height, w/ conical crown shape) in partial-cut (370 saplings/ha) stands. These results indicate that harvest stimulated natural regeneration of Douglas-fir. However, regeneration was not evenly spaced throughout the plots. For example, seedling frequency averaged 0.45 in thinned and 0.46 in partial-cut stands (0-1.0 scale). Frequency and density of regeneration tended to increase as stand density index

(SDI) decreased. Height growth of regeneration generally increased as SDI decreased. Sapling height growth in partial-cuts was greatest on steep, south facing slopes compared to other slope and aspect combinations. The fastest growing third of individual seedlings had an average annual leader growth of 10 cm/yr. and saplings 38 cm/yr. Shrub cover averaged 61% and increased with time since harvest and on north facing slopes (adj. $r^2 = 0.33$, $p < 0.001$). Shrub cover was not related to density or frequency of Douglas-fir regeneration but it was negatively related to height growth of regeneration.

Results from this study indicate that natural regeneration of Douglas-fir in partially harvested stands is sufficient to maintain a significant component of this species in the stands with no further management, i.e. shrub control or future harvest. However, reductions in stand density and shrub cover could likely increase frequency, density, and growth rates of regeneration in an uneven-aged management scenario.

Natural Regeneration of Douglas-Fir in Uneven-Aged Stands in Southwest Oregon

by

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Natural Regeneration of Douglas-fir in Uneven-Aged Stands in Southwest Oregon

1.0 Introduction

Uneven-aged management is a general term for the suite of silvicultural methods which maintain high-forest cover and multiple age classes of trees on a site at all times. It was recently defined by Emmingham (1998) as a forest stand which has three functioning, i.e. vigorously growing, canopy layers or age cohorts of trees present in the stand at all times. Although poorly understood and little practiced in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) region of the Pacific Northwest (PNW), the system offers an alternative to even-aged management, which is widely disliked by the public (Emmingham 1998).

Even-aged management employs a single age class of trees in a particular stand and is usually regenerated every 40-90 years using the clearcut, shelterwood or seedtree method. The most common regeneration method in the Douglas-fir region of the PNW is the clearcut method. It is the clearcut method that is disliked by the public, not necessarily the even-aged stands that result from them (Emmingham 1998). Characteristics of stands managed using even-aged techniques include: high uniformity in tree size, shape and species, suppression of non-commercially valuable species and minimal retention of biologically important features such as large snags or down logs (Franklin et al. 1986). Aside from public concern over aesthetics, these characteristics of typical even-age management systems can have significant impacts on terrestrial and aquatic biological diversity, slope stability, stream morphology and the hydrologic cycle (Franklin 1989, McComb et al. 1993, Jones and Grant 1996, Kohm and Franklin

1997, Dunne 1998). However, much of the forest land in the Pacific Northwest (PNW) will probably continue to be managed using primarily even-aged systems for the foreseeable future because, according to Smith (1997), these systems are, " the best understood and simplest to manage."

In contrast, uneven-aged management is poorly understood for the Douglas-fir region of the PNW, largely because the method was abandoned after early failures in implementation (Munger 1950). A form of uneven-aged management known as the "selection system" was used in the PNW during the 1930's and early 1940's. The 'selection system' was a form of 'highgrading' where only the most valuable old-growth trees in a stand were harvested and the remaining stand left. Not surprisingly, regeneration was poor, windthrow was common, and the remaining trees, often damaged from the logging, succumbed to disease (Issac 1956). The system was judged a failure, and uneven-aged management was abandoned in the PNW (Munger 1950). Consequently, uneven-aged practices have been neglected in the PNW for the past 30-40 years in favor of even-age systems, primarily clearcutting (Guildin 1996). However, uneven-aged management has been practiced in Europe for centuries and is still in use there (Mustian 1976). Uneven-aged management also is currently in use in certain Sierra Nevada mixed conifer forests of California, Southeastern pine forests and eastern hardwood forests (Lilieholm et al. 1990, Shelton and Murphy 1994, Larsen 1997).

In its current form, uneven-aged management attempts to mimic the ecological pattern of scattered overstory mortality of trees, singly and in small groups, in mature 'natural' forest stands. The selective removal of overstory trees frees up growing space for regeneration to become established (Guildin 1996). Even-age management is purported to mimic the ecological pattern of catastrophic stand replacing disturbance, such as fire or massive windthrow (Smith et al. 1997). However, as Guildin (1996) points out, "when this is used to justify using only clearcutting for every reproduction cut imposed on a given ranger district the parallel breaks down: not every mature tree dies with 40 acres of its associates in a square block on the hillside." Similarly, not every forest regenerates through scattered overstory mortality, as in the uneven-aged model. Rather, forests have always had a variety of mechanisms that stimulate regeneration events and forest management at a landscape scale could more closely emulate this pattern by using uneven-aged and even-aged techniques in combination (Franklin et al. 1986).

Uneven-aged management has the potential to assuage public concerns over forest management by not using the visually shocking clearcut system of regeneration. Use of uneven-aged techniques may also reduce impacts to terrestrial and aquatic ecosystems (Fiedler and Cully 1995, Carey and Curtis 1996). In contrast to even-aged systems, stands managed using uneven-aged techniques retain: 1) more constant above ground vegetative cover, 2) greater root strength in the soil profile, 3) a higher abundance of symbiotic fungal species and, 4) a more constant suite of floral and faunal species in terms of seral stage (Borchers and Perry 1989, Brooks et al. 1991, Kimmins 1997).

The problem with uneven-aged management is that the technical details for implementation of have not been well developed for all regions. For example, an important silvicultural detail that has not been worked out for the PNW region is how to attain adequate regeneration of desired species after harvest. Gibbs (1976) pointed out some reasons why regeneration methods have not been developed for the region and results of managing without this knowledge:

> Many of our problems in uneven-aged management are attributable to the fact that for years we considered only volume in the regulation of uneven-aged stands. Regeneration was largely ignored and harvests were confined to the sawlog portion of the stand. Harvests were based on past or projected growth without adequate treatment of the pole and sapling segment of the stand. At best simple volume control has resulted in uneven-aged stands progressing toward even-aged conditions and at worst there have been severe reductions in long term yields, decreases in stand quality, and undesirable changes in species composition (Gibbs 1976).

The regeneration problem still has not been addressed sufficiently, and the practice has not been adopted widely in the PNW.

Since there are few examples of stands in Douglas-fir forests of the PNW that have been managed on an uneven-aged basis little research has been conducted in uneven-aged systems (Emmingham 1998). Although research results from uneven-aged stands are rare in the PNW, results from numerous studies conducted in shelterwoods, modified clearcuts and thinned even-age stands may be applicable (Franklin 1963, Worthington and Heebner 1964, McCreary and Perry 1983, Tesch and Mann 1991, Bailey 1996). There also are research results from the Sierra Nevada of northern California, where uneven-aged management has been carried out and studied for the past 40 years (Helms and Tappeiner 1996).

2.0 Literature Review

2.1 Limiting Factors to Seedling Regeneration and Growth

The primary environmental factors that affect seedling growth are pathogens, moisture, temperature, light, nutrition, and mechanical stress (Hobbs 1992). Hobbs (1992) noted that in southwest Oregon and northern California light is the most important characteristic affecting seedling performance in the field. Overstory canopy density and understory shrub cover are the focus of this study and are known to alter the light, water and temperature regimes in the regeneration environment, thereby affecting seedling performance (Radosevich et al. 1976, Dunlap and Helms 1983, Tappeiner et al. 1992). The alterations in light, water and temperature regimes may either aid or impair seedling establishment and growth, depending on the degree of alteration and age of the seedling.

2.2 Light and Recruitment of Regeneration

In general, there are two distinct stages in the regeneration of natural or planted seedlings in any silvicultural system: 1) initial survival and, 2) growth rate after establishment. These two stages often have different environmental requirements (Smith et al. 1997). Young and newly germinated seedlings of most species are intolerant of high soil temperatures, strong sunlight, and low soil moisture. Many species of trees have cotyledons and/or juvenile foliage that is more shade tolerant or photosynthetically efficient at lower light levels than the adult foliage of the same species (Smith et al. 1997).

To avoid killing seedlings in the early stages of development, some shade may be necessary so that soil surface temperatures do not become excessively high during hot summer days. Herbs and shrubs on site, residual canopy shade, or artificial shade cards may reduce soil temperatures enough for early seedling survival. For example, a study in southwest Oregon found that stands with overstory canopy densities of 60% had the highest rates of natural regeneration, in contrast to clearcuts which had a harsher regeneration environment and lower rates of natural regeneration (Graham 1982). Minore (1982) found that most natural regeneration in partial-cuts in the Applegate area of southwest Oregon occurred in forests with overstory canopy densities of 45-75%. However, it was noted in that study that neither overstory basal area or canopy density was statistically related to regeneration. Minore (1982) also noted that the poor correlation was probably the result of irregular cutting, which caused large variations in canopy and basal area, so that accurate sampling of these forests was difficult.

2.3 Light and Growth of Regeneration

Although some degree of initial shading may be required in order to establish regeneration, low light levels may impede growth as the seedling develops. This is because light, which has a major influence on rates of photosynthesis, is a significant factor controlling seedling growth rates (Emmingham and Waring 1973, Del Rio and Berg 1979, Tappeiner et al. 1997). For example, Witler (1975) found that Douglas-fir seedlings were able to establish, but not grow well or even survive very long under a thinned Douglas-fir overstory in the Oregon Coast Range that averaged 22-29 m^2/ha basal area. Worthington and Heebner (1964) observed that Douglas-fir seedlings were able to establish but not survive in stands in the Washington Coast Range that had been thinned to 43 m^2/ha basal area with 4.9 % of full sunlight.

Light levels in the understory of forest stands are largely controlled by overstory density. Dunlap and Helms (1983) demonstrated this relationship in a study of shelterwood cuts of differing overstory densities. They found that understory light levels were 12, 51, 57 and 76% of full sunlight under stands with basal areas of 75, 20, 15, and 10 m^2/ha, respectively (Dunlap and Helms 1983).

In general as canopy density decreases and understory light levels increase, the growth rates of regeneration also increase (Pacala et al. 1994). In a comparison of growth rates for mixed species of regenerating conifers under various harvesting methods in northern California, McDonald (1976) observed that as light exposure decreased and canopy density increased from clearcut to single tree selection, height growth of all understory conifers decreased regardless of relative shade tolerance. In the mixed evergreen forests of southwest Oregon, Minore et al. (1977) observed that Douglas-fir seedlings were 10-23 cm shorter under a partial-cut canopy with 33 m^2/ha of residual basal area than similar aged seedlings in a nearby clearcut. Similar results of height growth decreasing linearly with increased canopy density have been observed in hardwood and conifer forests throughout the PNW and in hardwood forests in the Ozark highlands (Del Rio and Berg 1979, Minore et al. 1977, Emmingham et al. 1989, Oliver and Dolph 1992, Deal and Farr 1994, Bailey 1996, Chan et al. 1996, Owston and Chan 1996 and Larsen et al. 1997). Table 2.1 includes data for annual height

Table 2.1. Review of studies conducted in N. California and W. Oregon that include data on stand condition and Douglas-fir regeneration characteristics. 'Location' is the region where the study was conducted; 'Ave. BA (m^2/ha)' is the average basal area of the stand in m^2/hectare; 'Gap Size' is the area of the opening in which regeneration was measured; 'Stand Type' is the silvicultural method applied to the stand; 'Annual Height Growth (cm)' is the average annual leader elongation reported for regeneration in cm; 'Trees/ha' is the density of regeneration in trees per hectare; 'Height (m)' is the average height of regeneration in meters; 'Ave.Age' is the average age of regeneration.

Stand Characteristics		Douglas-Fir Regeneration Characteristics				
Location	Ave. BA (m2/ha), Gap Size, or Stand Type	Annual Height Growth (cm/yr)	Trees/ha	Height (m)	Ave. Age	Reference
W.Oregon	53	3.0	232	1.3	12	Bailey and Tappeiner 1997
	32	11.0	1432	1.3	12	
Sierra Nevada	75	2.3	n/a	n/a	3	Dunlap and Helms 1983
	10	3.1	n/a	n/a	3	
S.W. Oregon	34	n/a	10,138	0.26	5	Minore et.al. 1977
	.65 -1.34 ha gaps	n/a	3,809	0.33	5	
	clearcut	n/a	961	0.4	5	
Oregon Coast Range	37 - 44	4.0	2825	0.26	8	Del Rio and Berg 1979
	30 - 37	6.0	4966	0.34	8	
	23 - 30	7.4	5099	0.4	8	
	clearcut	20.1	n/a		8	
Sierra Nevada	36	11.0	n/a	.3 -.11	10 - 20	Oliver and Dolph 1992
	23	17.0	n/a	.3 -.10	10 - 20	
	9	22.0	n/a	.3 -.9	10 - 20	
Sierra Nevada	49.5	19.0	n/a	6.7	44	Lilieholm et.al. 1990
	35	3.8	n/a	0.58	20	
	34	11.8	n/a	3.2	43	
Oregon Coast Range	23	17.0	n/a	0.76	3	Owston and Chan 1996
	14	24.0	n/a	0.9	3	
	7	26.0	n/a	0.93	3	
	single tree	n/a	760	0.21	8	
Sierra Nevada	group	n/a	322	0.45	8	McDonald 1976
	shelterwood	n/a	198	0.79	8	
	seed tree	n/a	430	0.94	8	
	clearcut	n/a	388	1.28	8	

growth of Douglas-fir regeneration observed in forests with different levels of overstory density, these values might be useful for forest managers making decisions regarding desired residual stand density or regeneration methods for uneven-aged stands.

2.4 Soil Moisture

Inadequate soil moisture also can impair growth of regeneration, because small decreases in soil moisture content above permanent wilting point can reduce net photosynthesis rates, which reduces seedling growth rates (Zavitkovski and Ferrell 1970, Stransky and Wilson 1964). Soil moisture trends tend to be similar to light level trends in forests of different overstory densities; i.e. less dense overstory stands tend to have higher understory light levels and higher soil moisture contents than more dense stands. For example, Dunlap and Helms (1983) found that soil moisture contents in both shelterwood and uncut, mixed conifer stands were 35% in May but, by the end of the growing season had dropped to 18% in low density shelterwoods (10-15 m^2/ha basal area) versus 12% in uncut stands (75 m^2/ha basal area). Therefore, reductions in stand density may increase growth rates of regeneration by making both soil moisture and light more available than in uncut stands.

2.5 Temperature

The primary threats to seedling survival and growth in terms of temperature are excessive soil surface and freezing air temperatures (Hobbs 1992). Retaining some canopy cover in the form of shelterwoods or uneven-aged management can ameliorate both conditions. In a study conducted in southwest Oregon, Childs et al. (1985) found that maximum summer soil temperatures as deep as 30 cm below the soil surface were

11° C cooler in shelterwoods versus adjacent clearcuts. In a study of the impacts of frost damage on regeneration in different stand types Williamson and Minore (1978) found 90% survival of planted Douglas-fir seedlings under shelterwood canopies with 24-36 m^2/ha of residual basal area but only 16-37% survival in an adjacent clearcut due to frost damage.

2.6 Rocky Soils

Rocky soils have been identified as being associated with low levels of conifer regeneration in southwest Oregon (Minore 1982, Graham 1982). Minore and Graham found that natural conifer regeneration was negatively correlated with increasing surface gravel cover in partial-cuts.

2.7 Slope and Aspect

Slope and aspect can influence levels of natural regeneration in partial-cut forests of southwest Oregon. In the Hungry-Pickett area, Graham (1982) found that slope and aspect accounted for 24% of the variation in stocking, with highest stocking occurring on gentle slopes (< 5% slope) with south-southeast or northwest aspects. In a regional study of southwest Oregon regeneration, Stein (1986) observed that stocking of natural Douglas-fir regeneration was highest for partial-cuts that were most exposed to the sun and for clearcuts least exposed to the sun.

2.8 Response of Advanced Regeneration to Overstory Removal

The utility of advanced regeneration in timber management operations is often debated. Much of the skepticism regarding the utility of advanced regeneration is because foresters are unsure if advanced regeneration will increase its growth rate, or "release" in response to the removal of overstory canopy. There also is concern that using advanced regeneration will increase the stocking of shade tolerant species, such as grand fir (*Abies grandis* (Dougl.) Lindl.) or western hemlock (*Tsuga heterophylla* (Raf.) Sargl), as opposed to the shade intolerant but economically more valuable species such as Douglas-fir and the pines (Tesch and Korpela 1993). Although these concerns have been addressed for even-aged systems (Gordon 1973, Helms and Standiford 1985, Tesch and Korpela 1993), little is known about performance of advanced regeneration in uneven-aged systems.

Tesch and Korpela (1993) observed in even-aged systems that eventually (within 20 years) almost all Douglas-fir and white fir advance regeneration responded to overstory removal by increasing growth rates. Trees with the greatest height growth before release, responded more quickly and consistently to release than trees with low pre-release height growth. After 5 years, they found little correlation between the amount of overstory removed and the post-release growth. As with many other studies conducted in southwest Oregon, they encountered high variability in their data and could generally explain less than 60% of the variability using regression models.

In a study conducted in northern California, it was found that pre-release height growth was the best predictor of post-release height growth and response rate (Helms and Standiford 1985). The authors observed trees growing at < 20 cm/yr. pre-release took 4.3 years to respond to release, while trees growing at or > 30 cm/yr. pre-release took just 2.2 years to respond to release. Both of the preceding studies were conducted on sites that had been clearcut for final release, not partial-cut.

In a regeneration study conducted in partial-cuts and clearcuts in the Glendale-Galice area of southwest Oregon, Stein (1986) made the following observations: 1) advanced regeneration was present on 65% of partial-cut plots and constituted 75% of total stocking, 2) Douglas-fir was the most common species of advanced regeneration, present on 80% of sites, 3) hardwood advanced regeneration was present on only 20% of sites and, 4) stocking of Douglas-fir was positively correlated with amount of disturbed seedbed. Despite the high level of stocking observed for natural regeneration, field notes indicated that many of the trees grew slowly, suppressed by both thick hardwood and shrub understories or an overly dense canopy (Stein 1986). However, Stein did not quantify 'slowly', 'thick', or 'overly dense' in the previous observations.

2.9 Understory Shrub and Herb Responses to Thinning

There is a consensus in the literature that as thinning intensity increases, abundance of understory vegetation also increases (Tappeiner et al. 1992, Mayrsohn 1995). However, due to the extreme variability of results within and between stands and regions it is unclear if herbs, shrubs or trees generally increase the most in abundance.

