


AN ABSTRACT OF THE THESIS OF

John Duff Bailey for the degree of Doctor of Philosophy in Forest Science, presented July 12, 1996. Title: Effects of Stand Density Reduction on Structural Development in Western Oregon Douglas-fir Forests -- A Reconstruction Study

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Abstract approved:

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This research examined thinning effects on stand structure and species composition in 50- to 120-year-old Douglas-fir forests. Thirty-two paired stands (thinned and unthinned) were measured throughout western Oregon, as were 20 old-growth stands for comparison. Thinnings occurred 10 to 24 years previously and ranged in intensity from 8 to 60% volume removal. Overstory and intermediate tree characteristics, conifer and hardwood regeneration, and shrub/herbaceous species composition and cover were recorded. From this, I assessed whether thinning young stands promoted vegetation structure and composition associated with old-growth stands.

Overstory trees in thinned stands had diameters, live crown ratios, crown radii, and radial growth rates greater than those in unthinned stands, and equal to or approaching those found in old-growth stands. Stand volume production was neither affected by earlier clearcut harvesting nor by thinning. Intermediate trees in thinned stands, like old-growth stands, were typically young saplings with radial growth rates and live crown ratios greater than those in unthinned stands (typically suppressed members of the original cohort). Living intermediate structure (multi-storied canopies) was common

to thinned and old-growth stands. Given such overstory and intermediate tree responses, canopy leaf area in stands thinned ≥ 20 years previously was greater than in unthinned stands.

Conifer regeneration density, frequency and growth rates were greater in thinned stands than in old-growth and unthinned stands. Densities and frequencies of tall shrubs were similar in thinned and old-growth stands, and greater than unthinned stands. Low shrub and herbaceous cover were 33% and 25% greater, respectively, in thinned than other stand types. Herbaceous species frequency and richness were similarly stimulated. Low shrub composition was altered by thinning (unthinned and old-growth stands did not ordinate differently). However, herbaceous species composition was similar across all stand types and showed more variability among sites than among stand types.

Thinning appeared to create old-growth-type structure by stimulating overstory and intermediate tree crowns and growth rates, tall shrub densities and conifer regeneration. Though low shrub and herbaceous species cover and frequency were greatest in thinned stands, composition was not affected by thinning, nor by clearcut harvesting 50 to 120 years ago or other differences in stand origin.

Effects of Stand Density Reduction on Structural Development in Western Oregon
Douglas-fir Forests -- A Reconstruction Study

by

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CONTRIBUTION OF AUTHORS

Dr. John Tappeiner, my major professor, was involved in the design, analysis and writing of both manuscripts. Dr. Paul Doescher, a committee member, was involved in the analysis and interpretation of shrub and herbaceous data, and served as major professor to Cheryl Mayrsohn. Ms. Mayrsohn collected and analyzed a subset of the data in partial fulfillment of the requirements for a Master of Science degree in Range Management, and was involved in the writing of the second manuscript. Ms. Elizabeth St. Pierre was involved in the collection and analysis of shrub and herbaceous data, and the writing of the second manuscript.

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PREFACE

This dissertation consists of four chapters: 1) a common introduction, which includes the literature review and research rationale; 2) a manuscript intended for the forest scientists addressing overstory and understory tree characteristics and competing vegetation; 3) a manuscript intended for ecologists addressing issues of understory species cover, frequency, composition and richness following forest management; and 4) a comprehensive summary. An appendix is attached to provide a complete low shrub and herbaceous species list, and to list all sites with their stand averages. These form the columns and rows, respectively, of the multivariate procedures.

Effects of Stand Density Reduction on Structural Development in Western Oregon Douglas-fir Forests -- A Reconstruction Study

INTRODUCTION

Interest in Late-Successional Forests

Public forest management in western Oregon is changing in response to recent concerns by the general public for maintaining late-successional or "old-growth" Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in the landscape for the plant and animal species which inhabit them. Prominent among these is the northern spotted owl (*Strix occidentalis caurina*), first considered for listing by the US Fish and Wildlife Service in the early 1980s and listed July 23, 1990 (Lujan et al. 1992). Both the April 1990 Interagency Science Committee report (Thomas et al. 1990) and Recovery Plan for the Northern Spotted Owl (Lujan et al. 1992) summarized evidence of the owl's affinity for forests with complex structure (e.g., many canopy layers), considered critical to the owl's recovery. Lujan et al. (1992) also considered other species that could benefit from actions taken to enhance owl recovery. With the proposed listing of the marbled murrelet and some Pacific salmon runs, public interest in maintaining and promoting old-growth forests has grown, as has their interest in use of the forest for recreational and spiritual opportunities. The legal and social pressures brought by these interests have essentially halted traditional timber harvesting practices on federal lands.

Traditional harvesting practices in western Oregon have been clearcutting and planting with Douglas-fir seedlings, followed by early control of shrubs and hardwoods (Scott 1980). These practices have resulted in thousands of acres of young stands of 750+ Douglas-fir trees/ha intended to produce timber. Such management typically includes clearcut harvest as early as 40 years of age, typically closer to 60 years, following one or two commercial thinnings. Applied over many thousands of acres, it would not likely provide habitat for spotted owls and other species which prefer diverse,

multi-storied stands unless pursued to long rotations (Lujan et al. 1992) unless areas with certain old-growth features could be created and/or maintained within such a young, managed landscape. Thus, there is a need to refine silvicultural practices to a point at which forest managers can manage these many acres of young stands to provide habitat for plants and animals that use older forests while still producing wood (Tappeiner 1992).

In early 1993, President Clinton created an interagency working group (FEMAT) to assess management options for public forests that would maintain and/or restore habitat conditions for viable populations of species "known or reasonably expected to be" associated with old-growth forests. This process identified three types of lands with varying management implications: 1) areas where management is restricted to actions that foster late-successional or old-growth habitat (e.g., Late-Successional and Riparian Reserves); 2) Adaptive Management Areas (AMAs), to develop and test innovative management approaches which blend habitat creation and product yield; and 3) "Matrix" lands, for more traditional timber-based management practices. The working group estimated the consequences of these three land allocations with regards to timber yields, economic stability of communities and regions, and population stability of >1000 plant and animal species (FEMAT 1993).

The FEMAT document (1993) and the 'standard and guidelines' attached to the Record of Decision (1994) specify silvicultural guidelines for management activities in Late-Successional Reserves (LSRs), AMAs and matrix lands. Within LSRs, activities should concentrate on "young stands where stocking, structure or composition will prevent or significantly retard development of late-successional conditions" (FEMAT 1993) -- areas with dense stocking of small trees in a single canopy layer less than 80 years old in western Oregon and Washington. Activities should produce stand structure over time, and identify key components needed in particular stands (e.g., snags) and monitor their progress over time. Further, silvicultural activities should be applied variably across a landscape (or watershed as the basis of management) to promote

heterogeneity and diversity, and protect against catastrophic loss. These guidelines may be used in AMA and matrix lands as well (Record of Decision 1994).

BLM Districts assumed the philosophy, direction and responsibilities of the Record of Decision in their respective Resource Management Plans (e.g., Salem District RMP 1994). The Salem District designated 200,000 acres (80,000 ha) of LSRs, 30% of which falls within 120,000 acres (50,000 ha) of AMA land. The district also includes 100,000 acres (40,000 ha) of matrix lands. These land managers are currently faced with specific objectives to produce late-successional old-growth habitat on thousands of acres of young and middle-aged timber, and general guidelines to promote old-growth forest characteristics across all of their management acreage. Thinning, a reduction in stand density via partial removal of the overstory canopy, is generally perceived as a major tool in meeting these objectives (Tappeiner 1992; Record of Decision 1994, Cole 1996).

Forest Structure and Composition -- Young and Old

Douglas-fir Stand Development

The young stands of Douglas-fir that currently dominate many areas of western Oregon were born of medium- to small-scale disturbances: clearcut harvesting, wind events and disease, fire, or large-scale fire exclusion (Scott 1980; Franklin and Dyrness 1984; Hermann and Lavendar 1990). Specifically, stands like those in study (50- to 120-years old) regenerated naturally prior to current reforestation technology and laws which encourage dense, uniform stocking. Natural Douglas-fir regeneration was enhanced by the heavy site disturbance associated with past ground-based logging systems and subsequent broadcast slash burning, and by natural disturbances (Hermann and Lavender 1990). Densities ranged up to 2500 seedlings/ha depending on seed source availability, seed year periodicity (the normal cycle between abundant and light seed production years), fire return intervals, or other disturbances. Though some stands did not return to full conifer stocking, many stands became well- to over-stocked (Scott 1980). Nearly all

stands ≤ 50 years of age (established since 1960) have been planted at densities > 750 trees/ha and are considered well-stocked by most professionals.