Studies in the central Oregon Coast Range at Black Rock Experimental Forest found that as thinning intensity increased, biomass of understory herbs and shrubs increased. However, the increase in biomass of woody shrubs was highly variable within and between stands (Witler 1975, Del Rio and Berg 1979). Mayrsohn (1995) found that in the western Cascades and in the Oregon Coast Range shrub cover increased due to thinning, but that the increase had no clear relationship to the intensity of thinning. Alaback and Herman (1988) observed that mean cover of understory herb, shrub and moss species increased in thinned stands versus unthinned stands, but that the high degree of variability often rendered the treatment response insignificant between different levels of thinning intensity.

In this same study it was also discovered that thinning generally caused a significant community shift in the understory, from primarily herbs and ferns in unthinned and light thinnings to a 90% shrub dominated understory in the heavily thinned stands (Alaback and Herman 1988). This finding is contradicted by an earlier finding that as thinning intensity increased the proportion of herbaceous cover to shrub cover increased (Del Rio and Berg 1979).

Dense overstory canopies have been shown to impair the growth and sprouting potential of some hardwoods in the understory. Tappeiner (1984) observed that tanoak (*Lithocarpus-densiflorus* (Hook. and Arn.)Rehd.) growing under dense conifer overstories had much slower growth rates than tanoak growing in recent clearcuts. This trend was consistent for tanoak seedlings and stump and burl resprouts. McDonald (1978) observed that at 5 years of age, height and diameter of sprout clumps were 30, 40, and 50% less for Pacific madrone (*Arbutus-menziesii* Pursh), tanoak and black oak (*Quercus kelloggii* Newb.), respectively, in shelterwoods versus clearcuts.

2.10 Competitive Effect of Shrubs on Regeneration

Density and frequency of naturally regenerated conifer seedlings has been observed to be negatively related to shrub cover in thinned stands (Bailey 1996).

Bailey (1996) found that seedling densities at shrub covers greater than 70% were only 40% of densities found in areas where shrub cover was less than 20%. This may be because high understory shrub densities can decrease soil moisture content and light availability, thereby impairing seedling establishment and growth (Tesch and Hobbs 1989, White and Newton 1989).

Two sprouting hardwoods that are common in southwest Oregon, and were common on the plots in this study, are tanoak and Pacific madrone. Tanoak has been observed to exert a greater competitive effect on Douglas-fir seedlings than Pacific madrone in clearcut areas (Harrington 1991). This greater competitive ability was attributed to tanoak's faster growth rate and higher leaf area (7.0 m^2 leaf area/m^2 ground area) versus madrone (4.1 m^2/m^2). It has also been observed that the clump size of tanoak sprouts was related to parent tree diameter before cutting and that tanoak developed its sprouting potential slowly in the understory (Tappeiner 1984).

3.0 Goals and Objectives

The goal of this study was to ascertain how stand density and shrub cover affected the quantity, distribution and growth rates of Douglas-fir regeneration in the western Siskiyous in southwest Oregon. The specific objectives were to determine:

1) if the dates of partial harvest activity (partial-cuts or thinnings) were correlated with the time of establishment of natural regeneration,
2) if variations in overstory, understory or total stand density as measured using basal area (BA) or stand density index (SDI) (Reineke 1933) were linearly or non-linearly related to density, frequency or height growth rates of natural regeneration,
3) if variations in percent shrub cover as a whole, or by individual species, were linearly or non-linearly related to the density, frequency or height growth rates of natural regeneration or stand density,
4) if the date of partial harvest activity was correlated with the timing of abrupt and sustained increases in radial growth rates by residual intermediate and co-dominant trees and,
5) if variations in percent shrub cover as a whole, or by individual species, were linearly or non-linearly related to past (immediately post harvest) or present overstory, understory or total stand density as measured using basal area (BA) or stand density index (SDI) (Reineke 1933).

4.0 Methods

Since pre-harvest stand conditions were unknown and none of the stands in this study received any experimental manipulation, a retrospective approach was used to examine how past harvests may have influenced: 1) density, frequency and age of regeneration, 2) current shrub density and; 3) growth patterns of intermediate and co-dominant conifer trees in the understory. An observational approach was used to examine the effects of current canopy density and shrub cover on growth rates of regeneration.

4.1 Study Location

The study was conducted at elevations ranging from 484 to 1045 meters in the Mixed-Evergreen (*Pseudotsuga*-sclerophyll type) and Interior Valley (*Pinus-Quercus-Pseudotsuga* type) vegetation zones in the western Siskiyou Mountains of southwest Oregon (Franklin and Dyrness 1973). The species composition and growing conditions of the forests in this region are a complex, hybrid of conditions found in California mixed conifer forests and the more northerly PNW forests, but are generally more similar to California forests (Barret 1980). Forest structure is characterized by an overstory (upper strata) of evergreen needle-leafed trees, usually dominated by Douglas-fir (*Pseudotsuga-menziesii* (Mirb.) Franco) and an understory (lower strata) of sclerophyllous broad-leaved trees. The understory is generally dominated by four species of hardwoods, which may take either a tree or shrub form (listed in order of dominance); tanoak (*Lithocarpus-densiflorus* (Hook &Arn.) Rehd), Pacific madrone (*Arbutus-menziesii* Pursh), canyon live oak (*Quercus-chrysolepis* Liebm.) and golden chinquapin (*Castanopsis chrysophylla* (Dougl.) A. DC.). Common overstory conifers include; ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws), sugar pine (*Pinus lambertiana* Dougl.), and incense cedar (*Libocedrus decurrens* Torr.).

Soils in the region are complex due to the variety of parent materials present (Franklin and Dyrness 1973). Study sites were located on soils which varied from shallow and stony profiles to deep and well developed silty clay loams. Soils dominated by peridotite and serpentine parent materials were avoided in this study because vegetation composition and growth rates are unique to these soil types. Steep slopes and highly dissected terrain were common. Study sites were installed on slopes that ranged from 0° to 45°, average slope was 21°. A variety of aspects were sampled, with a fairly even distribution of north and south aspects (Appendix 1).

Hot dry summers and cool wet winters, with minimal snow accumulation characterize the climate within the study zones. Mean temperatures range from 0° C in January to 29° C in July (U.S. Weather Bureau 1960). Annual precipitation ranges from 75 – 200 cm (Graham et al. 1982).

4.2 Site Selection

In the spring of 1997 a number of locations (Marial Ridge, Jack Creek, etc.) on the Glendale and Grants Pass Resource Areas of the Medford District, Bureau of Land Management were reviewed. Only locations which met the following criteria were selected for study: 1) not located on serpentine or peridotite parent material soil types, 2) stands with a wide range of canopy densities were in close proximity to each other, 3) there were partial-cut or thinned stands that had been harvested within the past 30 years, and 4) recent, post-treatment, air photos were available for each location.

Within each of the selected locations, potential study sites were selected based on canopy density visible in aerial photographs. Study sites were chosen that represented points along a continuum of overstory densities, including uncut and clearcut sites. After locating each of the study sites on the ground a plot was installed in the interior of the stand at a random location (plots characteristics are described in section 4.4).

Thirty-two plots were installed in partial-cut stands, sixteen plots in thinned stands, two plots in clearcut stands, three plots in gaps[1] within thinned stands and four plots in uncut stands (Appendix 1). Six to eleven plots were installed at each location, for a total of 57 plots from six locations.

4.3 Stand Characteristics

Since managed uneven-aged stands are rare in southwest Oregon, surrogates were used in this study, i.e. stands which had some portion of the overstory removed in the past and had sufficient time to recruit natural regeneration of trees and shrubs in the understory since then. However, these stands were not harvested with the specific objective of creating uneven-age stand structure or recruiting regeneration of a particular species. These were 'accidental' un-even age stands and some may not fit the Emmingham (1998) definition of uneven-aged stands (see page 1). However, such

[1] The three plots that were installed in gaps within thinned stands were all in one area (Rattlesnake Ridge). The gaps were generally located along cable skidding corridors, where the corridor was somewhat enlarged by additional tree harvest on the edges of the corridor. Gaps were defined as areas in the forest with an 18 m diameter area free of overstory trees greater than 15 m in height. The gaps were 18-25 meters in diameter (0.1 - 0.2 ha) as measured from bole to bole of trees on the boundry of the gap. These plots were installed early in the study in anticipation of finding more gaps like these, however no other stands had similar gaps. The method for plot installation was different in the gap areas. In the stand where the gaps were located I walked through and identified all of the gaps and numbered them. Then I randomly chose three in which to install plots.

'surrogate' stands were instructive because the response of understory trees and shrubs to varying levels of overstory canopy density could be observed.

The most common type of 'surrogate' uneven-aged stands studied were partial-cut[2] stands. The term 'partial-cut' refers to the practice of removing large overstory trees singly and/or in groups. Partial-cutting was commonly used in mature and old-growth (i.e. >200 years) stands in southwestern Oregon during the 1970's to remove unhealthy or deformed trees; this particular form of partial-cutting was known as a 'sanitation harvest'. Partial-cuts also were carried out during the construction of access roads for fire prevention or future timber harvest (Oakley pers. comm. 1997). Common practices in partial-cut stands were: 1) regeneration was not the goal, 2) shrubs were not controlled and, 3) the canopy was not uniformly thinned, which resulted in high within and between stand heterogeneity in overstory density.

Thinned, predominantly even-aged Douglas-fir stands were the second most common stand type studied. The thinned stands were dominated by 60-year old Douglas-fir in the overstory with scattered old growth trees (>200 years) in a few stands. The thinning operations mainly removed the smaller intermediate and co-dominant trees, commonly referred to as 'thinning from below' (Smith et al. 1997). It was assumed that most of the thinned stands naturally regenerated following fire exclusion, since large stumps were not generally present from earlier harvests. These stands were more uniform in their overstory density than partial-cut stands, but still had high between stand heterogeneity. Average stand characteristics for each stand type

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[2] The term 'partial-cut' is commonly used by silviculturalists in the region and was used extensively by Minore and Stein in their studies of southwest Oregon (Minore 1982, Stein 1986).

(gap, thin, partial-cut, etc.) are presented in table 4.1, a more detailed description of each plot within each of the stand types is presented in Appendix 1.

The partial-cut and thinned stands were surrogates for different stages of uneven-aged stand development. Of the stand types studied, partial-cut stands most closely resembled "true" uneven-aged stands, i.e. multiple canopy layers were present and regeneration was often already established. While thinned stands were analogous to even-aged stands in the early stages of conversion into uneven-aged stands, i.e. the second and third canopy layers were not yet developed and regeneration was still fairly young. The conversion from even to uneven-aged stand is a multi-stage process requiring repeated silvicultural interventions (Emmingham 1998).

It is evident from table 4.1 that partial-cut stands had a higher total stand density (BA and SDI) than thinned stands. However, a more important factor that relates to light transmission through the canopy is how the stand density is allocated among crown classes. Thinned stands tended to have the majority of stand density concentrated in the dominant crown class, which resulted in a homogenous, dense, single overstory canopy layer (Figure 4.1). While in partial-cuts, stand density was more evenly distributed among crown classes (Figure 4.1), which resulted in a heterogeneous overstory canopy composed of multiple strata. The heterogeneous canopy in partial-cut stands seemed to allow more light to penetrate to the understory than a thinned stand of comparable SDI (personal observation). Bailey and Tappeiner (1998) suggested that survival and growth rates of seedlings decreased as the relatively uniform canopy of thinned, even-aged stands closed (grew) over time.

Table 4.1. Summary characteristics of each stand type sampled, data range in parentheses after each value. Values for each characteristic are the average of all plots within each stand type. Data for individual plots are in Appendix 1. Stand density index (SDI) is a measure of tree stem density, $SDI = TPA*[(DBH/10)^{1.6}]$ where: TPA = trees/acre, DBH = diameter of trees at breast height (inches) (Reineke 1933); SDI was calculated for each size class of trees then summed to yield cumulative values for understory and ovestory classes. Understory refers to all trees < 20 cm DBH, overstory is trees > 20 cm DBH. Methods for measuring basal area, trees/hectare, shrub cover and canopy openness are described in section 4; pre and post-harvest basal area values were calculated not measured, see section 4.6.

Characteristic	partial cut	thinned	uncut	gap	clearcut
number of plots sampled	32	16	4	3	2
total basal area (m^2/ha)	41 (9-112)	33 (20-50)	55 (41-65)	24 (20-26)	2 (0-5)
mean DBH (cm) - overstory	69 (25-123)	51 (33-92)	62 (40-91)	69 (54-88)	33 (0-65)
trees/ha - overstory	187 (15-496)	221 (71-498)	356 (98-633)	101 (31-172)	7 (0-14)
trees/ha - understory	1968 (380-4495)	467 (0-1729)	890 (277-2109)	265 (207-346)	294 (138-450)
SDI - overstory	190 (25-520)	195 (25-520)	302 (217-390)	136 (88-164)	12 (0-25)
SDI - understory	88 (20-173)	30 (0-179)	56 (13-89)	10 (2-27)	3 (1-4)
shrub cover (%)	70 (7-100)	49 (1-96)	45 (2-94)	53 (27-75)	70 (54-85)
canopy openness (%)	47 (0-100)	39 (0-84)	5 (0-8)	57 (24-83)	100 (100-100)
years since harvest	24 (22-31)	11 (9-17)	n/a	9 (9-9)	11 (11-11)
pre-harvest basal area (m^2/ha)	65 (22-168)	52 (35-66)	n/a	50 (47-55)	68 (68-68)
post-harvest basal area (m^2/ha)	31 (12-101)	26 (15-36)	n/a	20 (17-24)	5 (5-5)

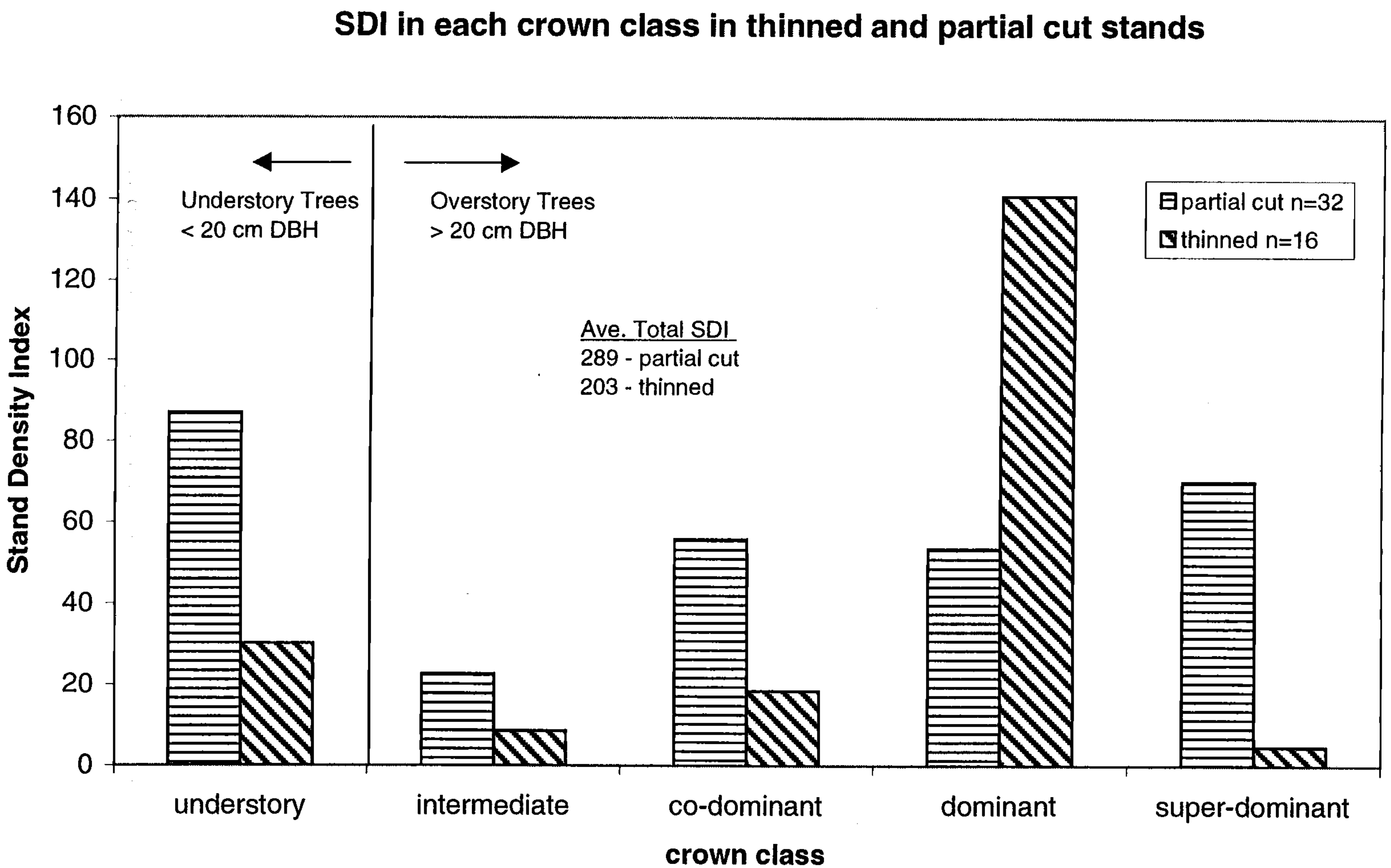


Figure 4.1. Comparison of stand density index (SDI) values for each crown class in partial-cut and thinned stands, all tree species. Number of observations (n) displayed in legend.

4.4 Plot Size and Data Collection

Study plots consisted of a variable radius plot for trees > 20 cm dbh, 11.2 m fixed radius sub-plot to tally stumps, four nested fixed radius sub-plots for trees <20 cm dbh and three 10 m long transects for shrub cover (Figure 4.2).