Most Douglas-fir stands pass through a 'stem exclusion' successional stage at some point in their development depending on actual density and site conditions such as mesoclimate and soil productivity (Oliver and Larsen 1990). During stem exclusion, trees of smaller stature are progressively overtopped by their neighbors until they die from shading and other resource limitations. Douglas-fir is intermediate in shade tolerance at this stage of development (Hermann and Lavendar 1990). Even the dominant trees in a stand show reduced vigor and growth rates, reduced live crowns as lower branches die, and large height:diameter ratios during this stage (Smith 1962). Foresters have long understood this self-thinning process and manage their stands accordingly (see section III).

In the next stage of succession, "stem re-initiation", shade-tolerant species present from the original stand, or which are seeded into the small openings created by suppression mortality, are released from competition by the death of neighbors and grow into the canopy as the stand develops (Oliver and Larsen 1990). With time, the processes of stem exclusion and new stem re-initiation create multi-storied canopies and species mixes. The point at which these stands achieve full, late-successional, old-growth structure and composition depends on: 1) the amount of "legacy" structure from the previous stand (i.e., the carryover of large living trees, snags, and/or downed wood); and 2) the species mix and growth rates of understory conifer and hardwood regeneration which produces multi-storied canopies. Without major disturbance to initiate shade-intolerant and intermediate species, the ultimate endpoint of this successional model is a steady-state, climax forest comprised only of shade-tolerant species (not Douglas-fir) with consequences on ecosystem structure and function.

The development of understory vegetation parallels that of the overstory. Understory richness (number of species) is high in early stages of forest succession prior

to canopy closure and stem exclusion. At that point in stand development, disturbance-resistant species from the previous and early seral species, including exotics, occupy disturbed sites (Schoonmaker and McKee 1988, Oliver and Larsen 1990, Halpern and Spies 1995). Richness declines as overstory relative density increases and canopy closure reaches maximum, resulting in characteristic dense stands with little-to-no understory vascular plant cover. Richness later returns to high levels in mature and old-growth forests as various disturbances create openings in the canopy allowing stem re-initiation (Alaback and Herman, 1988; Long and Turner, 1975; MacLean and Wein, 1977). This slow rebound in richness may be explained by the increased number and diversity of microhabitats following low-intensity disturbances (Alaback, 1982).

Tappeiner et al. (submitted) question this successional model relative to the historical development of old-growth stands in the Coast Range mountains of western Oregon. The authors present six lines of evidence to establish that such old-growth stands developed at low densities of 50 to 100 trees/ha:

- 1) diameter at age 50, and diameter growth rates between ages 50 and 100, were significantly greater in old-growth stands than nearby young stands with high density (densities common in the current landscape);
- 2) diameter growth rates in old-growth trees were most similar to that of the least dense stands (≤ 100 trees/ha) in long-term level-of-growing-stock experiments (Curtis and Marshall 1986, Marshall 1990);
- 3) projected stand development in ORGANON, a stand simulator developed by Hester et al. (1989), beginning with 45 to 102 trees/ha (very low densities) most closely approximated the conditions measured in old-growth stands, and was substantial different from projections of nearby young stands with higher densities;

4) diameter at age 50 and diameter growth rates of only the largest trees in young, dense stands were significantly less than that of old-growth, suggesting that old-growth stands are not composed of the “survivors” of stem exclusion;

5) younger, smaller trees in old-growth stands grew more rapidly than their counterparts of similar size in young, dense stands, suggesting more space to grow; and

6) relative density in old-growth stands was below 0.55, the density at which self-thinning is likely (Drew and Flewelling 1979). Growth rates and projection data suggest this has always been the case in most old-growth stands sampled.

Regardless of the successional/developmental path taken to old-growth conditions, or the spatial scale (square meters to hectares) at which one looks for evidence of self-thinning, most old-growth trees display evidence of ample growing space (e.g., large upper-crown branches and higher live crown ratios). An appropriate density of large trees is but one characteristic of old-growth stands.

Old-Growth Structure and Composition

This study and all the references in Section I are based on an interim old-growth definition established in the USDA Forest Service General Technical Report PNW-GTR-285, and specifically Franklin and Spies (1991) in that volume. For Douglas-fir forests on ‘western hemlock sites’, the *Tsuga heterophylla* Zone in Franklin and Dyrness (1984), that definition includes:

- ≥ two species with a wide range of ages/sizes, forming a deep, multilayered canopy;
- ≥ 20 Douglas-fir trees/ha > 81 cm in diameter or > 200 years old;
- ≥ 30 trees/ha of associated species (e.g., western hemlock) > 41 cm in diameter;
- ≥ 10 conifer snags/ha > 51 cm in diameter and 4.6 m in height; and
- ≥ 34 metric tons/acre of downed logs, including 10 pieces > 61 cm in diameter and > 15 m in length.

This definition changes slightly as one moves into the drier Mixed Conifer zone (Franklin and Dyrness 1984) of southwestern Oregon, or locally onto drier ridges and Willamette Valley foothills, containing some research sites from this study:

- ≥ two species with a wide range of ages and tree sizes, forming a multilayered canopy;
- ≥ 20 Douglas-fir trees/ha (and/or ponderosa or sugar pine) > 76 cm in diameter or > 200 years old;
- intermediate and small size class of associated species (e.g., incense cedar) singly or in mixture;
- ≥ 3.7 conifer snags/ha > 51 cm in diameter and 4.6 m in height; and
- ≥ 22 metric tons/acre of downed logs, including 5 pieces > 61 cm in diameter and > 15 m in length.

These two definitions reflect differences in inherent productivity, species mixes, fire intensity and return intervals, and other disturbances (e.g., diseases) in the two zones.

Vascular plant species diversity and relative abundance may also be unique in old-growth stands, primarily driven by the understory which contains most species. Spies (1991) and Halpern and Spies (1995) present evidence that diversity remains constant or increases slightly as stands age (after canopy closure and stem exclusion). Spies (1991) found the frequency of occurrence of 15-20% of the understory species increased with stand age class. The author hypothesized four factors which could contribute to these community differences: changes in resource availability (primarily light), changes in horizontal heterogeneity (e.g., gap formation), changes in vertical heterogeneity (specifically, the number of canopy layers), and changes in stand development pathway (primarily the lack of fire). Franklin and Dyrness (1984) and Spies (1991) list the plant species commonly found in late-successional Douglas-fir stands. However, few of these species are present in areas densely shaded by multi-storied canopies of hemlock and/or true fir trees, which become more common as succession proceeds.

Mayrsohn (1995), working with a subsample of the sites from this study, found understory diversity (richness) lowest in the older stands and there was no increase in frequency of occurrence of some understory species. These results agree with those of Schoonmaker and McKee (1988) but differ from those of the larger (but less intensive) studies by Spies (1991) and Halpren and Spies (1995). Mayrsohn (1995) found that the arrangement (or relative mix) of understory species differed between old-growth and younger stands, driven primarily by shrub species composition.

The above definitions and descriptions establish the basic structural/compositional differences between young (dense) stands of Douglas-fir and old-growth Douglas-fir stands: large living trees with large crowns/branches, associated species in multiple size and age classes within and below the main canopy, large standing dead snags, and large downed logs. Stand structure was removed or simplified during their harvesting and burning histories, or was never present due to recurrent fire. Subsequent thinning and other management, at least between 1970 and 1985 when stands in this study were thinned, typically removed additional structure (e.g., snags and downed logs) for fuel reduction, safety reasons, and/or to simplify their management (Franklin et al. 1986). However, thinning and other management activities *can* include objectives to retain or create such structure, and structural diversity, rather than remove it.

Silviculture and Old-growth Development -- Two Case Studies

Silviculture, the manipulation of trees and other vegetation to some desired objective, can be used to immediately create old-growth-type structures (e.g., snags) *and* to push a stand onto a trajectory which achieves old-growth-type structure sooner than would otherwise be expected given the earlier natural succession model (Oliver and Larsen 1990). Indeed, young stands at high densities may be incapable of achieving old-growth-type characteristics in terms of measures like height to the first live branch

without some management. Tappeiner (1992) reviews nine key points to support stand management as key in meeting northern spotted owl habitat needs:

- 1) variable size and intensity disturbances are a natural part of stand development;
- 2) thinning increases growth rates, crown sizes, and diameters of residual trees;
- 3) self-thinning mortality typically produces only small snags and downed logs;
- 4) it may be necessary to kill larger trees in some stands to provide for large snags and downed logs where not provided naturally by weather, disease or insects;
- 5) multi-storied canopies require disturbance to develop, and may need to be assisted with management over time;
- 6) treatments should come early in the stand's life while there are opportunities for crown development and tree stability;
- 7) thinning can help relieve disease and insect pressures on stands;
- 8) thinning can help relieve fuel loading in fire prone areas; and
- 9) shrub control may be necessary to attain adequate regeneration of desired species in the understory.