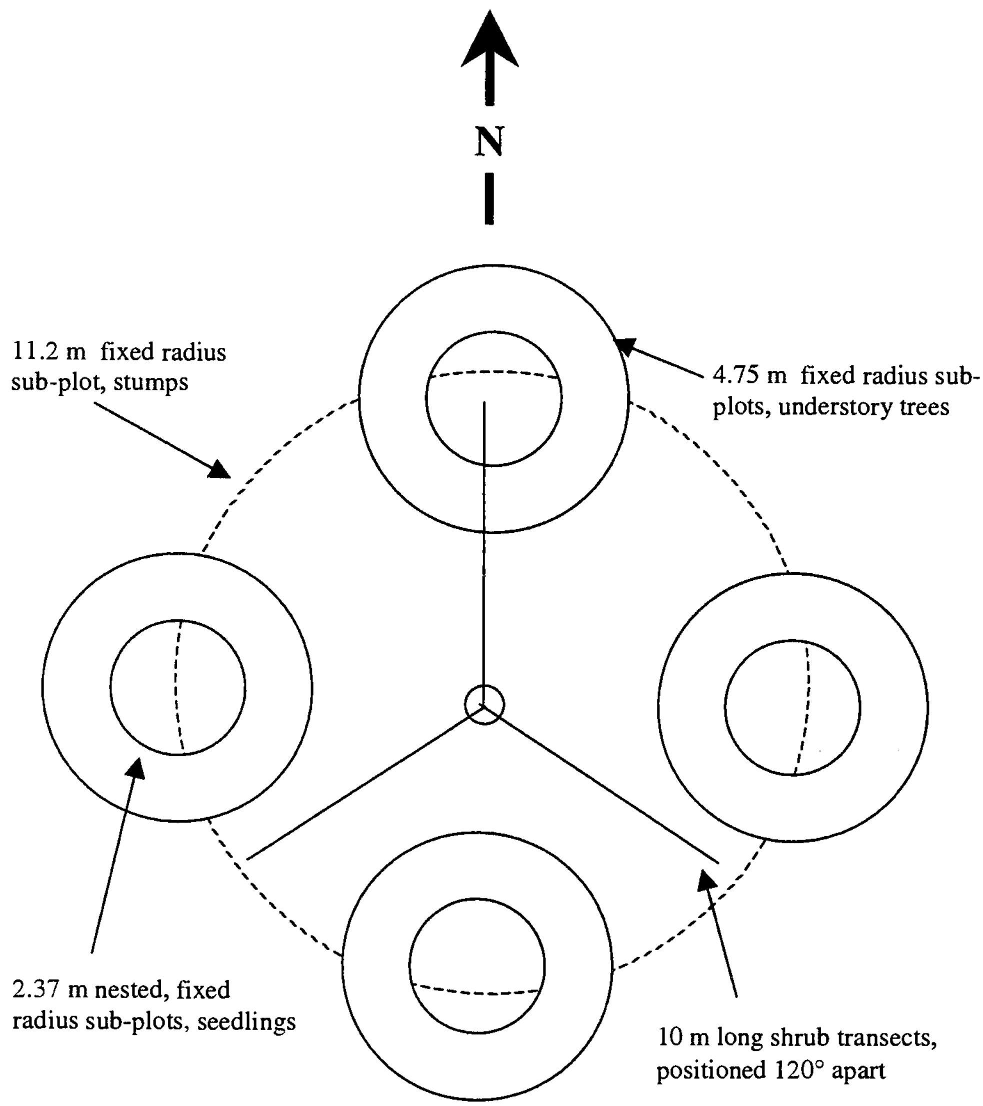


Figure 4.2. Layout of sample plot. Variable radius plot for overstory trees (>20 cm dbh) originates at plot center. Four, nested, fixed radius sub-plots are positioned 10 from plot center in cardinal directions; one 2.37 m radius sub-plot for seedlings is nested within each 4.75 m radius sub-plot for understory trees (<20 cm dbh). Three, 10 m long shrub transects originate at plot center, and are spaced 120° apart starting at 0°. An 11.2 m fixed radius sub-plot for stumps originates at plot center.

4.4.1 Overstory Trees

Trees larger than 20.5 cm dbh were defined as overstory trees and data were collected on them using the variable radius plot method (Hester et al.1989). The 20 BAF scale was used on a Relaskop (Spiegel Relaskop, Austria) to tally all 'in' trees between 20.5 cm and 90 cm dbh. Trees larger than 90 cm dbh were tallied using the 40 BAF scale. All 'in' trees were recorded by species in 10-cm dbh size classes according to crown class (Nicholas et al. 1990). From these 'basic' data, trees per hectare, basal area in m^2/ha, and stand density index based on English units (SDI) were calculated for each plot (Reineke 1933). Slope, aspect and elevation were recorded at plot center.

An 'intensive' data set was collected on a sub-sample of these overstory trees. Representative trees were chosen subjectively from each species and crown class for intensive measurements based on their physical resemblance to the majority of other trees in that species and crown class. Intensive measurements included dbh, height, height to live crown and, an increment core to the pith, if possible.

In addition to current stand density, stumps were counted to determine pre-harvest stand density. An 11.2 meter fixed radius plot was installed at plot center and all stumps within the plot were tallied by species and diameter.

4.4.2 Understory Trees

Four, nested, fixed radius plots (Hester et al. 1989) were established 10 meters from plot center in cardinal directions to characterize trees less 20.5 cm dbh. Trees taller than 1.4 m (breast height) but less than 20.5 cm dbh were tallied from a 4.75 m fixed radius plot according to species, 5 cm dbh size class, and crown class. Trees less than 1.4 m tall but taller than 15 cm were classified as seedlings and recorded by species and height class. The three height classes for seedlings were 15-50 cm, 50-100 cm, and 100-140 cm.

A representative sample of understory trees (average of 6 per plot, range 1-10) and seedlings (average of 3/plot, range 1-8) were subjectively chosen for 'intensive' measurements based on their physical resemblance to other trees in the species and crown class. The intensive measurements for understory trees were dbh (diameter at 15 cm from ground for seedlings), height, height to crown and an increment core. Age was determined either by increment core or whorl counts. Whorl counts were used when the diameter of tree was to small to obtain an increment core without damaging the tree. Annual leader growth for each of the past three years was recorded for seedlings and saplings. Increment cores and leader growth data were collected only for conifers.

Canopy density was estimated in two ways on each sub-plot. First, a reading of percent open sky (inverse of canopy density) visible through a 'moosehorn', a modified canopy denisometer, was recorded for each plot (Schraeder 1998). Second a visual estimate was made of whether the plot was under a canopy of greater or less than 50% cover.

4.4.3 Shrubs

Shrub cover was recorded for each plot using three 10-m long line transects which originated from plot center at 0, 120, and 240 degrees azimuth. Each shrub encountered along the length of the transect was recorded by species, start and end point of coverage on the transect and height. Shrubs and ferns were recorded as well as shrub forms of hardwood trees such as tanoak, madrone, and liveoak. Data from each of the three transects were averaged for each plot, then percent cover and average height were calculated for all shrubs combined and each species individually.

4.5 Tree Core Analysis

Tree cores were obtained using an increment borer (Haglof, Inc.) for most intensively measured conifer trees. Cores were placed in labeled paper straws for transport to Oregon State University. Cores were sanded to clearly reveal growth rings. Growth rings were counted under a dissecting microscope to determine tree age. Abrupt and sustained increases in growth were recorded as 'releases' (Deal unpublished). Radial growth for five years preceding any release date and five years following release was recorded to determine the magnitude of release. The year (ring) that the tree released was noted and compared to known harvest activity in the stand.

4.6 Stand Reconstruction

Stand reconstruction techniques were used to determine the basal area of the stand before and after harvests (Bailey and Tappeiner 1998). Four components of the stand: 1) diameter growth of currently living overstory trees since harvest, 2) basal area removed at harvest, 3) growth of the understory since harvest, and 4) basal area lost to morality since harvest were attained using the following procedures. Basal area immediately after harvest was calculated by subtracting overstory basal area growth, understory growth and in-growth of regeneration since harvest from current basal area. Basal area immediately before harvest was calculated by adding the estimate of basal area removed at harvest to the aforementioned estimate of basal area after harvest. The methods and calculations for each component are described below.

4.6.1 Overstory Basal Area Growth

Dates of past harvests were determined for each study site from BLM records. Radial growth since harvest was measured on increment cores of residual trees from the 'intensive' data set by counting back to the harvest date and measuring from that ring to the outermost ring with a micrometer. Diameter of each tree at the time of harvest was calculated by doubling the radial growth since harvest and subtracting it from current diameter. No attempt was made to account for bark growth.

Since increment core data was only collected for a sub-sample of trees that had been measured 'intensively', a statistical procedure was used to extrapolate these data to the remaining trees in the plot. Data from 87 trees, primarily Douglas-fir, were used to develop a regression equation which related the measured increase in diameter on 'intensive' trees to independent variables such as crown class and time since harvest, which were also known for all trees in the plot, i.e. the 'basic' data set. The final form of the equation (Table 4.2, Equation 4.6-1) employed only crown class and years since harvest as independent variables (size class, and current stand basal area were not significant) and the logarithm of diameter increase since harvest as the dependent variable (adj. $r^2 = 0.33$, $p < 0.01$, n = 85).

The increase in basal area (growth) of all overstory trees since harvest on each plot was either calculated or estimated as follows. Diameter at time of harvest for trees from the 'intensive' data set was calculated by subtracting the measured increase in

Table 4.2. Regression equations cited in Methods section (4.0) of the text. Equation 4.6-1 was developed in the SAS Program (SAS Institute Inc., 1989). Equation 4.6-2 was originally included in a manuscript by Dubrasich and Tappeiner (unpublished). The adjusted r – square value (adj.r2) and significance of the equation (*p*) are presented after the description of each equation. All terms in equations were significant at $p < 0.05$ level. Standard errors (SE) are presented below each coefficient in the equations. Definitions for terms are presented below equations. Terms preceded by 'ln' indicate that the natural logarithm of the term was used in the equation.

Equation	Description of equation, significance, sign and definition of terms and standard errors (SE).
4.6-1	Prediction of the increase in diameter since harvest for all overstory trees on each plot (adj.r2 = 0.33, $p < 0.001$, n = 85). ln (Dd) = 0.7435 + 0.0354 YRS + 0.5609 C3 + 0.8207 C4 + 0.8316 C5 SE = (0.2470) (0.0095) (0.2791) (0.1803) (0.1449) Dd = increase in diameter (cm); YRS = the number of years since harvest; C3, C4, C5 are indicator variables for each of the crown classes; C3 = intermediate; C4 = co-dominant; C5 = dominant; the reference level is super-dominant.
4.6-2	Prediction of dbh for trees based on diameter of stumps (adj.r2 = 0.9695, $p < 0.001$, n = 247). DBH = 0 + 2.172 DBASE - 4.3936 ln(DBASE) - (0.2418 DBASE * ln(DBASE)) SE = (0.4798) (1.4783) (0.0929) DBH = diameter at breast height, inches; DBASE = diameter at 6 inches above ground on the uphill side of the tree, inches.

diameter since harvest from current measured dbh. Diameter at time of harvest was estimated for each 'basic' tree by using Equation 4.6-1 to calculate the increase in diameter since harvest and then subtracting this value from the value for the midpoint of the current diameter class that the tree was recorded in. Then the data set of calculated dbh at time of harvest and current trees/hectare were used to calculate total basal area of live overstory trees at the time of harvest for each plot. No attempt was made to account for trees that would fall out of the variable radius plot if re-measured at the time of harvest.

Due to the wide variety of stand conditions sampled, low sample size, disparity in ages of trees, and mixture of species the regression equation explained only 33% of the variation in growth rates within the sample of measured trees. The error likely increased as the equation was extrapolated to all species and plots. The equation provided only an estimate of the basal area growth that occurred for each tree since harvest. However, the estimates proved to be reasonably accurate, see section 4.6.5.

4.6.2 Amount of Basal Area Removed at Harvest

Diameter and number of stumps present on the 11.2 m fixed radius sub-plots were used to calculate the basal area removed at the time of harvest. The diameter of each stump had to be converted into a diameter at breast height (DBH) in order to calculate basal area. An equation (Table 4.2, Equation 4.6-2) developed by Dubrasich and Tappeiner (unpublished) was used to convert stump diameters to dbh values. This equation was based on 247 trees measured at breast height and tree base in the same region as this study (Dubrasich and Tappeiner, unpublished).

4.6.3 Understory Growth and Recruitment of New Trees

Due to an incomplete intensive tree-core data set for small trees (<20 cm dbh), particularly hardwoods, increases in understory basal area could not be calculated. Instead, increases in understory basal area were estimated for each plot individually based on the available intensive radial growth data and the ages and numbers of regenerated seedlings/saplings. Since this component of the stand averaged only 15.6% (95% confidence interval for the mean = 12.0 – 19.2%) of total stand density, errors in estimation likely were small, and should not impair the general accuracy of the reconstruction.

4.6.4 Mortality

Overstory mortality was rare in the pre-harvested stands, since the goal of past harvests was to remove sick, dead, and dying trees. However when encountered, dead trees were not included in the calculations of current basal area, since it was assumed that they would not contribute significantly to moisture or light utilization. Hence, they were not included in estimates of density at harvest.

4.6.5 Validation of Reconstruction Methods

The accuracy of the estimated increases in stand basal area (BA) since harvest determined using the aforementioned stand reconstruction methods (which were based partly on Equation 4.6-1) were validated as follows. Estimates of the increase in average basal area since harvest for thinned and partial-cut stands based on reconstruction methods (see earlier discussion, section 4.6.1) were compared to estimates of stand growth projected using the southwest Oregon version of the ORGANON stand growth model (Hester et al. 1989).

Estimates based on reconstruction methods indicated that the average increase in BA since last harvest for thinned stands in this study was 8.6 m^2/ha (95% C.I. = 5.3 – 11.9). The average time since last harvest for thinned stands was 11 years. Estimates based on the ORGANON model indicated that a well stocked, even age plantation would increase 11.0 m^2/ha in a 10 year period after receiving a thinning similar to what the sample plots received. While the estimate based on the ORGANON model was higher, this observation was expected since the thinned stands in this study were not as evenly spaced, well stocked, or purely Douglas-fir as the stands used in the ORGANON projection.

Estimates based on reconstruction methods indicated that the average increase in BA since last harvest for partial-cut stands in this study was 12.9 m^2/ha (95% C.I. = 9.9 – 15.9). The average time since last harvest for partial-cut stands was 24 years. Data from an uneven-aged, mixed species stand which had 150 year old dominant trees was used as an input file to project growth for simulated partial-cut stands in the ORGANON model. ORGANON estimated that average BA increased by 14.1 m^2/ha in the simulated partial-cut stands over a 25 year period, which was similar to the growth estimates determined using stand reconstruction methods (Section 4.6.1).

4.7 Data Analysis

All statistical data analyses were performed using the SAS program (SAS Institute Inc. 1989).

4.7.1 Stand types

Although data were collected in uncut, clearcut, gap, thinned and partial-cut stands, the bulk of the analysis focused on partial-cut and thinned stands. Uncut, clearcut and gap stand types all had 4 or less observations (plots), so analysis of the variation in characteristics such as shrub cover, leader growth or regeneration density within these stand types was not possible. The purpose of collecting data in such stand types was to fill out a spectrum of overstory densities sampled in order to detect general trends of how stand density influenced understory characteristics such as shrub cover and tree regeneration. The second objective for such data collection was to determine if shrub cover and regeneration in those stand types differed significantly from partial-cut and thinned stands.

Two measures of stand density were used throughout the analysis, basal area (BA) and stand density index (SDI). Although these measures are similar, they differed in their statistical predictive ability and correlation in many analyses. Since neither measure consistently outperformed the other, results are stated using whichever measure performed best in a given analysis.

4.7.2 Definition of Classes of Douglas-Fir Regeneration

Douglas-fir regeneration in the understory was divided into two classes based primarily on height: seedlings and saplings. Seedlings were defined as being >15 cm but < 1.4 m in height. Saplings were defined as trees between 1.4 and 5.0 m in height that had conical shaped crowns. Trees greater than 1.4 m in height but with flattened or umbrella shaped crowns, indicating long periods of slow growth, were classified as suppressed trees. Suppressed trees were generally older (average age = 41 years, range 20-79) than either seedlings or saplings. However, there was some overlap in ages among suppressed trees and saplings in which case the two were considered separately.

4.7.3 Timing of Regeneration Events

Objective 1 (Section 3.0) was to determine if the date of partial harvest activity (partial-cuts and thinning) is correlated with time of establishment of natural Douglas-fir regeneration in each study site. To satisfy this objective the known dates of past harvests, as determined from BLM records, were compared to the ages of individual seedlings and saplings at each study site. Seedlings or saplings that were younger than the date of the most recent harvest were determined to have established since that harvest.

4.7.4 Overview of Statistical Methods for Regeneration

Regression, ANOVA, and correlation analyses methods were used to explore relationships that satisfied objectives 2 and 3. Details of each analysis are presented in the following sections (Sections 4.7.5 and 4.7.6).

Objective 2 (Section 3.0) was to determine if variations in overstory, understory or total stand density as measured using basal area (BA) or stand density index (SDI) (Reineke 1933) are linearly or non-linearly related to density, frequency or height growth of natural Douglas-fir regeneration. Objective 3 (Section 3.0) was to determine if variations in percent shrub cover as a whole, or by individual species, were linearly or non-linearly related to the density, frequency or height growth rates of natural regeneration. Douglas-fir seedlings and saplings were selected for analyses of regeneration trends that would satisfy objectives 1 and 2 because they were the most common species of conifer regeneration. The wide distribution of Douglas-fir allowed for comparisons across the entire range of shrub covers, stand densities and locations.

4.7.5 Average Density and Frequency of Douglas-fir Regeneration

First, the number of individuals per hectare for each sub-plot were calculated by using the appropriate expansion factor based on sub-plot area and the actual number of individual trees observed. Then density and frequency of understory Douglas-fir seedlings and saplings were calculated as follows:

Density, defined as the average number of individuals per hectare present on each plot, was calculated by summing the value of individuals per hectare for all sub-plots and dividing by the number of sub-plots (4).

Frequency, defined as the proportion of sub-plots containing trees was expressed as decimal. For example if 1 of 4 sub-plots had at least one seedling, then seedling frequency for the entire plot was 0.25, whereas if 2 of 4 sub-plots had trees, the frequency equaled 0.50, etc.

Regression equations were developed using a stepwise model-selection procedure to model frequency and density of regeneration with independent variables describing stand density, percent shrub cover and abiotic factors such as slope and aspect. Pearson correlation coefficients also were used to evaluate linear relationships between density and frequency of regeneration and independent variables. A 0.05

alpha level was used to evaluate the significance of all terms and models in the regression analyses and Pearson correlation coefficients.

Analysis of Variance (ANOVA) procedures were used to compare average density and frequency of regeneration values per plot between different stand type categories (clearcut, thinned, etc.). An ANOVA procedure also was used to compare average stand density values for each plot between categories of plot-level seedling frequency values (0, 0.25, 0.50, etc.). Since these procedures involved multiple, unplanned comparisons between categories with unbalanced sample sizes, a Tukey-Kramer adjustment procedure was used to control the group-wise error (Ramsey and Schaefer 1997). A 0.1 alpha level was used in the ANOVA procedures because sample sizes were small, variation was high, and the consequences of committing Type I errors were not problematic in this context (Stafford and Sabin 1998).

4.7.6 Growth of Douglas-fir Regeneration

Average annual leader growth values for Douglas-fir seedlings and saplings were used as an index of understory growth potential. In order to differentiate average growth potential on each plot from potential growth of individuals on each plot, the data were analyzed in two ways: 1) at the plot-level and, 2) at the individual tree level. Plot-level averages only indicate how site attributes (e.g. stand density or shrub cover) affected all individuals on the plot, on average. Plot-level averages do not indicate how site attributes affect growth potential of individuals on each plot. For example, above average growth rates for individuals may be observed even when conditions are not conducive to good growth for all individuals, i.e. plot-level average growth.