In addition, Newton and Cole (1987) document two Douglas-fir stands which were selectively harvested (40-50% volume removal) at ages 50 and 70, and treated again through hardwood sprout control at ages 95 and 115 in parts of the stands. At ages 120 and 140, these stands had sufficient numbers of large Douglas-fir (52 and 59 trees/ha > 81 cm diameter, respectively) to meet old-growth criteria for large living trees, and to produce large conifer snags and downed wood (particularly those with damage and defect). The distribution of tree sizes and number of damaged tops approached that of old-growth. Areas in which hardwood species were not killed met criteria for tolerant understory species; areas where they were killed had greater snag densities.

These two case studies demonstrate that density reduction can be a principal silvicultural tool involved in developing old-growth stand characteristics. Thinning can emulate small-scale disturbance (e.g., disease and wind) that Spies and Franklin (1989) established as important in the development of old-growth forests. Small-scale

disturbances enable regeneration of new cohorts of trees in the understory, leading to the development of multi-storied old-growth stands. Thus, density management could be viewed as a way to enhance or mimic natural stand development; silviculturists can reduce young stands density from 750+ trees/ha to establish new understory conifer and hardwood regeneration. Density management (from a plantation stocking perspective) and thinning (as a silvicultural tool) each have rich histories in the forestry literature.

Stand Density and Stocking

There are long-established and well-researched guidelines to relate stand growth and yield to different measures of 'stocking', 'stand density' and crown competition (Bickford et al. 1957, Curtis 1970, Long and Smith 1984). Drew and Flewelling (1979) believe that the first written reference to stand density effects on stand growth come from a Danish forest owner in 1811. The oldest spacing trial for Douglas-fir is thought to have been established in 1925 at Wind River (Smith and Reukema 1986). Reineke (1933) launched the current era of quantitative stand density analysis with his stand density index (SDI), based on the fundamental size density relationship between quadratic mean diameter and absolute number of trees per unit area:

$$\log N = -1.605 \log D + k$$

where N is the number of trees per acre, D is their average diameter, and k is a constant which varies by species. The index is based on a set of reference curves (anchored at DBH = 10 inches) and permits direct comparison of stands across species and varying densities within species. Long (1985) uses SDI for describing a practical management regime; growth models (e.g., Hester et al. 1989) use the concept of stand density index to estimate mortality during stand development.

Bickford et al. (1957), acting for the Society of American Foresters, defined and summarized the concepts/measurements of stocking and stand density, incorporating the European concept of the “normal forest” as the guideline of “full stocking” for maximum stand yield (Assmann 1970). Bickford et al. (1957) introduce evidence that maximum stand production may not occur, however, at full stocking but at some point below full stocking in which early thinnings yields offset reductions in final harvest volume. They recognized that this concept varies by the actual density and major forest types.

More recently, Curtis (1970) reviewed the definition of stocking and density, and the quantitative relationship among many measures of stand density:

actual density in trees per unit land area,

basal area per unit land area,

Reineke's (1933) Stand Density Index (SDI),

Chisman and Schumacher's (1940) tree-area ratio (TAR),

density in relation to average tree height (e.g., Wilson 1946),

density in relation to average tree volume (e.g., Briegleb 1952), and

Krajicek et al.'s (1961) crown competition factor (CCF).

Curtis (1970) concluded that these measures differ primarily in: 1) whether they express density absolutely (requiring knowledge of age and site index), relative to some standard open-growth tree (e.g., CCF in Krajicek et al. 1961), or relative to some standard, uniform, closed-canopy stand; 2) the “details of algebraic form and method of estimation of the constants”; and 3) the logical shortcomings for which some need minor adjustment. The choice of density measure therefore hinges on what data/information are available for a site, computational convenience (not an issue in 1996), and the “ready understanding and visualization” of a user.

Likewise, Larson and Cameron (1986) reviewed four indices for Douglas-fir and concluded that different situations and objectives lead to different choices in indices. No one index adequately addressed differences in stand structure seen following thinning. Other indices in the literature include: Lexen's (1943) Stand Bole-Area Index - a

function of diameter, height and density; Mulloy's (1944) Stand Intensity Index - a function of stand cubic volume and height; Hiley and Lehtpere's (1955) ratio of annual rings/inch to bole area; and Arney's (1973) Competitive Stress Index, a model of competition between neighboring trees. O'Hara (1988) downplays the role of all density indices, preferring to target stand structures and maintain "growing space efficiency", balancing individual tree growth with total stand production. From a stand-level biomass production perspective, growing space efficiency can be reduced to unacceptable levels with heavy thinning by creating under-utilized growing space (O'Hara 1988).

Drew and Flewelling (1977, 1979) improved on Reineke's (1933) and Curtis's (1970) analyses with the concept of relative density: "the ratio of actual stand density to the maximum stand density attainable in a stand with the same mean tree volume". Relative density is revisited by Curtis (1982). The concepts of maximum size-density, zone of imminent competition mortality, and the density management diagram were constructed from field observations of 313 Douglas-fir growth and yield plots. McCarter and Long (1986) used the same procedure to develop a stand density management diagram for lodgepole pine. Long and Smith (1984) explain self-thinning as a function of the redistribution of a finite amount of foliar volume that can be supported in a stand. Their approach is quite quantitative and fits well into that of Drew and Flewelling (1979) and Curtis (1982).

Oliver et al. (1986) discusses three phases during stand development (increasing diameters at a given density of trees) which also incorporates Drew and Flewelling's (1979) work:

1. "open grown": prior to crown closure with $RDI \leq 0.15$; stand volume increases are directly proportional to increases in individual tree volume.
2. "plastic": after crown closure but prior to heavy competitive pressures from neighbors, with $RDI > 0.15$ but ≤ 0.55 ; some crown differentiation; maximum stand volume is reached as early as $RDI = 0.40$ -- beyond that, stand volume is independent of tree

density (Drew and Flewelling 1979). Note: this is a major deviation from Assmann's (1970) "normal" forest theories on the greatest volume growth occurring only at optimal basal area (full stocking or RDI = 0.55).

3. "stagnation-mortality": where tree vigor is hampered by competition (RDI > 0.55); crowns differentiate and individuals suffer suppression-related mortality (insects, disease, and breakage).

Smith and Reukema (1986) also summarize the established role of close spacing (higher relative densities) in driving greater mortality sooner in the life of the stand, limiting diameter growth, reducing tree taper and crown dimensions, and accelerating self-pruning. Relative density (Drew and Flewelling 1979, Curtis 1982) and relative density index (RDI) are used extensively in my analyses based on: 1) parallels to those original papers (appropriateness to my research); 2) theoretical underpinnings of comparing actual density to a standard, dense stand; and 3) my "ready understanding and visualization" (Curtis 1970) of RDI and how it changes during stand development.

In summary, increasing stand density has its greatest effects in reducing average individual tree diameter and diameter growth rates, and much less effect on height growth (density increases height growth relative to open-grown trees, but later reduces height growth due to competition stress at very high densities). Stand cubic volume (biomass) increases with density up to relative densities of approximately 0.40 and then is independent of tree density (i.e., the same volume is arranged on variable numbers of stems). Site quality, tree species, and spatial arrangement (Stiell 1978) all impact tree and stand development, and thus the point at which stand volume is independent of density. These conclusions on the effects of stand density come from both planting trials (spacing trials) and thinning experiments.

Stand Response to Thinning

Thinning has long been an intermediate treatment in Douglas-fir forests, though it has been practiced on much fewer acres than clearcutting (Worthington and Staebler 1961, Scott 1980, Wierman and Knapp 1986). Historically, thinning has been viewed as a method of regulating the growing space to: 1) improve residual tree growth (and value) by redistributing the productive potential of the stand to selected trees; and 2) proactively capture volume associated with self-thinning mortality and thereby utilize all the biomass produced (Hawley 1937, Penistan 1961, Smith 1962). Thus, the emphasis has historically been placed on “low thinning” or “thinning from below” in which suppressed and/or intermediate (overtopped) individuals are removed. Smith (1962) stated that the bottomline objective of thinning is “to keep the most promising trees growing steadily by removing less desirable, neighboring trees before their competition become injurious.” Promising trees were in dominant or codominant canopy positions with good crowns, little damage, and a healthy appearance. It seems that until 1985 (through the time period of this study), this type of crop tree objective was the overriding consideration in thinning.

Overstory Canopy

Table 1.1 summarizes much of the peer-reviewed evidence of thinning responses across different forest types, summarized by Smith (1962) and Barrett (1980) among others. The intensity of thinning response varies whether one examines all trees that comprise a stand or only selected trees from each stand (e.g., largest 100 trees/ha). Regardless, common thinning responses include:

- 1) increased tree diameter (and diameter growth rates), merchantable volume accumulation and economic value production, via selection for desired tree sizes, species and form classes (NOTE: total cubic volume production may or may not increase depending on the number and characteristics of residual trees);

Table 1.1. Common thinning responses (as discussed in text) by forest types, with emphasis on the Douglas-fir forest type.

FOREST TYPE	TREE DIAMETER GROWTH, and VOLUME/VALUE ACCUMULATION	TREE VIGOR and MORTALITY	TREE CROWN DEVELOPMENT
Douglas-fir	Briegleb 1952 Warrack 1952 Worthington and Isaac 1952 Eversole 1955 Heiberg and Haddock 1955 Steele 1955 Staebler 1960 Worthington 1961 anonymous 1972 Reukema 1972 Berg 1978 Reukema 1979 Williamson 1982 Harrington and Reukema 1983 King 1986 Omule 1988 O'Hara 1988 Gardner 1990 Marshall 1990 Curtis 1992 Marshall <i>et al.</i> 1992	Warrack 1952 Worthington and Isaac 1952 Eversole 1955 Steele 1955 Worthington 1961 Williamson and Price 1971 Reukema 1972 Berg 1978 Reukema 1979 Williamson 1982 King 1986 Gardner 1990 Marshall 1990 Marshall <i>et al.</i> 1992	Worthington 1961 Eversole 1955 Brix 1983 O'Hara 1988 Gardner 1990 Marshall 1990 MacGuire <i>et al.</i> 1991 Curtis 1992 Marshall <i>et al.</i> 1992
true firs	Oliver and Kenady 1982 Oliver 1988	Oliver 1988	
western pines	Stuart and Roeser 1944 Baker 1953 Myers 1958 Stage 1958 Alexander 1960 Barrett 1961 Agee and Biswell 1970 Barrett 1970 Barrett 1982 Cochran and Barrett 1993	Myers 1958 Alexander 1960 Barrett 1961 Agee and Biswell 1970 Barrett 1970 Cochran and Barrett 1993	Barrett 1970
jack, red and white pine	Adams and Chapman 1942 Luther and Cook 1948 Roe and Stoeckeler 1950 Wilson 1951 Wahlenberg 1955 Wilson 1955 Dosen <i>et al.</i> 1957 Spurr <i>et al.</i> 1957	Roe and Stoeckeler 1950 Schantz-Hansen 1952 Schenk <i>et al.</i> 1957 Spurr <i>et al.</i> 1957	Adams and Chapman 1942 Wilson 1951 Dosen <i>et al.</i> 1957 Spurr <i>et al.</i> 1957
southern pines	Stahelin 1949 Bull 1950 Mann 1952 Chapman 1953 Gruschov and Evans 1959 Zahner and Whitmore 1960		Averell 1945 Chapman 1953 Gruschov and Evans 1959 Zahner and Whitmore 1960
northern hardwoods	Hough and Taylor 1946 Zehngraff 1949 Zasada 1952 Wahlenberg 1952 Conover and Ralston 1959	Hough and Taylor 1946 Conover and Ralston 1959	Conover and Ralston 1959

- 2) reduced mortality (after any initial damage/sunscald mortality) via improved residual tree vigor and, in many cases, associated reduction in insect/disease activity; and
- 3) stimulation of branch size and live crown development (not frequently reported but likely present in most or all cases).

As an additional consequence of thinning, fuels are reduced and undesirable species or genotypes are reduced or removed from the stand (Worthington and Staebler 1961, Smith 1962). Staebler (1956), among others, document "thinning shock", reduced height growth within a year of heavy thinnings, though Harrington and Reukema (1983) report that the effects of the thinning shock in Staebler's plots were negligible after 10 years.

To a far lesser extent, thinning has been shown to have the following effects on the understory (see discussion below):

- 4) rapid expansion of root systems (Zahner and Whitmore 1960); and
- 5) growth stimulation of one or more ages/classes of conifers and hardwood trees below the main canopy (Oliver and Murray 1983, Oliver et al. 1986, Harrington and Wierman 1990, Marshall 1990);
- 6) establishment of new cohorts of coniferous and hardwood tree regeneration which can grow into the main canopy under the right conditions (Zasada 1952, Barrett 1961, Del Rio and Berg 1979, Barrett 1982, Alaback and Herman 1988, Fried et al. 1988, Tappeiner and Zasada 1993);
- 7) stimulation of desirable and undesirable subordinate vegetation (Barrett 1961, Long and Turner 1975, Tappeiner et al. 1991, Tappeiner and Zasada 1993, Huffman et al. 1994, O'Dea et al. 1995);

It should be noted that Smith (1962) felt that simultaneous pursuit of volume/crop tree objectives (#1-3) and understory/regeneration objectives (#4-7) resulted in an "incomplete compromise". However, judging from the rest of the literature (e.g., Drew and Flewelling 1979), there are situations dictated by initial density, time of harvest, and harvest intensity that may adequately balance both objectives. In other words, there is a range of relative density within which stand volume production is unaffected by tree

density *and* understory growth can be stimulated in the near term. However, heavy understory vegetation measurably reduces growth performance of overstory trees (Barrett 1970). Operating at some balance point between over- and understory growth commits a manager to multiple re-entries to maintain an optimal range of densities.

Understory Vegetation

While objectives for maintaining optimal growth of overstory trees dictates lighter thinnings (i.e., reductions in RDI to 0.40 at most), understory vegetation likely benefits from heavier thinnings (i.e., operations which make more resources available to the understory). In addition to changes in light quantity and quality, thinnings modify water availability and surface temperatures proportional to the intensity of the thinning (e.g., Del Rio and Berg 1979). Wiltner (1975) specifically found that light penetration to the forest floor was negatively correlated with the log of residual overstory Douglas-fir basal area. These microclimate changes have direct and indirect effects on vegetation (Zobel et al. 1976).

A major contribution of thinning to the development of old-growth structure is the freeing of light and other resources for initiating and maintaining intermediate and understory trees which are otherwise suppressed by the overstory (Alaback and Herman 1988, Harrington and Wierman 1990, Marshall et al. 1992). All authors found broad evidence of increased survival, and limited evidence of released growth of intermediate structure following thinning. Del Rio and Berg (1979) found regeneration height growth to be positively correlated with light penetration through the canopy. Maintenance of an elevated light environment is particularly important for the less shade-tolerant species like Douglas-fir and red alder. Such species may germinate under reduced light conditions, but their growth and survival is low under the canopy of older trees (Herman and Lavender 1990).

Tree species, particularly small regeneration, must compete with other vegetation that also responds to new resource availability; shrub and herbaceous species can create dense patches which exclude tree seedlings especially on productive sites. Witler (1975) found immediate understory responses to thinning in Douglas-fir stands, and the increase in shrub and herbaceous cover and frequency were negatively related to overstory basal area. These increases consisted primarily of herbaceous species as opposed to woody species. Mayrsohn (1995), in a subsample of sites from this study, found that woody shrub species expand most aggressively following thinning. Alaback and Herman (1988) studied the response of understory vegetation to thinning in two coastal Oregon forest types (western hemlock/Douglas-fir and Sitka spruce type). They saw no immediate (≤ 6 month) difference in shrub, herb or moss composition or abundance between thinned and unthinned stands. However, differences in understory composition and cover were present 17 years after thinning in the Sitka spruce type. Total cover of shrubs and herbs decreased by age 30 in the hemlock type due to the abundance of regeneration. Variability in that cover increased with the amount of volume removed during thinning in both types (Alaback and Herman 1988). The inconsistency in these Douglas-fir/Oregon studies demonstrate the complexity of vegetation responses across different sites and under different conditions at different times. Barrett (1961, 1970), Agee and Biswell (1970) and McConnell and Smith (1970) reported grass, sedge, snowbush, manzanita and bitterbrush cover increases due to thinning in the drier ponderosa pine forest types.

Grime (1979) provides some basic rules governing vegetation response to disturbance. Thinning, like any disturbance, must favor the combination of two plant establishment and regeneration strategies:

- 1) tolerance of low intensity disturbance associated with harvest operations and changes in environment brought by thinning (brighter, drier, and warmer); and
- 2) rapid expansion into newly available resources via seedling or vegetative propagation.

Grasses and sedges (Barrett 1961, 1970), bracken fern (Witler 1975), salal (Huffman et al. 1994), vine maple (O'Dea et al 1995), and salmonberry (Tapeiner and Zasada 1993) each combine the tolerance/rapid expansion strategies and are known to increase in cover and frequency in thinned stands. Indeed, expansion of rhizomatous species may be particularly encouraged by thinning. Salal rhizomes expanded 23.7% annually in thinned stands, and 0% in unthinned stands (Huffman et al., 1994). Rhizome biomass, length and density, aerial stem biomass and density, and total biomass were all negatively correlated with overstory density in that study. Salal reduces water availability for overstory Douglas-fir and reduces its photosynthesis and growth (Price et al. 1986) and must be accounted for when projecting thinning responses (Sachs and Trofymow 1991).