4.7.6.1 Average Growth at the Plot-Level

Average annual leader growth values for each plot were calculated for the years 1995-1997 as follows: 1) the annual leader growth for each of the past 3 years was summed and divided by 3 for each individual, 2) these values were then summed for all individuals on each plot and divided by the number of individuals on the plot. The number of individuals from which each plot-level average was calculated ranged from 1 to 8, and averaged 3.

Regression equations were developed using a stepwise model-selection procedure to model plot-level average annual leader growth values with independent variables describing stand density, percent shrub cover and abiotic factors such as slope and aspect. Pearson correlation coefficients also were used to evaluate linear relationships between plot-level average leader growth and independent variables. A 0.05 alpha level was used to evaluate the significance of all terms and models in the regression analyses and Pearson correlation coefficients.

Analysis of Variance (ANOVA) procedures were used to compare plot-level average annual leader growth values between different stand type categories (clearcut, thinned, etc.). Since these procedures involved multiple, unplanned comparisons between categories with unbalanced sample sizes a Tukey-Kramer adjustment procedure was used control the group-wise error (Ramsey and Schaefer 1997). A 0.1 alpha level was used in the ANOVA procedures because sample sizes were small, variation was high, and the consequences of committing Type I errors were not problematic in this context (Stafford and Sabin 1998).

4.7.6.2 Average Growth of Individuals

A separate analysis was carried out for individual Douglas fir seedling and saplings, i.e. data from the 'intensive' data set, (section 4.4.2). The data for individuals were not statistically independent, as multiple individuals often occupied the same plot. Therefore statistical tests such as the ones described in the previous section (Section 4.7.6.1) were not appropriate.

Instead, the data set of physical characteristics for individual seedlings and saplings was ranked by average annual leader growth for each individual and then divided into upper, middle and lower thirds based on average annual leader growth. The mean values for the physical characteristics of each individual and associated site factors, such as percent open canopy, shrub cover, and plot basal area for each third, were then displayed together and trends were examined.

4.7.7 Growth 'Release' of Intermediate and Co-Dominant Trees

Objective 4 (Section 3) was to determine if the date of partial harvest activity is correlated with the timing of abrupt and sustained increases in radial growth rates by residual intermediate and co-dominant trees, i.e. 'release'. To satisfy this objective, the known dates of past harvests were compared to the dates of release for each tree, known from tree core analysis. If the date of release occurred within 5 years of the most recent harvest the tree was determined to have been released by the harvest activity.

4.7.8 Shrub Data Analysis

Objective 5 (Section 3.0) was to determine if variations in percent shrub cover as a whole, or by individual species, were linearly or non-linearly related to past (immediately post harvest) or present overstory, understory or total stand density as measured using basal area (BA) or stand density index (SDI) (Reineke 1933). To satisfy this objective, the relationships between total shrub cover (all species) and independent variables such as current, pre and post-harvest stand density, proportion of stand density removed at harvest, and abiotic variables were analyzed using the same statistical methods (regression, correlation, and ANOVA) and p-values as those presented in section 4.7.5.

An analysis of individual shrub species was also performed. To focus on shrub species that may have had a significant affect on regeneration, only species that covered more than 15% of any plot were evaluated. This percentage was chosen subjectively after reviewing the data. I then evaluated which of this sub-set of shrub species were occurring at different overstory densities and locations, what effect they were having on the growth of seedling/saplings and how widely distributed across the study sites they were. Once again methods and p-values were similar to those presented in 4.7.5.

5.0 Results and Discussion

5.1 Timing and Recruitment Patterns for Douglas-Fir Regeneration

It appears that past harvests in partial-cut and thinned stands created an opportunity for natural Douglas-fir regeneration to become established (Figure 5.1). Harvesting in partial-cuts, which occurred 22-31 years ago (average = 24), preceded the establishment of 82% of saplings and 98% of seedlings observed. The average age of seedlings in partial-cut stands was 12 years old and average height was 63 cm (Table 5.1). The average age of saplings in partial-cut stands was 23 years old and average height was 3 m (Table 5.2).

Thus, adequate 'safe sites' apparently were available for regeneration and growth of Douglas-fir after harvest. 'Safe sites' are defined as areas where there is: 1) an appropriate stimulus to break seed dormancy; 2) the conditions and resources required for germination are present; 3) specific mortality agents such as animals, diseases, toxic or lethal soil conditions, and competition for light and soil resources are tolerable (Harper 1977).

The Douglas-fir seedlings that established immediately after harvest in partial-cut stands grew into the large age classes of 16-25 year old saplings currently in the stands (Figure 5.1). This group of saplings represents the most likely cohort of regeneration to emerge into the overstory in future years. There were an average of 370 saplings/ha (range 0-1700) and 1300 seedlings/ha (range 0-5200) in partial-cut stands (Figure 5.2).

Table 5.1 Average characteristics of all individual Douglas-fir seedlings observed in each stand type, from the intensive data set. These values are not plot level averages, so may differ from 'average' characteristics cited at the plot level. The miniumum (min.) and maximum (max.) values and number of observations for each characteristic (n), are also displayed.

Douglas-fir Seedlings					
stand type	**characteristic**	**mean**	**min.**	**max.**	**n**
clearcut	height (cm)	49.6	18.0	119.0	11
	diameter (mm)	0.7	0.1	2.0	11
	age (years)	5.9	4.0	10.0	10
	ave. annual leader growth	8.2	3.7	16.5	11
gap	height (cm)	29.3	15.0	55.0	13
	diameter (mm)	0.5	0.3	1.4	9
	age (years)	4.3	3.0	6.0	13
	leader growth (cm)	7.7	3.6	15.7	13
partial-cut	height (cm)	62.6	15.0	138.0	57
	diameter (mm)	0.8	0.1	2.2	55
	age (years)	12.4	4.0	27.0	53
	leader growth (cm)	4.9	1.2	15.6	57
thinned	height (cm)	36.5	12.0	120.0	43
	diameter (mm)	0.8	0.1	4.0	33
	age (years)	5.3	2.0	13.0	29
	leader growth (cm)	6.6	0.2	16.3	43
uncut	height (cm)	87.0	87.0	87.0	1
	diameter (mm)	0.9	0.9	0.9	1
	age (years)	30.0	30.0	30.0	1
	leader growth (cm)	2.0	2.0	2.0	1

Table 5.2 Average characteristics of all individual Douglas-fir saplings observed in each stand type, from the intensive data set. These values are not plot level averages, so may differ from 'average' characteristics cited at the plot level. The miniumum (min.) and maximum (max.) values and number of observations for each characteristic (n), are also displayed.

Douglas-fir Saplings					
stand type	**characteristic**	**mean**	**min.**	**max.**	**n**
clearcut	height (m)	1.9	1.5	2.3	5
	diameter (cm)	1.0	0.4	1.4	5
	age (years)	12.2	10.0	21.0	5
	ave. annual leader growth (cm)	37.6	21.3	57.0	5
gap	height (m)	3.6	3.6	3.6	1
	diameter (cm)	3.9	3.9	3.9	1
	age (years)	9.0	9.0	9.0	1
	ave. annual leader growth (cm)	51.0	51.0	51.0	1
partial-cut	height (m)	2.9	1.4	5.1	40
	diameter (cm)	2.6	0.2	5.5	39
	age (years)	23.1	11.0	74.0	38
	ave. annual leader growth (cm)	22.7	6.3	44.0	40
thinned	height (m)	2.9	2.1	3.7	5
	diameter (cm)	2.4	1.3	3.2	3
	age (years)	26.0	13.0	50.0	5
	ave. annual leader growth (cm)	19.2	12.0	24.3	5
uncut	height (m)	3.0	3.0	3.0	1
	diameter (cm)	2.7	2.7	2.7	1
	age (years)	44.0	44.0	44.0	1
	ave. annual leader growth (cm)	9.3	9.3	9.3	1

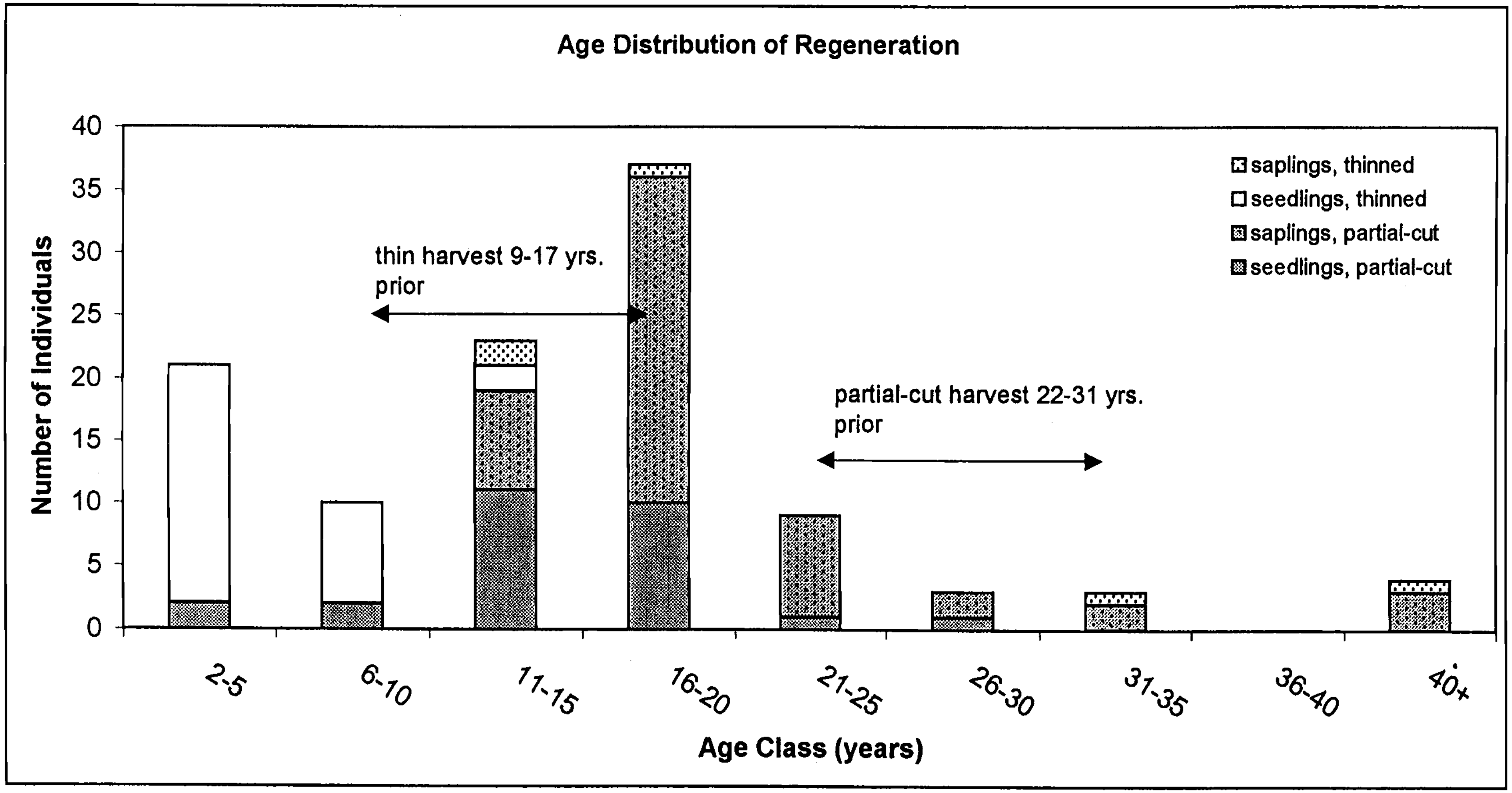
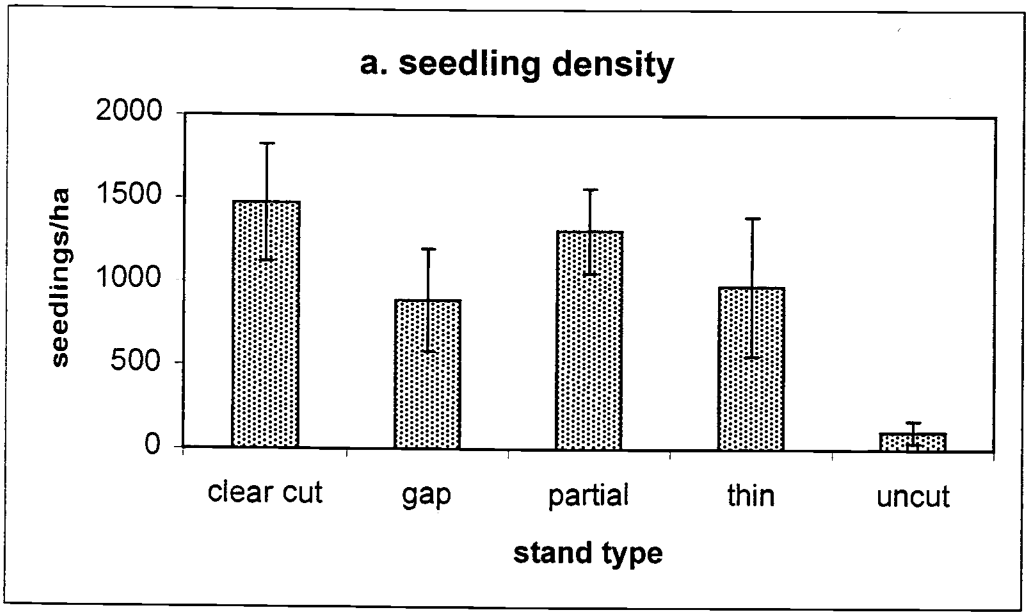


Figure 5.1. Total number of individual seedlings and saplings in each age class for thinned and partial-cut stand types. Data are from a sub-sample of individuals on each plot for which age was determined. The timing of regeneration recruitment can be seen for each stand type, notice that the majority of regeneration occurs after the most recent harvests in both stand types (<9 years in thinned & < 22 years in partial-cut stands). Also notice that recruitment in partial-cut stands decreased in the most recent 2-10 year time period, indicating that only a short period after harvest exists for recruitment to occur naturally (see section 5.1). Thinned stands: n=5 for saplings, n=29 for seedlings. Partial-cut stands: n=38 for saplings, n=53 for seedlings.



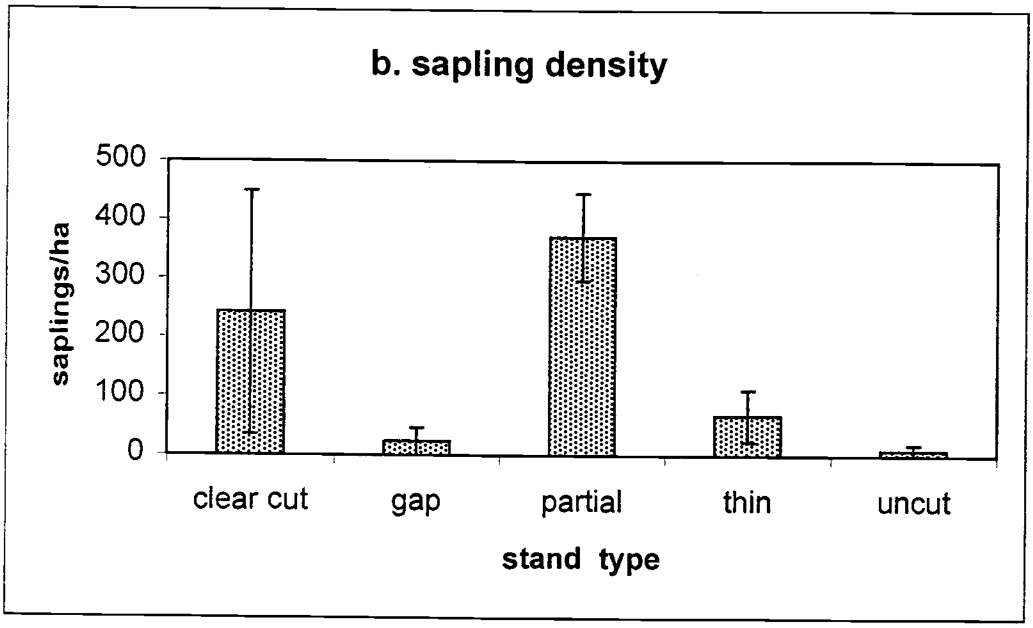


Figure 5.2. Average (a) seedling and (b) sapling density within each stand type. The number of observations used for each calculation is: clearcut n=2, gap n=3, partial-cut n=32, thinned n=16, uncut n=4. Vertical lines represent one standard error.

New cohorts of regeneration were recruited annually for 16 years following harvest in partial-cuts. However, for the most recent period, 16-24 years after harvest, recruitment declined dramatically (Figure 5.1) as only 8% of seedlings and 0% of saplings originated during this period. This may be because seed production was low during this period or adequate 'safe sites' were no longer available.

The density of saplings in all stand types was positively correlated with time since harvest (r = 0.33), which may be why thinned stands had significantly ($p < 0.001$) fewer saplings (67 saplings/ha) than partial-cut stands (Figure 5.2b). The average age of saplings in thinned stands was 26 years old and the average height was 3 m (Table 5.2). This indicates that the majority of 'saplings' in thinned stands were actually advanced regeneration which had established prior to the most recent harvest.

There is one plot that was a notable exception to the general trend observed in thinned stands that few or no saplings originated from the most recent harvest. A south facing (aspect = 202°) slope in one of the thinned locations had a 30 m diameter gap, in the center of which, 3 similar Douglas-fir saplings were growing. One sapling was measured intensively: it was 9 years old, 3.6 m tall, 3.8 cm dbh and had been growing at >50 cm/yr. for each of the past 3 years. The sapling had the 2nd highest annual leader growth recorded in the study, a sapling in a clearcut was 1st at 57 cm/yr. This gap was in an enlarged cable skidding corridor from the harvest which had occurred 9 years prior. The stand around the gap had 31 m^2/ha of basal area. These 3 saplings, which were physically similar, may indicate the regeneration and growth potential possible in small gaps in uneven-aged stands.

Except for this example, few seedlings have grown into the sapling class in thinned stands. Thinned stands were harvested only 9-17 years ago (average = 11). Thus there have been only 11 years for seedlings to become established and grow into the sapling class. If regeneration in thinned stands grows more similarly to that of partial-cut stands rather than gaps, seedlings should move into the sapling class 11-15 years after germination, which was the age of the youngest saplings observed in partial-cuts (Figure 5.1).

Despite the general paucity of saplings in thinned stands, harvests seemed to stimulate seedling production, as 96% of seedlings observed germinated since harvest. However, the basal area immediately before ($p=0.49$) and after harvest ($p=0.77$) and proportion of BA removed ($p=0.35$) were not correlated with seedling density. There were an average of 970 seedlings/ha (range 0-6868) in thinned stands and similarly high densities in gap and clearcut plots. For comparison, uncut stands, which were similar to thinned stands prior to harvest had an average of only 105 seedlings/ha (range 0-280). However, due to high variance and low sample size, differences were only weakly significant between partial-cut and uncut stands ($p = 0.09$) (Figure 5.2a).

Although the density of seedlings or saplings per hectare is important, it does not address how evenly they are distributed within a stand. Isolated patches of regeneration with extremely high densities may average to a relatively high number/ha statistically. However, the number of trees capable of advancement into the overstory may still be low because of infrequent patches and competition for resources within each patch. Therefore, in addition to density, frequency of regeneration also must be considered.

In this study seedling frequency averaged 0.13 in uncut, 0.45 in thinned, and 0.46 in partial-cut stands, and the average density and frequency of regeneration per plot tended to increase simultaneously (Figure 5.3). Bailey and Tappeiner (1998) observed that seedling frequency averaged 0.14 in unthinned and 0.51 in thinned stands and that density and frequency increased simultaneously. It was observed that 21 of 32 partial-cut plots and 12 of 16 thinned plots had 0.50 or greater frequency of seedlings (Figure 5.4). Furthermore, 20 of 32 partial-cut plots and 3 of 16 thinned plots had 0.50 or greater frequency of saplings (Figure 5.4). Again, years since harvest may be responsible for the poor distribution of sapling in thinned plots.

The trend of relatively high frequency and density in partial-cut and thinned stands versus uncut stands indicates that the harvests stimulated regeneration (Figure 5.2). Seedling densities were approximately the same (1000 seedlings/ha) in clearcuts, partial-cuts and thinned stands however, average seedling frequency was higher (though not significantly, due to low sample size) in clearcuts (0.88) than in partial-cut or thinned stands (< 0.50). This indicates that regeneration occurred in clumps within partial-cut and thinned stands, not as evenly spaced individuals as in the clearcut. Since natural regeneration was observed in clearcuts in addition to planted seedlings, the differences in frequencies may be due to increased light availability in clearcuts, as well as the actual planting of trees.

Frequency of regeneration tended to increase as overstory stand density index (SDI) decreased across all stand types, although not all differences were significant (Figure 5.5). Plots with the highest frequency (1.0) of seedlings were found in stands

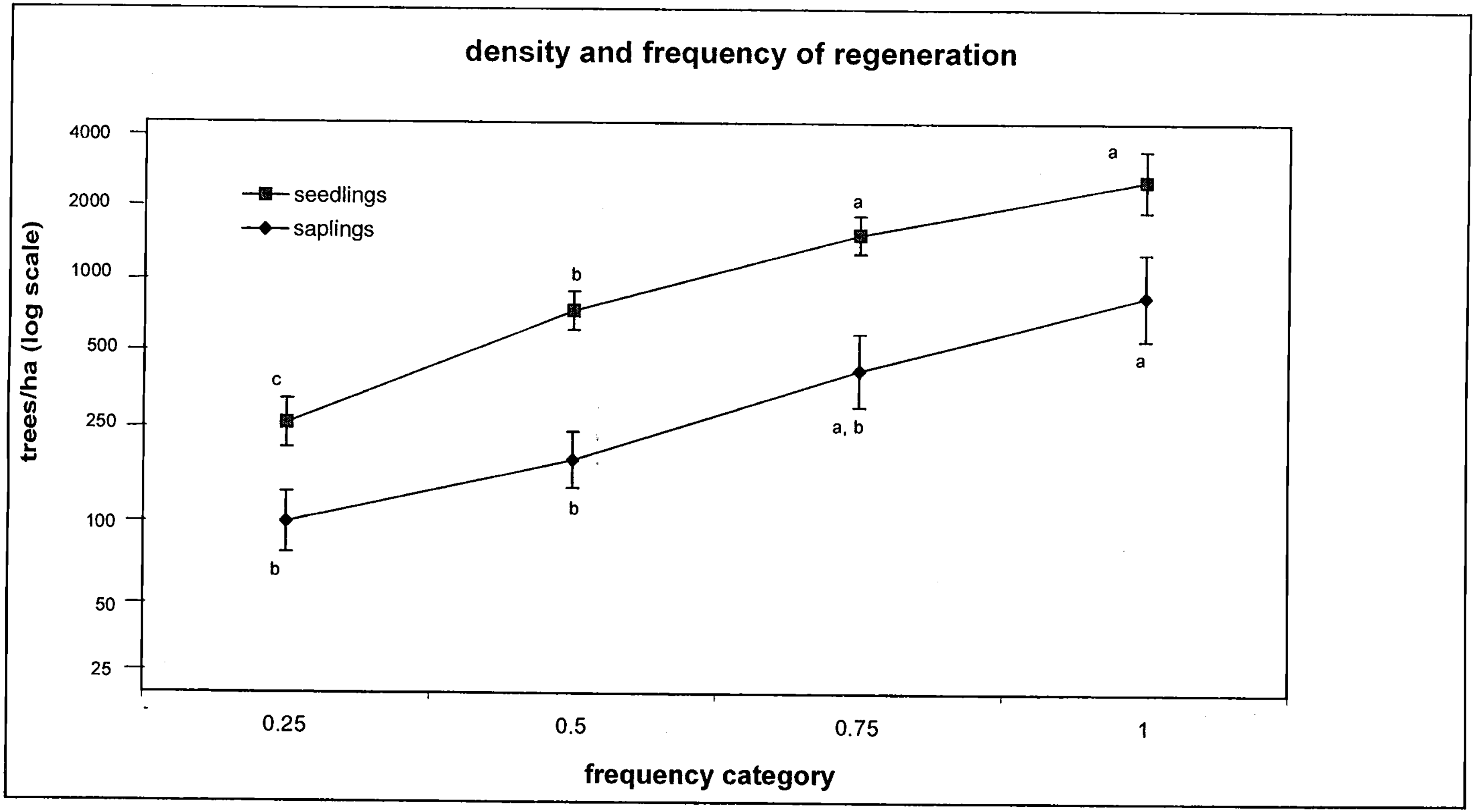
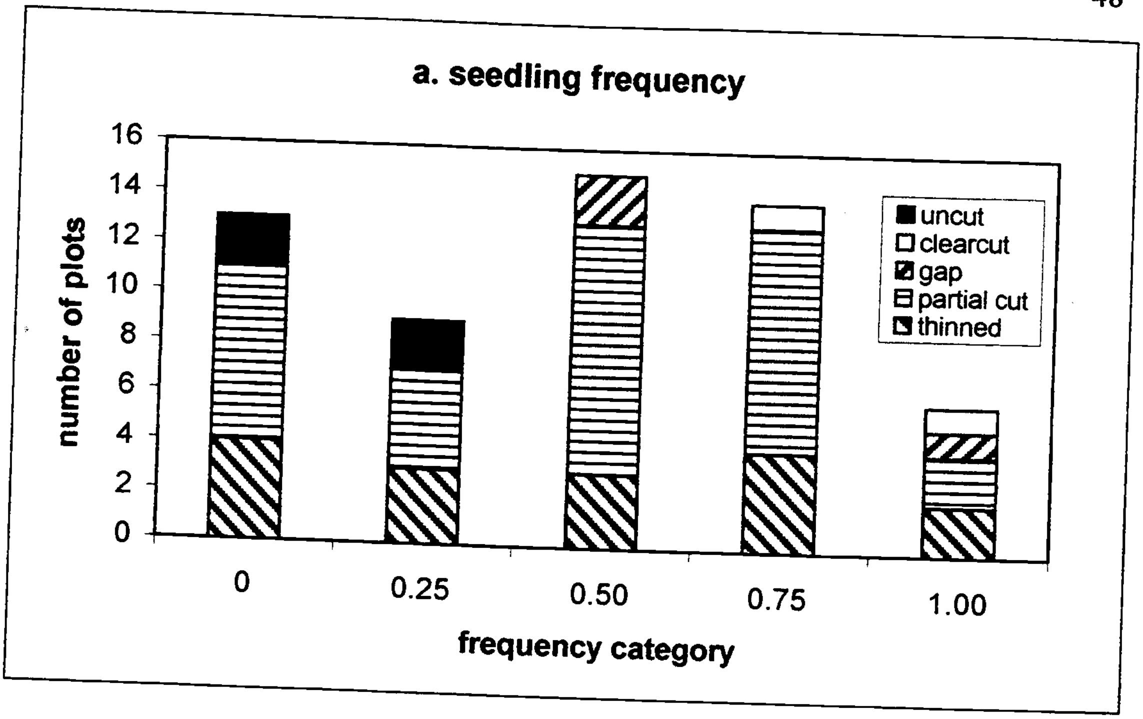


Figure 5.3. Average density of Douglas fir regeneration (seedlings and saplings) for each group of plots which had the same frequency of regeneration. For example, plots which had at least one seedling present on 1 of 4 sub-plots (0.25 frequency) had an average density of 257 seedlings per hectare. The figure was generated by comparing the (ln) mean density values between each frequency category using ANOVA. Frequency category data points with different letters have significantly ($p < 0.05$) different densities of regeneration. Vertical lines represent standard errors. Note that density (y-axis) is a natural log (ln) scale.



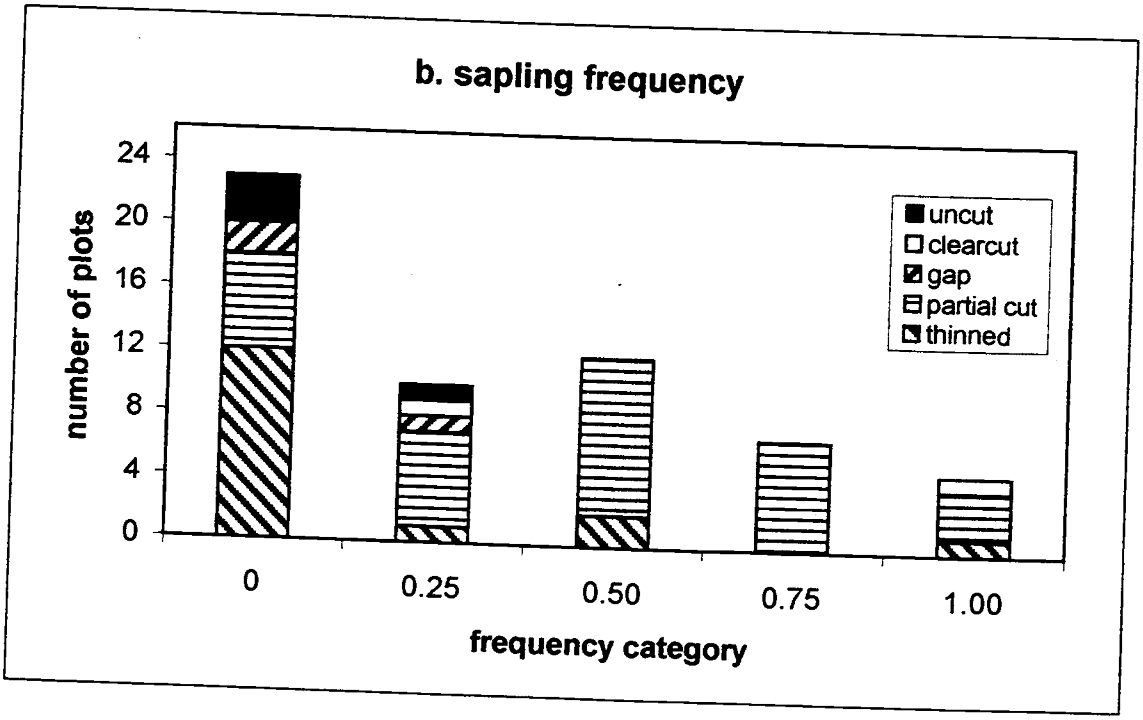


Figure 5.4 Depiction of how many plots had seedlings (a) or sapling (b) present and if present how evenly they were distributed, in terms of frequency. A 0 value indicates that no indidviduals were present, 0.25 indicates that individuals were rare and/or poorly distributed, at the other extreme 1.0 means that individuals were common and/or evenly distributed, 0.5 and 0.75 are intermediate. Patterns on bars are coded to each stand type.

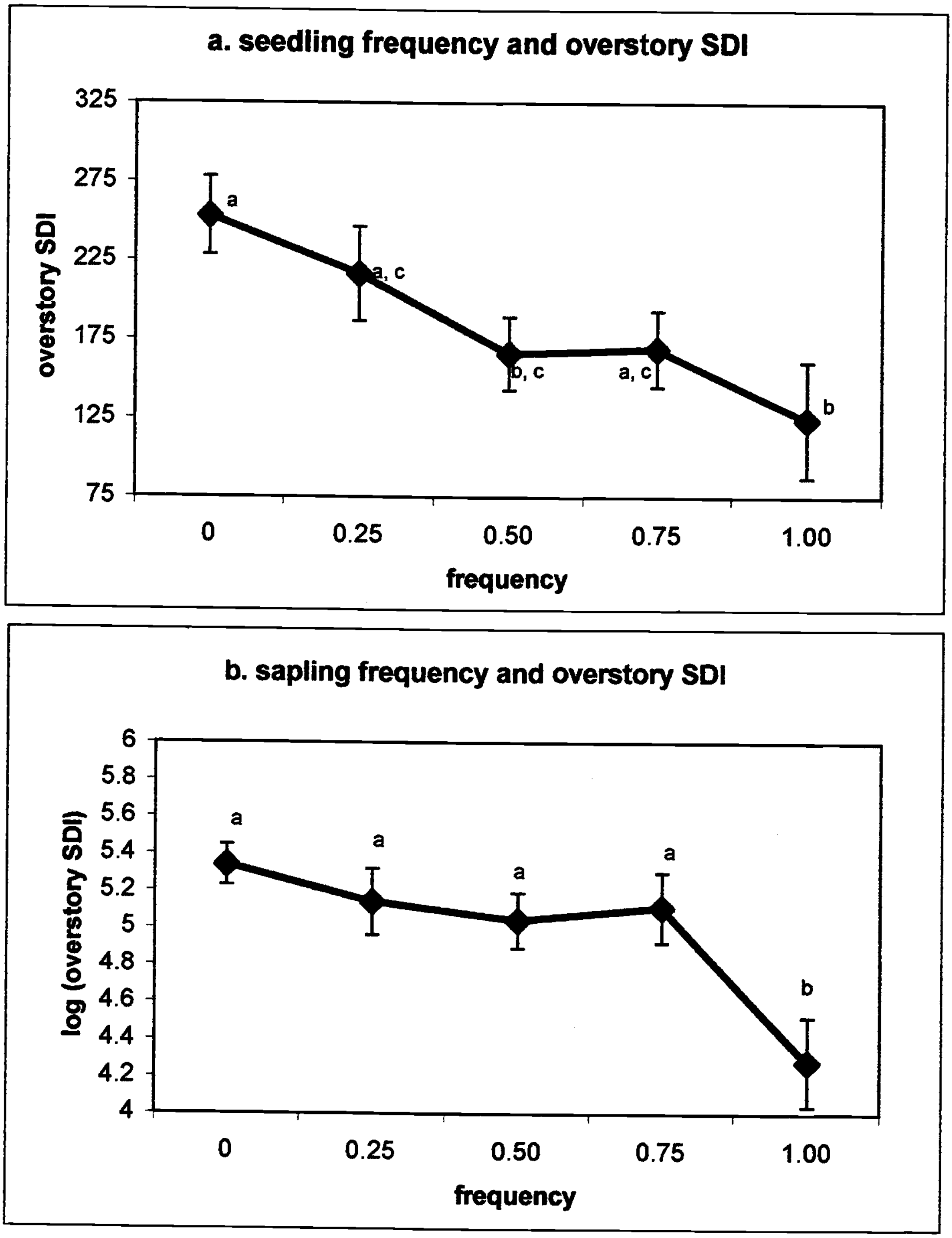


Figure 5.5 Average overstory stand density index (SDI) for plots in all stand types within each category of (a) seedling and (b) sapling frequency values. An ANOVA procedure was used to generate mean SDI values for plots within each frequency category and determine if significant differences existed between categories, points with different letters are significantly different ($p < 0.1$). Vertical lines represent one standard error. Note y-axis on (b) is natural log (ln) scale.

with an average overstory SDI of 124 (SE = 36.6), which is similar to Bailey and Tappeiner's (1998) finding that the highest frequency of seedlings were found in stands with a total SDI of 118 – 161 (Figure 5.5). In contrast to both of these studies, Graham et al. (1982) found that frequency of seedlings in partial cuts increased as residual basal area increased, up to 44 m^2/ha basal area.

5.2 The Effect of Shrub Cover on Density and Frequency of Regeneration

No statistically significant linear relationships were observed between total shrub cover and frequency or density of regeneration. In fact the density of regeneration did not decline even as shrub cover exceeded 70% (Figure 5.6). Nor were any linear relationships observed between frequency or density of regeneration and increasing cover of each of the following individual shrub species: salal (*Gaultheria shallon* Pursh), tanoak (*Lithocarpus densiflorus* (Hook. and Arn.)), rhododendron (*Rhododendron macrophyllum* G.Don), bracken fern (*Pterdium aquilinum* (L.) Kuhn), or western hazel (*Corylus cornuta* Marsh). See section 5.6 for complete information on shrub cover.

The results of this study contradict the results of another study conducted in western and southwestern Oregon (Bailey and Tappeiner 1998). Bailey and Tappeiner (1998) observed that seedling frequency and density were strongly, negatively correlated with shrub cover. The reason for the difference between the two studies may be the preponderance of plots (56%) that were in partial-cut stands in this study, whereas no partial-cut stands were used Bailey and Tappeiner's (1998) study.