Other strategies and adaptations may fit the combined tolerance/rapid expansion profile favored by low-intensity disturbances like self-thinning or mechanical thinning. Givinish (1987) viewed three 'economies' which define plant competitive interactions and adaptations: gas exchange, mechanical support, and biotic interactions. Groups of species which share certain adaptive traits may be predisposed to success or failure following thinning. For example, nitrogen-fixing species (biotic interaction) as a group are particularly well-adapted for heavily disturbed areas where the lack of available nitrogen from organic matter may preclude other species (e.g., skid trails). Conveniently, these species require additional light resources to exploit their nitrogen fixing abilities. Forest exotics, those introduced this century, also typically share the tolerance-rapid expansion characteristics: 1) long-range dispersal into a forest environment, often aided by disturbance; and 2) survival and reproduction in the new environment. Finally, vine genera (e.g., *Galium* and *Rubus*) are capable of rapid expansion and tolerance of warmer/drier conditions. Just as some strategies are positively associated with thinning, low-disturbance shade-tolerant plants, or plants with little mechanical support, may be selected against by thinning.

As in natural succession, however, understory species composition appears to be ultimately unaltered by management (Dyrness 1973, Schoonmaker and McKee 1988,

Halpren and Spies 1995). In thinned stands, specifically, the duration of the shrub stage following thinning was prolonged while the period of relatively low understory cover (stem exclusion) was reduced (Alaback 1984). Indeed, the mechanical damage introduced by thinning may actually be less disruptive to understory species than the exclusion of light resources for extended periods. The literature did not contain any references to long-term shifts in vegetation communities from light or heavy overstory canopy removal.

The dynamics between understory tree regeneration and shrub and herbaceous species bears immediately on issues of plant species composition, richness and diversity in young vs. old-growth Douglas-fir forests, and issues of wildlife habitat availability. More importantly, however, it impacts development of future stand structure. The presence of advanced reproduction of Douglas-fir or (typically) shade-tolerant species and/or the ability of these species to regenerate following thinning depends on, among other things, the density of shrub and herbaceous material on the site and how it responds to harvest. Rapidly spreading shrubs (e.g., salal) may preclude regeneration in many areas. Their presence and density/frequency in a stand prior to thinning may provide insight into the density of regeneration that can be anticipated.

Research Rationale

All research and analyses indicate that density reduction (thinning) will be an important tool in managing dense young stands to create or enhance diverse structures typical of older forests: larger trees growing faster, reduced mortality in small diameter classes, larger crowns on residual trees, and better opportunities for intermediate and understory growth below the main canopy. The BLM districts and the Oregon Department of Forestry in western Oregon have had thinning programs in Douglas-fir and Douglas-fir/western hemlock forests for several decades. This research was formulated to address five objectives, to:

- determine how past commercial thinning has affected natural regeneration and growth of understory conifer and hardwood trees.
- determine how the presence and abundance of shrub and herbaceous species are influenced by variation in overstory density caused by commercial thinning (or other methods of overstory management) and natural disturbance like windthrow.
- describe the structure (i.e., the vertical and horizontal arrangement of shrubs, herbs, conifers, and woody debris) in thinned and unthinned stands.
- compare plant species composition and assess plant biodiversity "richness" and structure in thinned, unthinned, and old unmanaged stands.
- develop procedures that managers can use to monitor or evaluate effects of stand management on vegetation.

While the stands available for evaluation were thinned with the goals of even-aged management and timber production, there was sufficient variation in canopy density and understory development within and among stands to provide information for developing a variety of stand management systems to produce and maintain multi-storied stands.

Chapter 2

**Effects of thinning on structural development in 40- to 100-year-old
Douglas-fir stands in western Oregon**

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intended for: *Forest Ecology and Management*

Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon

Introduction

Forest management is changing on public lands in western Oregon due to public concerns for maintaining diverse populations of forest plants and animals which inhabit old-growth forests, including rare and endangered species. Silvicultural systems are evolving to integrate our society's need for wood, economic stability of local communities, and maintenance of old-growth forest habitats. In particular, the Record of Decision (1994) for federal forest management calls for the creation and maintenance of stands with old-growth-like characteristics in Late-Successional Reserves and Riparian Reserves. Other public forest managers will likely face similar management challenges, and private managers may apply such silvicultural systems to valuable habitat areas within their holdings.

Historical forest management practices in much of western Oregon have involved clearcutting and planting with Douglas-fir nursery stock, followed by control of shrubs and hardwood to ensure adequate stocking. These practices have resulted in thousands of acres of productive young stands of more than 750 Douglas-fir trees/ha. These stands were planned to be managed for timber production on rotations of 40-80 years. This type of management applied over broad landscapes will not likely provide habitat for Northern Spotted Owls and other species which prefer diverse, multi-storied stands (Lujan et al. 1992). However, managers can likely enhance owl habitat by: 1) preserving small groves of older trees and snags scattered in a landscape; 2) implementing much longer rotations with little change in management practices; and/or 3) specifically pursuing the creation of owl habitat within stands managed on shorter rotations. In reference to the latter, Tappeiner (1992) outlined silvicultural systems designed to produce multi-storied stand structures typically associated with old-growth (Franklin and Spies 1991).

Thinning, the reduction of overstory tree density, can be a principal silvicultural practice to accelerate the formation of old-growth characteristics in younger stands. Thinning young Douglas-fir stands produces larger overstory trees (Curtis and Marshall 1986, King 1986; Marshall et al. 1992), stimulates the vigor and growth rate of residual overstory trees provided that sufficient crowns remain (Wierman and Knapp 1986), encourages the growth of one or more ages/classes of conifers and hardwoods below the main canopy (Newton and Cole 1987), and favors the establishment of new cohorts of conifers and hardwoods in the understory which can grow into the main canopy (Harrington and Wierman 1990, Marshall et al. 1992,). Thinning responses are thus similar in some ways to natural disturbance processes described by Spies and Franklin (1991) involved in the development of old-growth forests. Their work shows that small-scale disturbances (e.g., wind) enable regeneration of new cohorts of trees in the understory, thus leading to the development of multi-storied stands with increasing densities of shade-tolerant species.

Differences in early stand density and resultant growth rates between young and old-growth Douglas-fir stands may preclude the culturing of some characteristics (e.g., large, low branches). Tappeiner et al. (submitted) summarizes the differences in tree density and growth rates between young and old-growth stands in coastal Oregon, concluding that old-growth stands typically developed at extremely low densities which allowed development of complex stand structure. Spies and Franklin (1991) reported that old-growth forests in western Oregon typically had 16 to 23 large (>100 cm) trees/ha, with approximately 400 to 500 trees/ha of various sizes and ages growing among and beneath them. Our old-growth stand inventories showed 20 to 40 large (>90 cm) trees/ha with 300 to 650 trees/ha beneath them (95% confidence limits). Thinning lowers stands to densities more similar to their historic norms (for old-growth), and thereby mimic natural stand development. However, thinning may concurrently create species covers or mixes not typically associated with old-growth stands.

Thinning has been a common practice in Douglas-fir forest management (King 1986, Tappeiner 1992). There are well-researched guidelines to relate stand growth and yield to different measures of stocking or stand density (Reneike 1933, Drew and Flewelling 1979, Curtis and Marshall 1986) and growth models exist to estimate stand development after thinning (Curtis et al. 1981, Hester et al. 1989). In addition, there are examples of older managed stands (approximately 80 to 100+ years old) which are developing characteristics commonly associated with old-growth forests following density reduction (Newton and Cole, 1987). Broader examples of the effects of operational thinning in younger stands would help develop prescriptions for their continued management for both habitat and wood. A concurrent evaluation of older stands provides a view of potential structural and compositional goals for such management.

Federal managers in western Oregon have had thinning programs in Douglas-fir and Douglas-fir/western hemlock forests for several decades. Thirty-two stands selected from these programs were evaluated to determine how thinned stands differ from adjacent unthinned control stands and nearby old-growth forests. We further evaluated how variation in overstory canopy density and time since thinning affects overstory maturation, the release of intermediate and suppressed trees, and the establishment and growth of seedlings/saplings, hardwood sprouts, shrubs and herbaceous species in the understory. We pose the following questions: has thinning stimulated the establishment and growth of natural regeneration which would lead to the development of multistory stands, or does shrub growth preclude such regeneration? Can one establish a shade intolerant species like Douglas-fir in the presence of a residual overstory, and under what canopy densities?