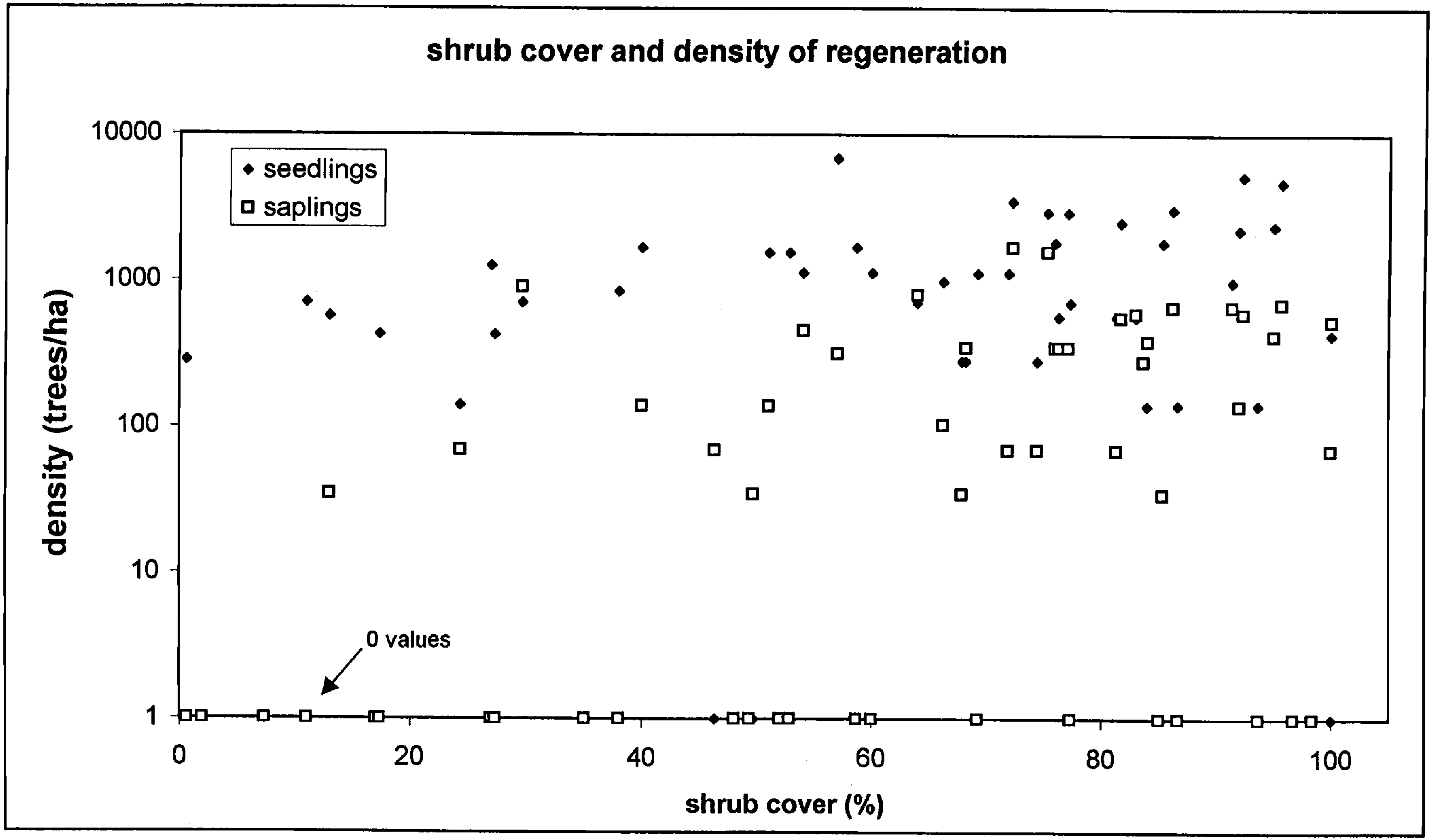


Figure 5.6. Average shrub cover and density of Douglas-fir seedlings/saplings on each plot. Data from all stand types were used, n=57. Tree density values of 0 were plotted as 1's along the X-axis because there is no log n value for 0. Note: Y-axis is on ln scale.

In this study, it seemed that the presence of shrubs was an indication that understory conditions were suitable for plant growth. In stands where dense overstory canopies blocked almost all sunlight, both shrubs and regeneration were excluded. In stands where shrubs were present (all stands, except 1 uncut stand), seedlings were generally present. In this study high percent shrub cover did not exclude tree regeneration or even decrease the density of regeneration (Figure 5.6).

5.3 Recruitment of Seedlings Into the Sapling Class

Seedling establishment is only the first step in the eventual recruitment of trees into the overstory. The second step is advancement into the sapling class. It appears that seedlings advanced into the sapling class 11-20 years after harvest in partial-cut stands (Figure 5.1), but saplings in general were observed on fewer plots and at lower densities and frequencies than seedlings (Figures 5.2, 5.3, 5.4). Some possible explanations for the observed difference in seedling and sapling density are: 1) seedlings died or were killed before advancing into the sapling class, 2) not enough time has passed for the seedlings to grow into the sapling class or, 3) seedlings became resource limited and moved into the suppressed class instead of the sapling class.

It was not possible to determine how many seedlings died before advancing into the sapling class in this retrospective study. Furthermore, since saplings were rarely observed in thinned stands, which were harvested more recently than partial-cut stands, time since harvest may have affected recruitment of saplings. Finally, it seems that the longer a seedling remains in the understory, the lower the chance it has of advancing into the sapling class. There are two pieces of evidence for this final observation: 1) density of suppressed trees was positively correlated with years since harvest ($r = 0.36$) and, 2) the best predictor of suppressed tree density in all stands was stand density index of understory trees (adj. $r^2 = 0.40$, $p < 0.001$) (Table 5.3, Equation 5.3-1). This indicates that as time goes on, trees that can not emerge from the seedling class become suppressed under trees that do.

5.4 Growth of Douglas-Fir Seedlings

5.4.1 Average Growth Per Plot

Mean annual leader growth of Douglas-fir seedlings across all stand types was 5.6 cm/yr. (range 1.6 to 13.3). Mean annual leader growth was 4.9 cm/yr. in partial-cut stands, 6.4 cm/yr. in thinned stands, and 8.2 cm/yr. in clearcuts (Table 5.1). Using ANOVA techniques it was determined the differences in leader growth between partial-cut and thinned stands were significant ($p = 0.06$). The lack of observed differences between other stand types was due to low sample size and high variance.

Using data from all stand types, it was determined that plot-level average annual seedling leader growth (growth) was negatively related to overstory and understory SDI and slope (adj. $r^2 = 0.45$, $p\text{-}value < 0.001$) (Table 5.3, Equation 5.4-1). This indicates that growth increased as over- and understory stand density decreased and slopes became more gentle. Elevation, aspect and shrub cover were not linearly related to growth ($p = 0.77, 0.53, 0.82$ respectively). However, seedling leader growth was not correlated with overstory SDI when partial-cut ($p = 0.35$) and

Table 5.3. Regression equations cited in Results and Discussion section (5.0) of the text. All equations were developed in the SAS Program (SAS Institute Inc., 1989). The adjusted r – square value (adj.r2), significance of the equation (*p*) and number of observations (n) are presented after the description of each equation. All terms in equations are significant at $p < 0.05$ level. Standard errors (SE) are presented below each coefficient in the equations. Definitions for terms are presented below equations. Terms preceded by 'ln' indicate that the natural logarithm of the term was used in the equation.

Equation	Description of equation,significance, sign and definition of terms and standard errors (SE).
5.3-1	Prediction of the density (trees/ha) of suppressed crown class trees (adj.r2 = 0.040, $p < 0.001$, n = 39). $\ln(\text{SUPR}) = 4.0455 + 0.017\ \text{SUNDR}$ SE = (0.2940) (0.0033) SUPR = density of suppressed trees per hectare; SUNDR = cumulative stand density index (SDI) of understory trees (trees <20 cm dbh) on each plot.
5.4-1	Prediction of plot-level average annual leader growth for seedlings (adj.r2 = 0.45, $p = 0.001$, n = 41). $\ln(\text{LEAD}) = 2.9872 - 0.0062\ \text{SUNDR} - 0.0024\ \text{SOVER} - 0.0284\ \text{SLOPE}$ SE = (0.2773) (0.0012) (0.0008) (0.0074) LEAD = average annual leader elongation (cm); SUNDR = cumulative SDI of understory trees on each plot; SOVER = cumulative SDI of overstory (trees>20 cm dbh) trees on each plot; SLOPE = angle of slope in degrees.
5.4-2	Prediction of plot-level average annual leader growth for seedlings in thinned stands (adj.r2 = 0.72, p = 0.0013, n = 11). $\ln(\text{LEAD}) = 2.8927 - 0.0389\ \text{SLOPE} - 0.0081\ \text{SHRUB}$ SE = (0.2292) (0.0070) (0.0023) LEAD = average annual leader elongation (cm); SLOPE = angle of slope in degrees; SHRUB = percent shrub cover of all shrub and sprouting hardwood species.

Table 5.3. Continued.

Equation	**Description of equation, significance, sign and definition of terms and standard errors (SE).**
5.4-3	Prediction of plot-level average annual leader growth for seedlings in partial-cut stands (adj.r2 = 0.32, $p = 0.0024$, n = 23). $\ln(\text{LEAD}) = 1.9595 - 0.0714\ \text{BUNDR}$ SE = (0.1688) (0.0208) LEAD = average annual leader elongation (cm); BUNDR = cumulative basal area (BA) of understory trees (trees <20 cm dbh) on each plot.
5.5-1	Prediction of plot-level average annual leader growth for saplings in partial-cut stands (adj.r2 = 0.76, $p < 0.001$, n = 21). $\ln(\text{LEAD}) = 2.984 - 0.0059\ \text{SHRUB} + 0.0235\ \text{SLOPE} - 0.6316\ \text{COSASP} + 0.0227\ \text{SLOPE*COSASP}$ SE = (0.2121) (0.0024) (0.0056) (0.016) (0.0076) LEAD = average annual leader elongation (cm); SHRUB = percent cover of all shrub and sprouting hardwood species; SLOPE = angle of slope in degrees; COSASP = cosine of aspect.
5.6-1	Prediction of percent cover of all shrub and sprouting hardwood species on each plot (adj.r2 = 0.33, $p < 0.001$, n = 43). $\text{SHRUB} = 42.3655 + 1.2138\ \text{YRSHRV} + 14.3185\ \text{COSASP}$ SE = (10.9895) (0.5245) (4.7046) SHRUB = percent shrub cover of all shrub and sprouting hardwood species; YRSHRV = number of years since harvest; COSASP = cosine of aspect.

thinned ($p = 0.07$) stand types were analyzed separately from other stand types (Figure 5.7 b). Trends relating overstory density to seedling growth were strongest when all stand types were analyzed together than when each stand type was analyzed separately (Figure 5.7 b). This may be because the range of overstory densities was broader when all stand types were considered together, including very open clearcuts and very dense uncut stands.

In thinned stands, seedling growth was negatively related to slope and shrub cover (adj.$r^2 = 0.72$, $p = 0.0013$) (Table 5.3, Equation 5.4-2). This result may be because steeper slopes in thinned stands tended to have shallow stony soils, which are generally associated with poor growing conditions (Smith et al. 1997). Negative effects of shrub cover on seedling growth have been observed in other studies within southwest Oregon as well [see review by Tappeiner et al. (1992)].

Seedling leader growth in partial-cuts stands was negatively associated with understory basal area (adj. $r^2 = 0.32$, $p = 0.0024$) (Table 5.3, Equation 5.4-3). However, leader growth in thinned stands was positively correlated with understory BA ($r = 0.62$) (Figure 5.7a). The reason for these contradictory trends may be that average understory basal area was over twice as high in partial-cut stands (7.2 m^2/ha) versus thinned stands (3.0 m^2/ha). And although understory density seems to affect seedling growth, it may not have been high enough in thinned stands to impair growth. Furthermore, average leader growth in all stand types varied widely and often ranged up to 8 cm/yr. at understory BA levels below 8 m^2/ha (Figure 5.7a). However, average leader growth values on plots which exceeded this BA level (partial-cuts only) did not vary as widely and did not exceed 6 cm/yr.

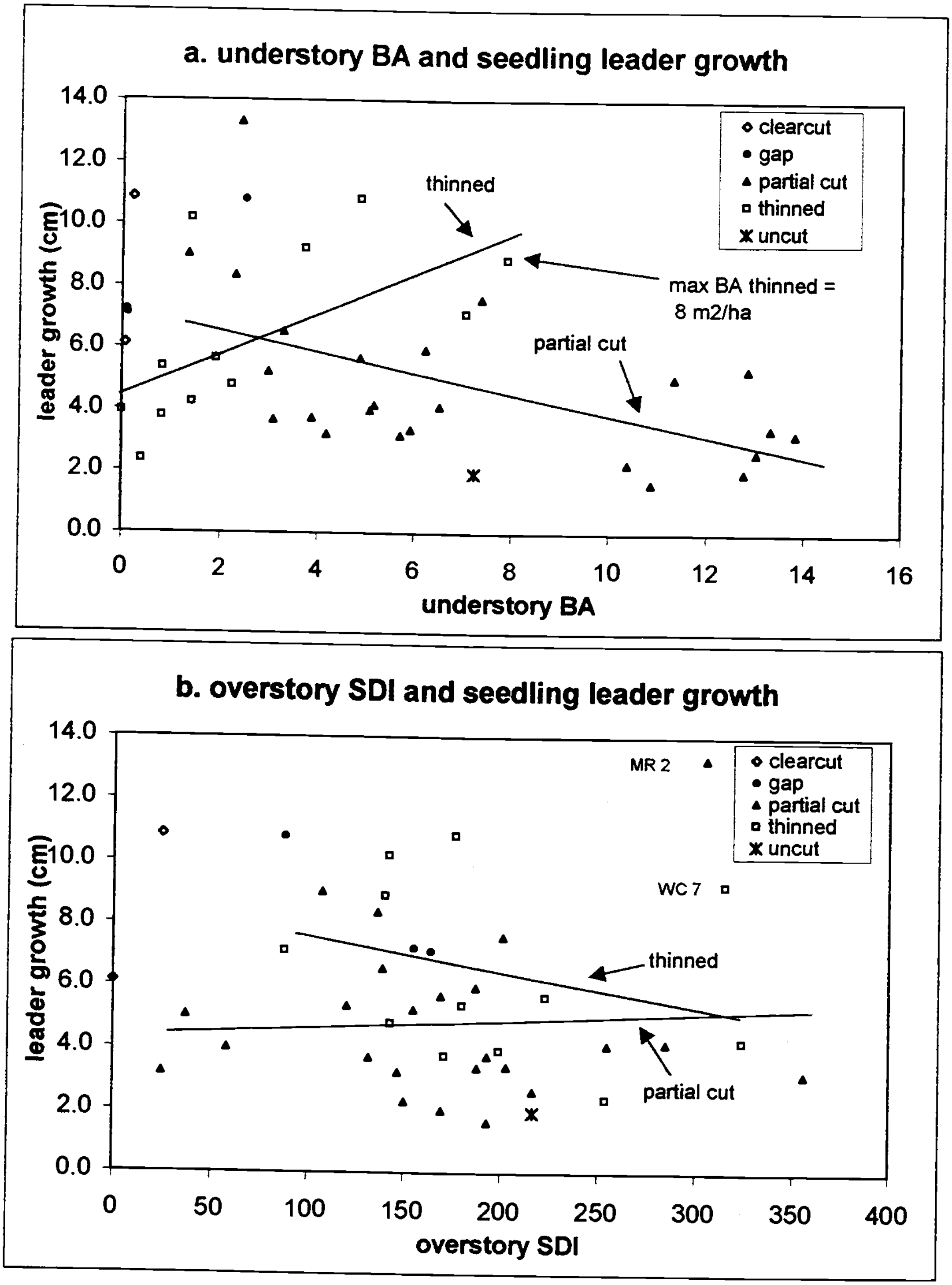


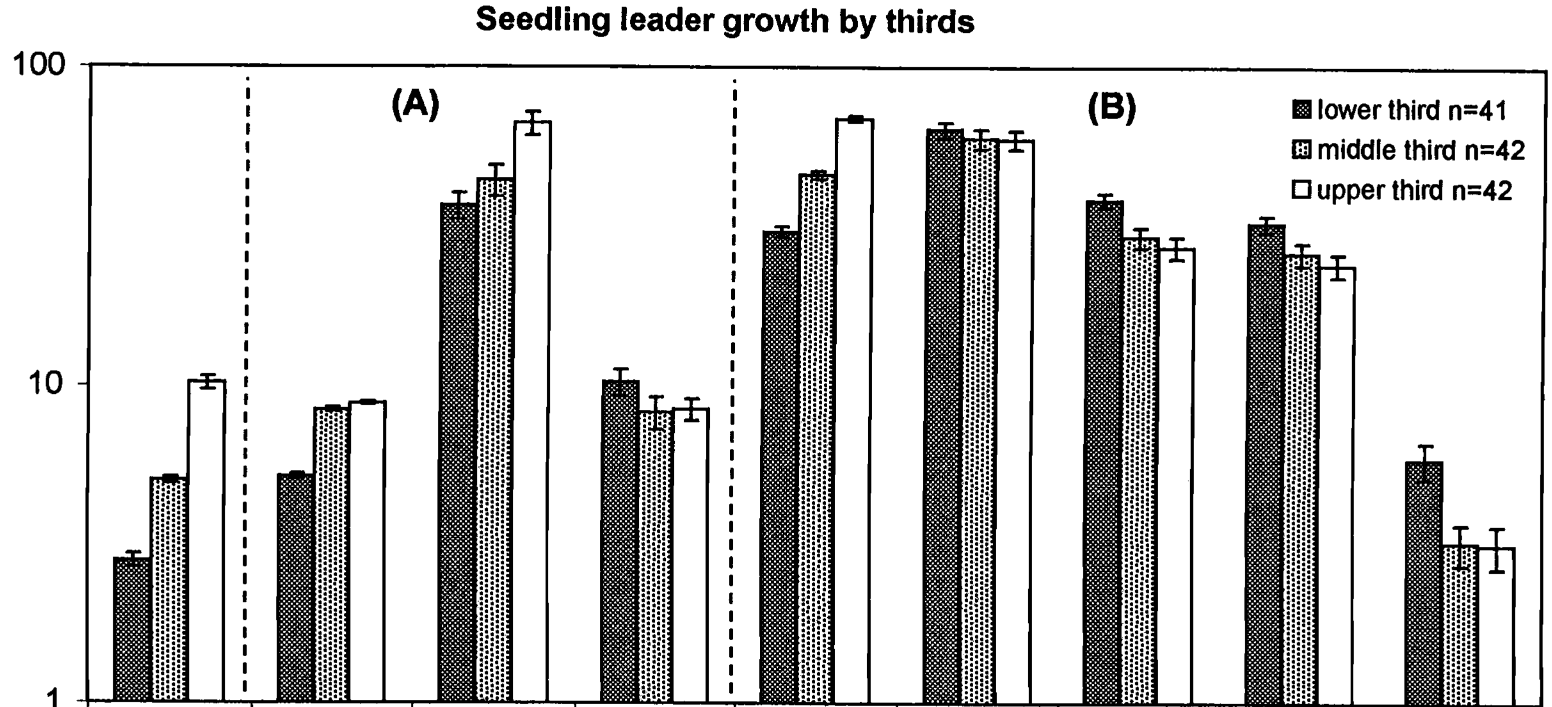
Figure 5.7 Scatterplots of average seedling leader growth on each plot compared to: a) understory basal area (BA) and, b) overstory stand density index (SDI) for the plot. Cut types are denoted in the legend. Least squares trendlines for partial cut and thinned stands on each graph are for illustrative purposes only, and are not necessarily significant. Individual plots MR2 and WC 7 on (b) are discussed in Section 5.3.3.

This may indicate that understory BA levels above 8-10 m^2/ha impair seedling growth rates while understory densities below this level have no consistent affect.

5.4.2 Individual Seedling Growth

The average annual leader growth for individuals in the upper third of the growth range of all seedlings grew at a rate of 10 cm/year, nearly double the plot-level average. The lower third of the seedlings had an average growth rate of only 3 cm/year, half of the plot-level average. The upper third of the seedlings were taller and larger in diameter than the lower two thirds of the seedlings, but not older (Figure 5.8). Average height for the upper third of the seedlings was 66 cm while height for the lower two thirds of the seedlings was < 50 cm. There were an average of 200 seedlings/ha that were 50 cm tall or greater in thinned stands and 580/ha in partial-cut stands.

Only 44 of the 57 total plots (77%) had seedlings present. Twenty-two of the 44 plots (50%) with seedlings had individuals in the upper third of the growth range. Twenty-eight of the 44 plots (64%) with seedlings had individuals in the lower third of the growth range. Eleven of the 44 plots (25%) with seedlings had individuals from both the lower and upper third of the growth range present on the same plot. Since seedlings from the upper and lower thirds of the growth range were not present on the same plot in 75% of cases (plots) this indicates that the average characteristics for each plot, i.e. canopy cover and stand density, exerted a dominant influence on seedling growth rates.



	annual leader growth (cm)	diameter (mm)	height (cm)	age (years)	canopy openness (%)	shrub cover (%)	total basal area (m2/ha)	overstory basal area (m2/ha)	understory basal area (m2/ha)
lower third n=41	2.81	5.20	36.78	10.27	30.52	63.60	38.29	32.41	5.88
middle third n=42	5.06	8.40	44.14	8.23	46.00	59.70	29.34	26.14	3.20
upper third n=42	10.22	8.80	66.40	8.41	68.80	59.16	27.24	24.10	3.15

Figure 5.8 Average characteristics of each third of: (A) Douglas-fir seedlings and, (B) associated site attributes. The data set of individual seedling observations from all stand types was sorted by average leader growth then divided into upper, lower and middle thirds (number of observations displayed in legend). All seedling and site characteritics are the average values of each third of the data set. Units are in parentheses, vertical lines represent one standard error. Note: Y-axis is on log scale.

However, inter-plot variation in growth conditions were also important for seedlings, as individuals from the extremes of the growth range were found on the same plot in 25% of cases (plots).

Generally, canopy openness increased and stand density decreased from the lower third to the upper third of the seedlings and shrub cover changed little (range 59-64%) (Figure 5.8). The upper third of the seedlings grew in plots with an average overstory basal area of 24 m^2/ha, understory basal area of 3 m^2/ha and canopy openness of 69%, while the lower third had an average overstory BA of 32 m^2/ha, understory of 6 m^2/ha and canopy openness of 30% (Figure 5.8). Lilieholm et al. (1990) observed results similar to those observed in this study for the range of leader growth values and stand densities for the upper third of seedlings. He found that the upper 25% of seedlings in uneven-aged stands in the central Sierra grew at 8 cm/yr. in stands with a total basal area of 31 m^2/ha.

Eighty three seedlings were observed in sub-plots which were estimated to have more than 50% canopy cover by visual estimate. Their mean leader growth was 5.0 cm. Forty-two seedlings were observed on sub-plots with a canopy of less than 50% cover and their mean annual leader growth was 8 cm. This indicates that even small gaps (<10-m diameter over sub-plots) in canopy cover may result in increased seedling growth rates.

5.4.3 Conclusions for Seedling Regeneration

Results from the analysis of individual seedling growth (Figure 5.8) indicated that average annual leader growth increased as canopy openness increased and overstory/understory stand density decreased, while shrub cover seemed to have little effect. Results from the plot-level analyses were similar except that in the thinned stand type shrub cover was negatively associated with seedling leader growth. This result may be because although shrub cover did not vary between stand types, average height of shrubs was higher in partial-cut stands than thinned stands (see Section 5.6). Perhaps the taller average height of shrubs in partial-cut stands uniformly suppressed seedling growth, (growth was significantly lower in partial-cut stands than thinned stands, Table 5.1) and reduced the significance of the relationship between shrub cover and leader growth in partial-cut stands.

Variance was high in analyses of plot-level and individual growth, suggesting that growth potential varied within each plot. For example, there were two plots (Marial Ridge 2 and Whitehorse Creek 7) where overstory stand density was extremely high (>300 SDI) and growth conditions should not have been favorable according to the trends established in the plot-level and individual seedling data analysis. Despite the trends, one sub-plot on each plot had individuals (Figure 5.7b, n=1 for MR 2, n=2 for WC 7) that had leader growth in the upper 15% of all individuals. These two cases (sub-plots) may illustrate how small a 'safe site' is required for successful regeneration and growth within partially harvested stands. Although overstory density was high enough to prevent frequent distribution of healthy seedlings, one 2.37-m radius sub-plot in each 15-m radius whole plot apparently received enough resources to produce 1-2 seedlings with above average growth rates.

Additionally, data from the analysis of individual seedling growth indicated that while increased light levels generally increased growth rates, simple reductions in stand density did not increase understory light levels evenly throughout the plot. Favorable microsites existed, as did unfavorable ones. However, based on results from the plot-level analysis which included all stand types, it seems that greater reductions in stand density tended to increase the frequency of favorable microsites, since plot-level average growth increased as overstory and understory stand density decreased.

5.5 Growth of Douglas-Fir Saplings

5.5.1 Average Growth Per Plot

The mean annual leader growth of saplings in all stand types was 23 cm/yr., (range 7-51 cm/yr.). Since leader growth was not significantly different among stand types ($p = 0.65$), the analysis for this section was conducted using data from partial cuts only, where 76% of the plots with saplings were observed. There were not enough observations (only 4) in thinned stands or any other stand type to conduct a separate analysis.

Sapling leader growth was negatively correlated with current total SDI (r = -0.45) and understory BA (r = -0.32). However, the best fitting regression equation only included terms indicating that saplings grew better as slopes became steeper and more south facing and shrub cover decreased (adj. $r^2 = 0.76$, $p < 0.001$) (Table 5.3, Equation

5.5-1). The regression equation (Table 5.3, Equation 5.5-1) included terms for slope and cosine of aspect and the interaction of those two terms. This indicates that slopes that were steep *and* south facing had saplings with higher growth rates than any other slope and aspect combination. Based on the results of the regression equation and correlation analysis it seems that steep south facing slopes with low stand density and shrub cover will tend promote the greatest sapling growth.

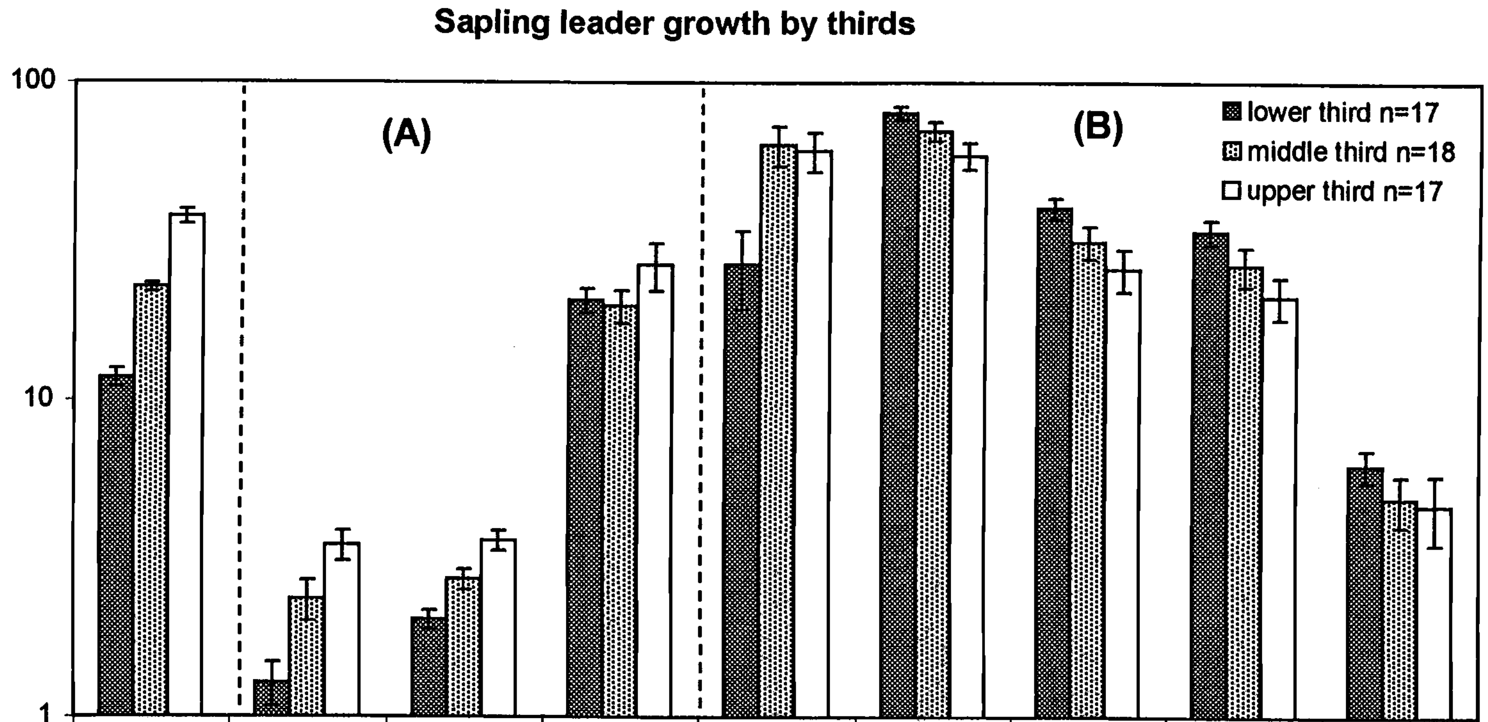
One reason that the regression equation (Table 5.3, Equation 5.5-1) indicated that lower growth of saplings occurred on north slopes may be related to dense salal and rhododendron cover. Percent cover for these shrub species was positively correlated with the cosine of aspect ($r = 0.38$ and 0.36 respectively), indicating that percent cover increased on north facing aspects. Average salal cover was 42% for the 22 plots on which it was present, but only 12 of these plots had Douglas-fir saplings on them. Average leader growth on these plots was 18 cm/yr., 5 cm below average. Average rhododendron cover was 36% on the 10 plots where it was present and only 4 of these plots had saplings. Average leader growth on these plots was 11 cm/year, less than half of the average sapling growth rate. The combination of north aspects and heavy coverage by these two shrub species seems to impair sapling growth rates. Furthermore, out of 23 plots that had no saplings, 10 had salal and 6 had rhododendron present, which may indicate that Douglas-fir does not establish or grow well in habitat where these shrub species are present.

5.5.2 Individual Sapling Growth

The mean annual leader growth of the upper third of individual saplings was 38 cm/yr., which was 15 cm/yr. greater than the plot-level average sapling growth rate. The lower third of saplings had an average leader growth rate of 12 cm/yr., which was 11 cm/yr. lower than the plot-level average. The upper third of the saplings were taller, larger in diameter and older than the lower 2/3's of saplings (Figure 5.9). Because of limitations in the data set, it was not possible to determine the density of saplings per hectare that each third of the growth range represented.

Saplings from each third of the growth range were not widely distributed across all plots. Only 34 of the 57 total plots had saplings present. And not all plots with saplings had individuals from each third of the growth range present on them. Twelve of the 34 (35%) plots with saplings had individuals from the upper third of the growth range present on them. Fourteen of the 34 (38%) of plots with saplings had individuals from the lower third of the growth range present on them. Only 4 of 34 (12%) plots had saplings from the upper and lower thirds of the growth range present on the same plot. These data indicate that growing conditions varied more between plots than within plots and that saplings from each third of the growth range were generally restricted to a narrow range of stand conditions.

The average plot characteristics associated with the upper third of the saplings were: total BA = 26 m^2/ha, canopy opening = 61% and, shrub cover = 60% (Figure 5.9).



	annual leader growth (cm)	diameter (cm)	height (m)	age (years)	canopy openness (%)	shrub cover (%)	total basal area (m2/ha)	overstory basal area (m2/ha)	understory basal area (m2/ha)
lower third n=17	11.76	1.29	2.04	20.67	26.82	80.20	40.42	34.10	6.25
middle third n=18	22.67	2.36	2.73	19.83	63.78	70.50	31.62	26.60	4.90
upper third n=17	37.91	3.51	3.62	26.71	61.18	59.10	25.89	21.20	4.66

Figure 5.9 Average characteristics of each third of: (A) Douglas-fir saplings and, (B) associated site attributes. The data set of individual sapling observations from all stand types was sorted by average leader growth then divided into upper, lower and middle thirds (number of observations displayed in legend). All sapling and site characteritics are the average values of each third of the data set. Units are in parentheses, vertical lines represent one standard error. Note: Y-axis is on log scale.

The average plot characteristics associated with the lower third of the saplings were: total BA = 34 m^2/ha, canopy openness = 27% and, shrub cover = 80% (Figure 5.9). Generally, canopy openness increased and stand density and shrub cover decreased from the lower third to the upper third of the saplings.

5.5.3 Conclusions for Sapling Regeneration

Results from the analysis of plot-level sapling leader growth values indicate that leader growth increases as shrub cover and stand density decrease, particularly on steep south facing slopes. There also was evidence that saplings were not as abundant and did not grow as well in habitats where salal and rhododendron thrived – these habitats were generally on north facing slopes.

Results from the analysis of individual sapling leader growth values also indicate that annual leader growth increases as shrub cover and stand density decrease. Variations in growth rates for individual saplings on each plot were not as extreme as for individual

seedlings, indicating that favorable micro-sites did not have as big of an influence on saplings as they did on seedlings. That is, individual saplings responded more uniformly to plot level stand and canopy characteristics than individual seedlings did.

5.6 Patterns in Shrub and Hardwood Sprout Cover

Average shrub cover on each plot was 61% (range 1-100%), and did not differ between stand types ($p = 0.11$). Average shrub height was 71 cm (range 3-172 cm).

Shrubs were taller in partial-cut stands (average height = 83 cm) than in thinned stands (51 cm) ($p = 0.03$).

Percent shrub cover was not correlated with percent open canopy ($p=0.43$), current total basal area ($p=0.50$), BA before harvest ($p=0.74$) or after harvest ($p=0.42$), nor any other measures of stand density. Shrub cover was only related to cosine of aspect and years since the last harvest (adj. $r^2 = 0.33$, $p < 0.001$) (Table 5.3, Equation 5.6-1), indicating that shrub cover increased on northerly aspects and as the length of time since the last harvest increased.

Shrub cover was high on nearly every combination of plot characteristics. Individual plots exceeded 80% shrub cover on all aspects, but only northerly plots had coverages in the 90-100% range, hence the positive relationship between cosine of aspect and shrub cover. Plots harvested as recently as 9 years ago had shrub covers of 75% and one uncut plot had 94% shrub cover.

Individual shrub and sprouting hardwood species which occurred at >15% cover on 4 or more plots were classified as Common Dominant Species (CDS). Species which occurred at >15% coverage on 1-3 plots were classified as Dominant Species (DS) (Table 5.4). Statistics were only generated for CDS and DS species where coverage was greater than or equal to 15% on the plot. The five CDS species that were observed on the most plots at >15% coverage were (in order of most to least frequently observed): salal, tanoak, bracken fern, western hazel and rhododendron. The average cover on each plot for the top five CDS species ranged from 35% (western hazel) to 58%

Table 5.4. Distribution and coverage of shrub and sprouting hardwood common dominant species (CDS) and, dominant species (DS). Each plot was placed in a category based on the amount of total basal area (BA) observed on that plot. The 'Total BA categories' were divided into 22 m^2/ha increments. 'NumPlots' represents the number of plots in each total BA category that each shrub species was observed at a coverage > 15%. 'AveCov (%)' represents the average percent coverage of each shrub species that was observed in each category. 'All plots' is the total number of plots that each shrub species was observed on and average cover on those plots.

Common Dominant Species: occur at >15% coverage on 4 or more plots

species	Total BA categories (m2/ha)								All Plots	
	<22		22-33		33-44		>44			
	NumPlots	AveCov(%)	NumPlots	AveCov(%)	NumPlots	AveCov(%)	NumPlots	AveCov(%)	NumPlots	AveCov(%)
salal	3	42	4	38	4	62	6	39	17	45
tanoak	2	61	1	69	3	58	8	45	14	58
bracken fern	4	51	1	15	2	21	1	27	8	28
w.hazel	0	.	2	44	3	26	1	35	6	35
rhododendron	1	23	1	70	3	60	1	64	6	54
oregon grape	1	20	1	26	2	38	1	27	5	28
ocean spray	0	.	1	25	1	48	2	26	4	33
sword fern	0	.	3	23	1	17	0	.	4	20
liveoak	1	30	2	24	1	19	0	.	4	24
trailing blackberry	1	18	2	35	0	.	1	44	4	32

Dominant Species: occur at >15% coverage on 1-3 plots

species	Total BA categories (m2/ha)								All Plots	
	<22		22-33		33-44		>44			
	NumPlots	AveCov(%)	NumPlots	AveCov(%)	NumPlots	AveCov(%)	NumPlots	AveCov(%)	NumPlots	AveCov(%)
golden chinquapin	1	16	0	.	1	28	0	.	2	22
black oak	1	22	0	.	1	20	0	.	2	21
poison oak	0	.	1	15	1	17	0	.	2	16
evergreen huckleberry	0	.	0	.	1	19	1	23	2	21
vine maple	0	.	1	35	0	.	0	.	1	35
pacific madrone	1	43	0	.	0	.	0	.	1	43
varnishleaf ceanothus	0	.	0	.	0	.	1	21	1	21
princes pine	0	.	0	.	0	.	1	17	1	17
red-osier dogwood	0	.	0	.	1	15	0	.	1	15
black cap raspberry	0	.	0	.	1	18	0	.	1	18
thimbleberry	0	.	0	.	1	21	0	.	1	21
red huckleberry	0	.	0	.	1	15	0	.	1	15

(tanoak) (Table 5.4). All five of these species were observed in plots with total BA ranging from <22 m^2/ha to >44 m^2/ha, except for western hazel which did not occur at <22 m^2/ha (Table 5.4).