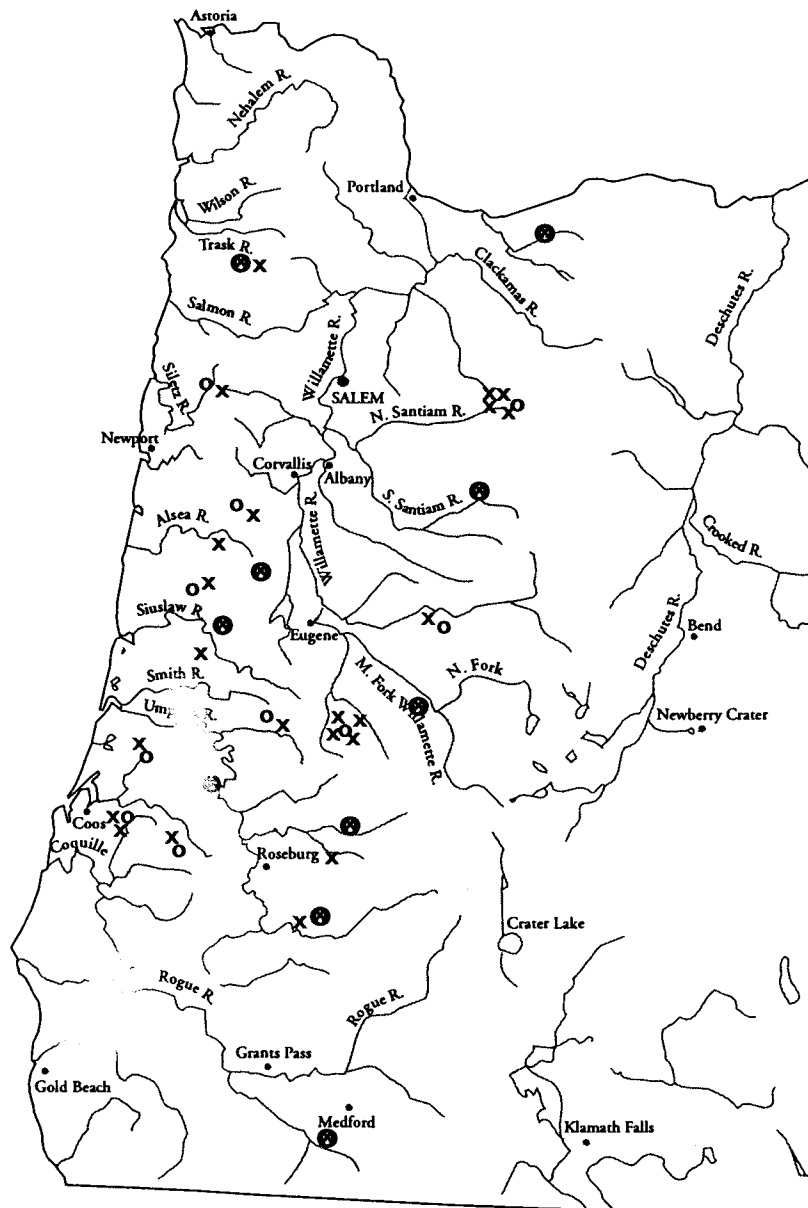
This study quantified the effects of commercial thinning across a wide range of sites and management histories to provide forest managers with information about thinning as tool for wildlife habitat creation and management. Most stands were thinned with the goals of even-aged management for timber production, but the intensities and

equipment varied among sites. Research sites also span regional differences in climate, soil, seed source availability, history, inherent site productivity, original tree composition and density. This variability provides for analyzing stand responses across a spectrum of conditions. Thus, we evaluate large-scale operational practices over a relatively large geographic area and relatively long time periods since thinning. Differences in stand structure seen consistently across such a study would suggest predictable responses to operational thinning in young stands.

Methods

Study area

This study was conducted in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests of the western Oregon Coast and Cascade Ranges managed by the Bureau of Land Management (BLM) and Oregon Department of Forestry (ODF). Using BLM and ODF inventory data, we located and sampled stand pairs during 1993-5 that met the following criteria: 1) stand ages were ≥ 50 years; 2) operational thinnings were conducted between 1971 and 1985 in part of the original stands, generating paired thinned and unthinned control stands; 3) records were available to document the time and intensity of thinning from pre-harvest, removed and/or residual stocking or volume data; 4) unthinned control stands were otherwise similar to thinned stands (e.g., slope and aspect); 5) no additional treatments (e.g., fertilization) were recorded in either the thinned or unthinned stands; 6) pairs were located near one of 20 old-growth stands (200+ years) exhibiting multi-storied stand structure, meaning some pairs share older stands for comparison; and 7) all three stand types contained greater than 25 acres of interior environment. The resulting 20 "triads" (all three stand types: T/U/OG) and 32 pairs of young stands (12 pairs without old-growth comparison) span much of western Oregon in both the Cascades and Coast Range mountains (Figure 2.1) and include a broad range of productivity (King's 1966) and stand ages (Table 2.1). Thinnings ranged from light to extremely heavy (8 to 60 % merchantable volume removal, respectively).



Legend

- x thinned/unthinned pair
- o old-growth
- ⊙ complete triad

Figure 2.1. Study site locations in western Oregon.

Table 2.1. Comparison of current tree density and basal area for trees >20.3 cm for all 32 young stand pairs, with 20 old-growth comparisons, arranged in order of 10-yr age class then descending years since thinning in the thinned stand. Note: "Beaver Flat" is one of 20 triads and one of 32 pairs; "Blue Ridge 35" is only a pair.

SITE	Age	Years since thinning	% of volume removed	SI ₅₀ ¹	Unthinned stands		Thinned stands		Old-growth stands	
					trees/ha	m ² /ha	trees/ha	m ² /ha	trees/ha	m ² /ha
Beaver Flat	50	19	51	130	323	51	151	32	47	61
Blue Ridge 26	50	18	10	127	447	63	230	58	62	60
Blue Ridge 35	50	12	28	127	447	63	163	35		
N. Ward Creek	50	10	50	130	237	43	153	27	54	54
Keel Flat	60	23	25	141	289	50	148	38	42	49
D-Line Road	60	23	12	121	388	48	183	41	77	54
Little Wolf Cr.	60	14	55	102	291	31	143	22	52	42
Perkins Cr. #1	60	12	36	134	259	37	195	26	106	67
Perkins Cr. #2	60	12	30	115	360	41	225	30		
Gnome	60	10	43	120	494	48	146	20	64	57
Gordon Creek	60	10	60	118	291	47	121	28	84	67
Wildwood Falls	65	12	22	121	541	60	252	36		
Sand Creek	70	22	32	128	415	62	289	55	54	65
Bald Mtn.	70	17	33	120	249	54	146	46		
Clay Creek	70	13	48	119	252	53	180	36		
Marten Ridge	70	12	50	127	272	65	59	25	69	62
Burnt Creek	80	19	33	117	153	47	77	31	62	78
Windy Ridge	80	17	40	115	388	55	175	32	69	69
Big River	80	16	15	130	259	59	175	51		
Highpass Rd.	90	22	20	114	160	45	133	45	49	48
Eagle's Rest	90	19	50	90	146	42	77	24	96	74
Days Creek	90	17	40	117	242	54	69	28		
Bummer Ridge	95	17	25	98	178	60	111	42		
Honey Creek	100	23	21	98	198	43	128	28	54	47
Bear Creek	100	21	27	134	133	46	128	47	81	80
Elliott St. For.	100	21	54	131	230	70	121	36	104	80
Horse Creek	110	22	20	82	188	53	153	44		
Rooster Rock	110	22	22	114	183	64	163	58	69	75
Little River	110	16	30	96	272	59	109	31		
Meyer Creek	120	23	23	106	269	69	126	47		
Fawn Creek	120	21	8	110	111	54	84	56		
Panther Gap	120	13	20	78	156	27	99	25	89	40

¹ King's site index, based age 50 (King 1966)

Most young stands regenerated naturally following cutting, ground skidding, and burning in the late-1800s and early-1900s. They were dominated by one age cohort in the overstory with few, if any, large trees or snags remaining from a previous stand. Old-growth stands showed little to no evidence of disturbance (e.g., old stumps and roads). Elevations ranged from 250 to 800 meters, where precipitation is primarily in the form of rain (100 to 300 cm). Temperatures tend to be mild with January lows of -2° to 0°C and July highs of 20° to 30°C (U.S. Weather Service). Most sites were in the Western Hemlock Zone (Franklin and Dyrness, 1984) where hemlock (*Tsuga heterophylla*) is considered climax. Douglas-fir may be climax, however, on drier sites in the southern Cascade Range and eastern edge of the Coast Range. Several of the southern sites were in, or near the transition into, the Douglas-Fir Zone (Franklin and Dyrness, 1984).

Data collection

We inventoried stands from mid-June to September in 1993-1995. Ten to 24 years since thinning was deemed sufficient time for changes in overstory and understory vegetation to develop. Pairs and triads were inventoried within days of one another to minimize the likelihood of observing differences due to time of year. We established six to twelve (typically ten) points on a systematic grid at 50-75 meter intervals in an interior area of each stand, 75 meters from any stand edge. To ensure an unbiased sample, the first point was established from a pre-assigned stand entry location, direction and distance, considering only the stand boundaries as viewed from an aerial photograph.