Statistical analyses were only performed on the top five CDS species since they were the most widespread and occurred at the highest coverages. As stated in section 5.2 there were no linear relationships between any of the top five CDS species and density, frequency or growth rates of seedling or sapling regeneration. However some observations were made in section 5.5.1 which related decreased sapling occurrence and leader growth with salal and rhododendron cover on north aspects. The only other significant trend within CDS species was that bracken fern cover was negatively correlated with overstory basal area (r = -0.28), indicating that bracken fern cover increased as overstory BA decreased.

5.7 Response of Intermediate and Co-Dominate Trees to Harvest

Intermediate crown class conifers which were older than the most recent harvest date were increment cored to determine if they 'released' after the most recent harvest. Twenty-one plots across all areas sampled had intermediate conifers that were measured. Of 31 conifers measured, 21 released within five years of harvest and 25 released within 10 years of harvest. For trees that released, average radial growth for the five years after release was 65% higher than the average radial growth in the five years preceding the release (range 28-95%).

The magnitude of increase in radial growth was not significantly related to pre-harvest plot basal area (*p-value = 0.96*) or proportion of basal removed at harvest (*p-*

value = 0.15). The magnitude of release was weakly, positively related to post-harvest plot basal area (r = 0.15, *p-value = 0.08*). The mean age of trees which released after harvest was 53 years old (range 21-89 years). These data indicate that the majority of intermediate and co-dominate trees in the understory were able to respond to partial overstory removal by increasing growth rates. Thus it is possible that these trees will eventually be recruited into the overstory to replace trees which were previously harvested.

6.0 Conclusions and Management Implications

A number of conclusions were made in this study, which have implications for uneven-aged management in southwest Oregon. Past harvests in partial-cut and thinned stands, the surrogates for uneven-aged stands in this study, seem to have stimulated the recruitment of multiple cohorts of natural Douglas-fir regeneration. Decreases in stand density tended to increase the frequency, density, and growth rates of regeneration. The majority of intermediate and co-dominant trees, which may be classified as advanced regeneration, also responded to past harvests by increasing radial growth rates.

Interestingly, no relationship between shrub cover and density of Douglas-fir regeneration were observed in this study, which indicates that even when high levels of shrub cover exist in the understory Douglas-fir can naturally regenerate. However, reduced shrub cover levels were associated with higher growth rates for regeneration. It was difficult to find plots where healthy regeneration and low shrub cover occurred simultaneously because shrub cover was high on most plots where regeneration occurred. Therefore it was not possible to make a comparisons between regenerating trees growing with and without high coverages of shrub species in otherwise similar environments. Further study on the relationship between shrubs and regeneration in uneven-aged stands is warranted. It would be interesting to compare plots with and without shrub control in uneven-aged stands where stand densities were within the range necessary for good growth of regeneration.

The range of stand densities which were associated with the fastest growth of Douglas-fir regeneration in this study were: 1) overstory (trees > 20 cm dbh) basal area of 20-25 m^2/ha, 2) understory basal area of 2-5 m^2/ha and, 3) canopy openness of 60-70%. While it may not be possible to retain 22-30 m^2/ha of total basal area in a stand and simultaneously maintain a canopy openness of 60-70% everywhere, the use of small canopy gaps may help meet canopy openness target in some locations. The favorable growth potential for tree regeneration in canopy gaps was pointed out by way of example in Section 5.1.

Slope and aspect, in addition to stand density and shrub cover, are important aspects of uneven-aged management prescriptions. Douglas-fir saplings grew best on steep south facing slopes in partial-cuts. This is significant because these sites have traditionally been difficult to regenerate using clearcut methods in southwest Oregon. Perhaps steep south facing slopes are best suited to uneven-aged management techniques, especially where aesthetics or other ecosystem management goals are important.

In conclusion it seems that natural regeneration of Douglas-fir in partially harvested stands is sufficient to maintain a significant component of the species in the stands with no further management, i.e. shrub control or future harvest. However, maintenance of stand density in the 22-30 m^2/ha basal area range and reductions in shrub cover could likely increase frequency, density, and growth rates of tree regeneration in an uneven-aged management scenario.

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Appendix

Appendix Table 1. Characteristics of each plot (see section 4.4). Area = geographic area in which plot was located. Glendale Resource Area: BC = Bear Crk., MR = Marial Ridge, RR = Rattlesnake Ridge, WC = Whitehorse Crk./Wildcat Ridge. Grants Pass Resource Area: JC = Jack Crk., MP = Mt. Peavine, QC = Quartz Crk., RC = Rum Crk; plot = plot number; stand type = indicates silvicultural treatment each area received; TRSU = township, range, section, unit identification; years since harvest = years since most recent harvest, from BLM records; pre and post harvest BA = basal area before and after most recent harvest, estimated using reconstruction techniques (see section 4.6 of text); current total BA = basal area of stand as measured summer 1997; open canopy = percent sky visible through the forest canopy (see section 4.4.2).

area	plot	stand type	TRSU	slope (degrees)	aspect (degrees)	elevation (m)	years since harvest	pre-harvest BA (m2/ha)	post-harvest BA (m2/ha)	current total BA (m2/ha)	open canopy (%)
BC	1	uncut	.	30	15	758	.	.	.	40	2
JC	1	partial cut	34-5-27.003	28	20	879	22	60	29	39	20
JC	2	partial cut	34-5-27.003	30	348	909	22	56	21	23	90
JC	3	partial cut	34-5-27.001	33	346	939	22	44	17	25	42
JC	4	partial cut	34-5-27.004	20	150	1000	22	30	30	44	7
JC	5	partial cut	34-5-27.014	26	306	970	.	.	.	42	22
JC	6	partial cut	34-5-27.01	15	230	1045	29	30	12	35	46
JC	7	partial cut	34-5-27.001	32	61	848	22	52	27	34	50
JC	8	partial cut	34-5-27.003	30	332	1030	22	74	20	25	14
MP	1	partial cut	34-8-16.005	26	143	1106	25	101	101	112	2
MP	2	partial cut	34-8-16.005	4	270	1106	25	168	27	59	22
MR	1	partial cut	33-9-5.001	18	233	1000	26	22	22	37	15
MR	2	partial cut	33-9-5.001	7	170	970	26	76	51	60	43
MR	3	partial cut	33-9-5.001	16	180	939	26	82	33	47	47
MR	4	partial cut	32-9-32.010	12	350	1012	26	73	30	41	8
MR	5	partial cut	32-9-31.008	9	343	1012	26	50	17	43	0
MR	6	partial cut	32-9-31.018	14	31	848	26	.	.	32	0
MR	7	partial cut	32-9-31.008	18	18	1015	26	77	34	54	3
MR	8	partial cut	32-9-32.010	8	10	1000	26	.	.	38	55
QC	1	partial cut	34-7-23.015	18	95	803	22	.	.	16	91
QC	2	partial cut	34-7-25.006	28	66	515	22	54	20	35	14
QC	3	partial cut	34-7-23.011	32	211	652	22	67	24	29	52
QC	4	partial cut	34-7-23.015	32	47	773	22	73	26	40	22
QC	5	uncut	34-7-23.014	24	288	606	.	.	.	51	4
QC	6	partial cut	34-7-23.003	23	240	697	31	67	19	37	0
QC	7	partial cut	34-7-23	18	184	530	.	.	.	14	8
QC	8	thinned	34-7-23	9	110	485	.	.	.	37	59

Appendix Table 1 Continued.

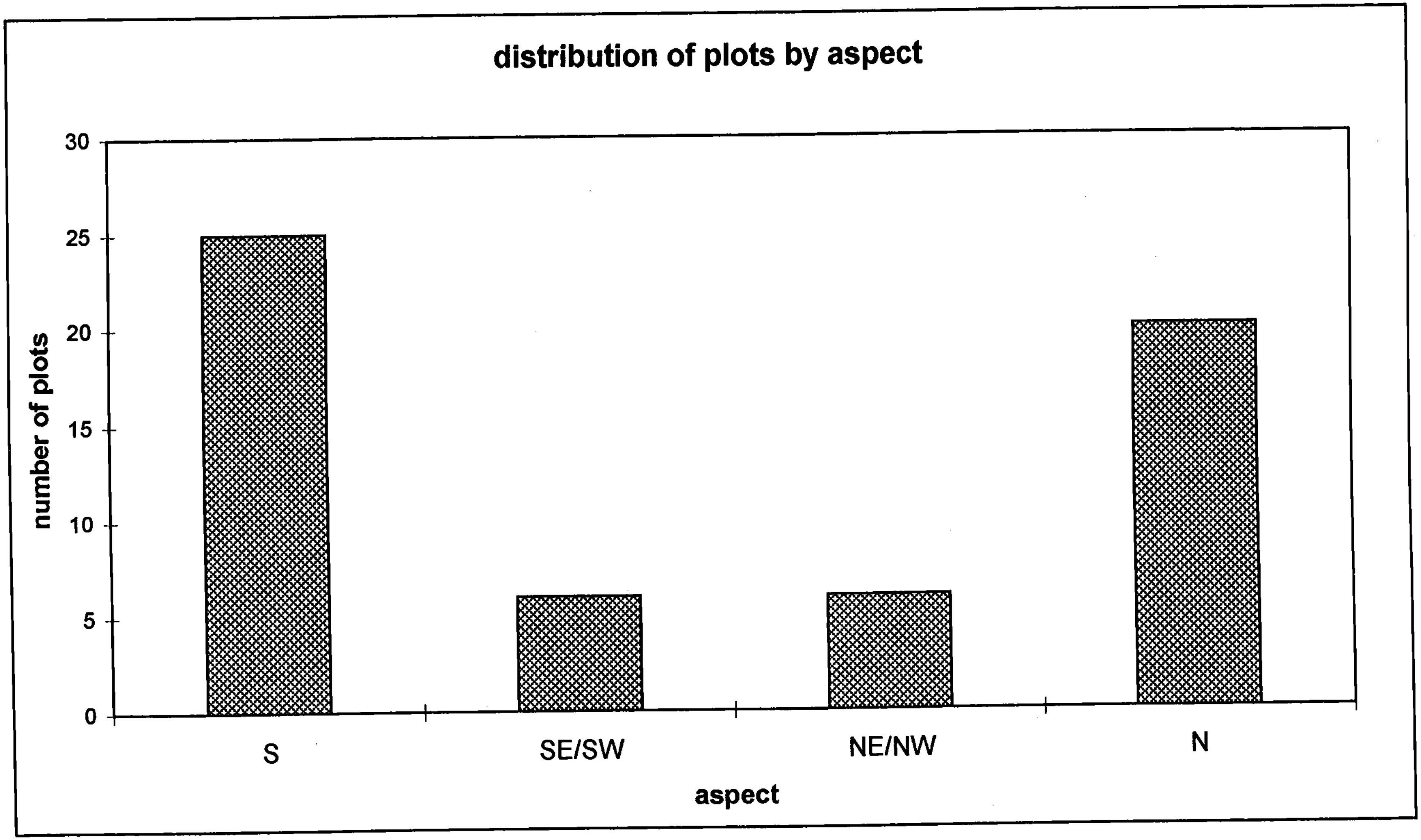
area	plot	stand type	TRSU	slope (degrees)	aspect (degrees)	elevation (m)	years since harvest	pre-harvest BA (m2/ha)	post-harvest BA (m2/ha)	current total BA (m2/ha)	open canopy (%)
RC	1	partial cut	34-8-10.023	12	238	939	25	83	34	53	23
RC	2	partial cut	34-8-10.023	8	230	927	25	45	30	48	0
RC	3	partial cut	34-8-10.013	21	308	1000	25	44	33	40	40
RC	4	partial cut	34-8-10	31	76	879	22	.	.	9	40
RC	5	partial cut	34-8-10.007	12	322	985	25	55	44	55	2
RC	6	partial cut	34-8-10	18	335	864	22	58	28	33	23
RC	7	partial cut	34-8-10.023	17	270	921	25	74	39	46	18
RC	8	partial cut	34-8-10.003	24	224	848	.	.	.	53	4
RR	1	thinned	33-7-15.009	16	178	970	10	.	.	37	5
RR	2	thinned	33-7-9.011	26	160	1000	9	47	36	50	12
RR	3	thinned	33-7-9.011	24	150	1000	9	62	26	32	8
RR	4	thinned	33-7-10.011	26	220	1000	9	39	18	24	27
RR	5	thinned	33-7-10.011	23	232	1000	9	61	29	34	15
RR	6	gap	33-7-15.009	26	140	970	9	48	17	20	66
RR	7	gap	33-7-10.011	15	220	1000	9	47	20	26	100
RR	8	gap	33-7-10.011	16	202	1000	9	55	24	27	86
RR	9	thinned	33-7-10.011	21	190	909	9	66	18	23	49
RR	10	clearcut	33-7-9.013	33	320	909	.	.	.	0	100
RR	11	uncut	33-7-10.011	25	190	1000	.	.	.	65	0
WC	1	thinned	32-4-10	6	230	570	.	.	.	29	29
WC	2	thinned	32-4-10	5	250	570	.	.	.	20	53
WC	3	thinned	32-4-11.019	36	345	818	11	53	21	27	4
WC	4	thinned	32-4-11.018	45	250	848	13	35	15	20	80
WC	5	thinned	32-4-11.019	31	320	788	11	56	29	40	0
WC	6	thinned	32-4-15.026	13	274	561	17	52	36	44	27
WC	7	thinned	32-4-9.017	0	230	524	17	46	29	48	9
WC	8	thinned	32-4-15.019	32	312	894	.	.	.	35	.
WC	9	thinned	32-4-15.007	18	280	576	.	.	.	25	6
WC	10	uncut	32-4-10.001	29	330	758	.	.	.	62	11
WC	11	clearcut	32-4-15.017	25	156	894	11	68	5	5	100

Appendix Table 2. Overstory and understory tree characteristics and shrub cover for each plot. Area, plot, stand type –see Appendix Table 1 caption; Overstory = data for all trees > 20 cm in diameter at breast height (dbh); Understory = data for all trees < 20 cm dbh; con SDI = cumulative stand density index (SDI) of all conifer trees; hard SDI = cumulative SDI of all hardwood trees; TPHa = trees per hectare, all species; ave. dbh = average dbh of all overstory trees on each plot; shrub cover = percent of each plot that is covered by sprouting hardwood and shrub species. SDI is a measure of stand density (Reineke 1933), $SDI = TPA_X * [(dbh_X / 10)^{1.6}]$ where: TPA = trees/acre, dbh = diameter at breast height (inches). SDI is calculated for each size class ($_X$) then summed for all size classes within the stand for cumulative SDI.

			Overstory (> 20 cm dbh)				Understory (<20 cm dbh)			
area	plot	stand type	con SDI	hard SDI	TPHa	ave. dbh (cm)	con SDI	hard SDI	TPHa	shrub cov.(%)
BC	1	uncut	219	0	133	76	4	9	484	94
JC	1	partial cut	156	37	150	75	37	16	1591	51
JC	2	partial cut	107	0	37	95	7	13	899	76
JC	3	partial cut	139	0	170	55	13	29	934	77
JC	4	partial cut	137	32	106	73	70	74	2248	68
JC	5	partial cut	90	103	254	58	107	28	2905	24
JC	6	partial cut	172	37	451	30	91	9	1660	7
JC	7	partial cut	156	0	69	89	11	35	2179	86
JC	8	partial cut	83	25	37	92	30	5	519	50
MP	1	partial cut	557	37	459	78	102	17	1279	52
MP	2	partial cut	356	0	496	49	65	17	3043	64
MR	1	partial cut	150	0	115	69	28	84	1037	72
MR	2	partial cut	279	51	167	73	23	10	1487	84
MR	3	partial cut	136	65	132	83	4	74	1037	76
MR	4	partial cut	187	0	139	78	65	14	2455	96
MR	5	partial cut	200	61	436	37	93	2	2075	100
MR	6	partial cut	61	138	358	33	2	52	380	98
MR	7	partial cut	118	166	308	63	31	43	3251	82
MR	8	partial cut	202	0	277	48	78	2	1349	92
QC	1	partial cut	0	37	93	25	122	24	3908	72
QC	2	partial cut	83	37	115	65	107	47	3251	84
QC	3	partial cut	132	0	44	92	13	25	761	81
QC	4	partial cut	122	25	131	73	54	117	4219	75
QC	5	uncut	192	25	98	91	32	57	2109	68
QC	6	partial cut	111	25	166	58	148	23	2939	49
QC	7	partial cut	58	32	105	40	54	9	2006	30
QC	8	thinned	212	29	498	33	54	13	1418	46

Appendix Table 2. Continued.

area	plot	stand type	Overstory (> 20 cm dbh) con SDI	hard SDI	TPHa	ave.dbh (cm)	Understory (<20 cm dbh) con SDI	hard SDI	TPHa	shrub cov.(%)
RC	1	partial cut	147	56	104	87	111	62	4495	40
RC	2	partial cut	43	175	275	57	83	70	3078	66
RC	3	partial cut	169	0	53	99	6	53	1522	83
RC	4	partial cut	0	25	15	65	10	41	865	100
RC	5	partial cut	247	32	190	84	46	33	1418	77
RC	6	partial cut	136	0	32	123	11	18	726	92
RC	7	partial cut	188	0	50	105	37	38	2109	95
RC	8	partial cut	36	285	452	56	15	40	1349	35
RR	1	thinned	253	0	225	49	20	0	173	59
RR	2	thinned	288	37	439	48	7	9	242	27
RR	3	thinned	180	0	110	65	8	0	69	11
RR	4	thinned	143	0	139	49	10	14	311	1
RR	5	thinned	140	0	71	92	54	24	484	17
RR	6	gap	88	0	31	88	27	1	346	60
RR	7	gap	155	0	100	65	0	2	207	27
RR	8	gap	194	0	172	54	1	1	242	75
RR	9	thinned	142	0	135	45	16	0	173	13
RR	10	clearcut	0	0	0	0	0	1	138	85
RR	11	uncut	426	0	561	40	44	36	692	2
WC	1	thinned	76	101	287	36	21	36	1487	57
WC	2	thinned	88	0	96	45	51	33	1729	91
WC	3	thinned	171	0	158	52	9	0	69	53
WC	4	thinned	114	0	110	50	26	0	242	85
WC	5	thinned	254	0	226	51	0	5	35	87
WC	6	thinned	260	0	259	43	47	0	277	97
WC	7	thinned	315	0	447	35	36	3	450	69
WC	8	thinned	199	0	126	78	0	0	0	38
WC	9	thinned	150	0	203	45	20	8	311	48
WC	10	uncut	381	74	633	40	19	25	277	17
WC	11	clearcut	25	0	14	65	4	0	450	54



Appendix Figure 1. Distribution of plots by aspect. The range of aspects for each category is: N = 0-45°, 315-360°; NE/NW = 45-90°, 270-315°; SE/SW = 90-135°; S = 135-225°.