Living dominant and co-dominant overstory trees > 20.3 cm (8 inches) were tallied using variable-radius (prism) points within a modified ORGANON sampling template (Hester et al. 1989). Tree species, DBH, height, height to live crown, crown radius, and damage code were recorded for each tree directly into electronic spreadsheets. We measured both five-year radial growth and incremental growth since the year of thinning for up to three trees per point by coring a range of tree sizes. Number of hard (recent) and soft snags (well-decayed legacies of the previous stand) which fell within the

point sample were also tallied. Breast height age was determined on a sufficient number of dominant and codominant trees to determine site index (King 1966). We recorded the same tree information for living intermediate and suppressed trees (2.54 to 20.3 cm DBH) sampled on five 4.75m-radius (15.56 ft) circular plots, one at the point center and four 15 m distant in each cardinal direction. Radial basal growth rates were measured on up to three of these smaller trees per point by taking a crosscut disc above any butt swell. Standing dead trees were summed for the entire point. Tree seedlings and saplings were tallied (<2.54cm DBH, >15cm in height) on five 2.37m-radius (7.78 ft) subplots centered at the same locations as intermediate tree data. We recorded seedling number and height by species for all species. Total age and 5-year height growth (vigor) were determined by whorl counts on Douglas-fir and true firs (fixed-growth species); a subset of seedlings of other species were aged by crosscut discs taken from the largest individual of that species. Height growth is presented in detail only for a triad and neighboring pair in southwestern Oregon where sufficient numbers of Douglas-fir seedlings were present.

Understory shrubs were measured on each 2.37m-radius subplot, segregated into two layers: "low shrubs" - typically 50 to 150 cm in height; and "tall shrubs" - typically greater than 1.5 meters. Although shrubs are defined by most authorities as having woody stems, sword fern (*Polystichum munitum*) and bracken fern (*Pteridium aquifolium*) were included in the low shrub layer given their apparent functional influence. Percent cover of Oregon grape (*Berberis nervosa*), salal (*Gaultheria shalon*), sword fern, bracken fern and other observed species were recorded by visual estimate in 5% classes. Trace cover was recorded as 1%. Low shrub cover could total one hundred percent, but typically included some empty space (i.e., bare ground). The number of stems of tall shrubs (e.g., vine maple, *Acer circinatum*), with their average height and crown radius to the nearest 15 cm, were recorded by species on each subplot.

Diameter and decay class (scale 1-5, from Spies and Cline 1988) were recorded for all downed woody debris >2.5 cm in diameter along a 15 m (50 ft) transect at each point and summed to calculate a stand average volume (Van Wagner 1968). Leaf Area

Index (LAI), which includes living and dead shade, was measured for the overstory canopy, tall shrubs, and low shrub layers at each point with a LICOR 2000 canopy area meter (LICOR Inc, Lincoln NE). We recorded slope, aspect, and the presence of major topographic or management features (e.g., roads) for later interpretation.

Data analysis

Statistical comparisons of means between paired stands in observational studies assume that the stands were initially identical and that the observed differences are due to some treatment effect (Cochran, 1983). Detailed pre-treatment data from stands to establish their similarity was not available, though the broad classification of habitat type and the aerial-photo-based overstory classification were once identical for every pair. Every effort was made to ensure compliance with this fundamental assumption of observational studies. Our strongest statistical comparisons were therefore made between individual pairs of thinned and unthinned stands (i.e., t-tests) using points as the experimental unit. Three-way ANOVA comparisons among thinned, unthinned and old-growth stand types are also presented even though they violate the shared-past assumption described in Cochran (1983). This violation is considered minor, however, since the study question shifts away from one of treatment effect to a simple question of how those stands may differ.

Variables analyzed include all overstory and intermediate tree data (e.g., densities, diameters, crown ratios/radii, and radial/basal area growth rates), LAI data, seedling and sprout data (densities and frequencies), and shrub data (densities/cover and frequency). Thirty-two independent pair-wise comparisons and 20 independent three-way ANOVAs were performed for each variable at each site using points (within stands) as the experimental unit (Snedecor and Cochran 1980). For many variables (e.g., shrub cover), data was averaged from a collection of equally-weighted subsamples. We tallied the number of pairs or triads (of 32 and 20, respectively) that show significant stand-type

differences at $p < 0.15$, considered meaningful for biological data. An exception is radial growth after thinning which was not measured during the first year and, thus, limited to 13 pairs. Remnant trees (large diameter individuals from the previous stand) were excluded from diameter averages because of their undue influence on that statistic. Seedling density and frequency was plotted on a stand density index chart (Reineke 1933) for interpretation, using reconstructed tree density and diameter (in the year immediately following harvesting in the thinned stand).

Density (count) data for seedlings and tall shrubs, cover of less-common low shrubs, tall and low shrub LAI, and intermediate tree data on most sites were typically non-normally distributed within and across stands (i.e., they were skewed by the predominance of zeros or low values). These data also typically showed markedly different variances among stand types as well. We therefore used Wilcoxon rank-sums comparisons classified by pair or triad with a Kruskal-Wallis Chi-square approximation test for significance (SAS Institute, Inc.). Blocking by triad was used for all three-way comparisons. We present p-values for stand type effect only; we found only a few cases in hundreds of comparisons where blocking by triad was not significant at $p \leq 0.10$.

Differences among the stand types that were consistent across many pairs and triads were detectable with comparisons of stand averages across stand types. Pairwise t-test comparisons of stand averages across 32 paired stands, and ANOVA comparisons with blocking across 20 triads, were used for normally-distributed data with equal variances (e.g., canopy and total LAI, DBHs, and intermediate tree height). As with point data, count and cover data were often non-normal and required Wilcoxon rank-sums comparisons classified by pair or triad with a Kruskal-Wallis Chi-square approximation test for significance (SAS Institute, Inc.). P-values for such comparisons are presented. Stand averages were also regressed against independent variables: stand age, site index, thinning intensity and years since thinning. We used stepwise multiple-regression to assess the strongest independent variables (SAS Institute, Inc.)

Old-growth stands varied greatly from triad to triad, and we were not confident in our ability to characterize old-growth stands with ≤ 10 points. Therefore, we also present a standard old-growth data range for board-foot volume based on observed stand-level averages of the median 10 old-growth stands. Current stand means and projections may be compared to this constructed standard rather than one specific set of old-growth points.

Tree data (≥ 2.5 cm DBH) were summarized using ORGANON (Hester et al. 1989), an empirical tree growth model for Douglas-fir stands, to yield stand-level average density, basal area, cubic foot volume, stand and relative density indices (Curtis 1971), average canopy closure, average crown ratio, and diameter distribution by species. Input data included tree species, diameter, height, LCR and 5-year radial growth for a subset of trees from each point representing all diameter classes. For calculations of cubic foot volume, we assumed a zero stump height and used a tree's total height. ORGANON summarizes data using all points from a stand to produce single stand-level estimates. Differences among stands were therefore absolute between pairs and stand types within triads (there is no variance estimate for testing statistical significance).

ORGANON was also used to project thinned and unthinned stand volume growth (potential productivity) and tree density to age 130, the upper age limit of the model. We compared the influence of site index and stand age at thinning on this volume growth over time using grouped data from multiple sites with similar ages and site indices. Each group contains a range of thinning intensities within groups; time since thinning was insignificant in this long-term view of stand development. As tree and stand development are projected within ORGANON, in-growth is not automatically inserted to maintain a cohort of small-diameter trees, even in lower density stands. Our projections were therefore enhanced by electronically planting seedlings proportional to stand-average seedling density data. Ten percent of seedlings for every species were assumed to in-grow after 10 years based on their current diameters, heights and growth rates. Additional seedlings were inserted for two additional 10-year cycles thereafter if age 130 was not exceeded. Such model entries had little effect on volume estimates, but provided

what we believe to be more realistic tree densities and diameter distributions over time. Most heights and crown ratios were measured but occasional missing values were replaced by ORGANON for projections using species-specific correlations from within the same stand.

Results and Discussion

Tree density (stocking) and basal area were consistently less in thinned stands than unthinned stands across 32 pairs due directly to harvesting (Table 2.1). Overstory trees/ha were lower in the thinned stands of all 32 pairs; relative density index (RDI) and basal area per hectare were lower in 31 of 32 and 28 or 32 pairs, respectively, using $p \leq 0.15$ as a significance threshold. The magnitude of difference was greatest in younger pairs (≤ 70 yrs) in which thinned stands had the greatest percent volume removed and least time since that removal (e.g., Little Wolf Creek, see Table 2.1). Small differences and the three exceptions noted above were associated with older stands having older and/or lighter thinnings. Two interacting factors could have led to this phenomenon: 1) trees lost from natural mortality in older (≥ 100 years) unthinned stands may have exceeded tree removal in lighter thinnings; and 2) increased radial growth in residual overstory trees and stimulation of intermediate trees may have increased stem diameters. Regardless, all pairs share some of the basic differences between thinned and unthinned stands addressed below.

The greatest differences in canopy leaf area index (LAI) were between thinned and unthinned stands in young stands where self-thinning had not yet occurred in the unthinned stands and thinnings were often most intense. Thinned stands had less canopy LAI on 19 of 23 sites < 100 years old; LAI was significantly lower in thinned stands across these 23 young pairs ($p \leq 0.0001$) and across all 32 pairs ($p = 0.0006$). Six of the nine pairs ≥ 100 years old had more canopy LAI in thinned stands. This likely resulted from: 1) self-thinning in older unthinned stands; 2) fuller overstory crowns and surviving

intermediate trees (described below) in thinned stands; and 3) more time since thinning in many of the older pairs. Within the age range of these stands, canopy LAI in unthinned stands is most dependent of site productivity ($r^2 = 0.31$) and years since thinning ($r^2 = 0.27$) in thinned stands. Crown closure was greater in unthinned stands (ranged from 64 to 100%) than in thinned stands (25 to 100%) across all 32 pairs ($p \leq 0.0001$).

Overstory trees

Dominant and co-dominant trees (all species) in thinned stands averaged at least 3 cm larger diameter on 25 of 32 pairs, significantly larger across all 32 sites ($p \leq 0.0001$). This difference resulted from the mathematical elimination of smaller diameter trees and stimulation of radial growth in thinned stands, particularly in residual Douglas-fir. Five of the seven exceptional pairs were those ≥ 100 years of age (e.g., Bear Creek, see Table 2.1), in which differences in density and basal area were marginal or insignificant. Large remnant Douglas-fir trees were more frequent in unthinned stands than thinned stands ($p = 0.0089$), averaging 11 and 7 trees/ha respectively, but were excluded from these diameter comparisons. Western hemlock and hardwood species trees, present in the overstory of more than half of all pairs, did not have different diameters on average in thinned and unthinned stand ($p = 0.26$ and 0.55 , respectively).

Thinned stands had greater 5-year radial growth rates than unthinned stands considering all species (but dominated by Douglas-fir) in 17 of 32 pairs (Table 2.2); radial growth was significantly greater in thinned stands across all 32 pairs at $p \leq 0.0001$. Across all thinned stands, 5-year radial growth rate was positively correlated with percent volume removed during thinning ($r = 0.45$) and negatively correlated with RDI across all stands, ($r = -0.61$; Figure 2.2). The scatter of points shows the complexity brought to the analysis by differences in thinning intensity (the dominant independent variable for

Table 2.2 Comparison of overstory tree characteristic within and across pairs and triads. P-values are tallied at the bottom, followed by averages and standard deviations for each stand types, with associated p-values for testing differences across all pairs and triads. ¹ denotes five stands with the greatest radial growth rates, delineated in Figure 2.2.

SITE	Live Crown Ratio					Crown Radius					Canopy L.A.I.					5yr Radial Growth		
	thinned	unth.	p-value	OG	diff.	thinned	unth.	p-value	OG	diff.	thinned	unth.	p-value	OG	diff.	thinned	unth.	p-value
Beaver Flat ¹	0.47	0.32	0.00	0.56	O>T>U	15	11	0.03	18	O>T>U	5.0	5.8	0.02	4.6	U>T,O	0.87	0.51	0.00
Blue Ridge 26	0.47	0.35	0.01	0.56	O>T,U	13	11	0.04	17	O>T>U	5.7	7.5	0.00	6.5	U,O>T	0.38	0.29	0.38
Blue Ridge 35	0.38	0.35	0.14			13	11	0.00			4.9	7.5	0.00			0.48	0.29	0.00
N. Ward Creek ¹	0.43	0.28	0.00	0.57	O>T>U	16	14	0.10	17	O>T>U	3.3	4.7	0.00	4.6	U,O>T	0.59	0.42	0.03
Keel Flat	0.52	0.41	0.00	0.58	O,T>U	14	13	0.27	18	O>T,U	6.0	6.2	0.57	5.7	0.76	0.52	0.46	0.26
D-Line Road	0.38	0.35	0.20	0.60	O>T,U	12	11	0.04	16	O>T,U	4.9	6.2	0.00	6.4	U,O>T	0.37	0.41	0.82
Little Wolf Cr.	0.51	0.38	0.00	0.58	O>T>U	12	9	0.36	16	O>T>U	4.8	6.5	0.00	5.5	U>O>T	0.50	0.37	0.02
Perkins Cr. #1	0.48	0.34	0.00	0.48	O,T>U	11	10	0.54	17	O>T,U	5.2	5.8	0.25	6.9	O>U,T	0.45	0.34	0.37
Perkins Cr. #2	0.48	0.40	0.17			11	11	0.97			5.1	6.3	0.03			0.35	0.33	0.54
Gnome ¹	0.37	0.31	0.82	0.44	O>T,U	11	8	0.00	16	O,T>U	3.8	7.1	0.00	6.0	U>O>T	0.55	0.35	0.06
Gordon Creek ¹	0.56	0.50	0.01	0.41	T>U>O	13	12	0.26	18	O>T,U	3.8	7.4	0.00	6.3	U,O>T	0.76	0.52	0.00
Wildwood Falls	0.43	0.41	0.17			11	12	0.82			6.4	7.7	0.00			0.37	0.22	0.01
Sand Creek	0.36	0.29	0.00	0.49	O>T>U	13	10	0.04	18	O>T,U	4.7	5.4	0.04	6.4	O,U>T	0.53	0.31	0.01
Bald Mtn.	0.44	0.44	0.66			12	10	0.04			4.9	5.1	0.07			0.32	0.28	0.70
Clay Creek	0.42	0.35	0.04			14	12	0.24			3.6	5.1	0.00			0.39	0.31	0.19
Marten Ridge	0.41	0.36	0.82	0.46	O>T,U	16	12	0.14	16	0.22	2.0	4.4	0.00	-	-	0.39	0.19	0.05
Burnt Creek	0.46	0.46	0.92	0.47	0.75	15	15	0.56	18	O>T,U	5.5	5.6	0.81	5.7	0.80	0.39	0.39	0.49
Windy Ridge	0.49	0.38	0.00	0.46	T,O>O,U	13	11	0.21	18	O>T,U	3.4	4.9	0.00	5.1	O,U>T	0.42	0.24	0.00
Big River	0.46	0.37	0.03			15	13	0.34			6.3	7.5	0.03			0.33	0.31	0.38
Highpass Rd.	0.40	0.35	0.41	0.45	0.24	16	14	0.29	17	0.26	4.7	5.0	0.10	4.9	0.26	0.39	0.35	0.73
Eagle's Rest	0.48	0.45	0.71	0.42	T,U>U,O	16	12	0.03	12	T>O,U	5.9	5.4	0.04	6.9	O>T>U	0.52	0.31	0.00
Days Creek	0.49	0.35	0.00			17	13	0.00			2.5	4.1	0.00			0.45	0.31	0.02
Bummer Ridge	0.34	0.35	0.60			14	13	0.32			3.9	5.3	0.05			0.52	0.43	0.91
Honey Creek	0.42	0.36	0.29	0.47	0.23	13	13	0.60	17	O>T,U	6.6	5.7	0.00	6.4	T>O>U	0.36	0.27	0.19
Bear Creek	0.43	0.48	0.20	0.44	0.28	15	14	0.62	16	0.65	4.7	4.5	0.11	6.3	O>T,U	0.43	0.25	0.00
Elliott St. For. ¹	0.55	0.42	0.00	0.52	T,O>U	14	12	0.00	17	O>T>U	5.1	4.1	0.05	7.5	O>T>U	0.58	0.29	0.00
Horse Creek	0.37	0.34	0.62			16	11	0.01			5.0	4.5	0.39			0.42	0.32	0.06
Rooster Rock	0.38	0.38	0.85	0.41	O>T,U	14	13	0.70	18	O>T,U	5.2	5.7	0.02	7.2	O>U>T	0.29	0.36	0.18
Little River	0.42	0.38	0.24			11	12	0.60			3.0	4.3	0.00			0.34	0.27	0.47
Meyer Creek	0.45	0.34	0.00			13	10	0.05			6.9	5.4	0.00			0.43	0.30	0.10
Fawn Creek	0.43	0.37	0.48			18	16	0.48			7.3	5.4	0.00			0.41	0.37	0.86
Panther Gap	0.35	0.25	0.02	0.38	O,T>U	14	11	0.00	14	O,T>U	2.0	3.4	0.01	3.4	O,U>T	0.44	0.23	0.05
> in thinned stands:			16					15					6					17
> in unthinned stands:			0					0					22					0
p-value:			0.0001		0.0001			0.0001		0.0001			0.0006		0.0055			
Avg:	0.44	0.37		0.49		14	12		17		4.8	5.6		5.9		0.45	0.33	
Std:	0.06	0.05		0.06		1.9	1.7		1.5		1.3	1.1		1.0		0.12	0.08	

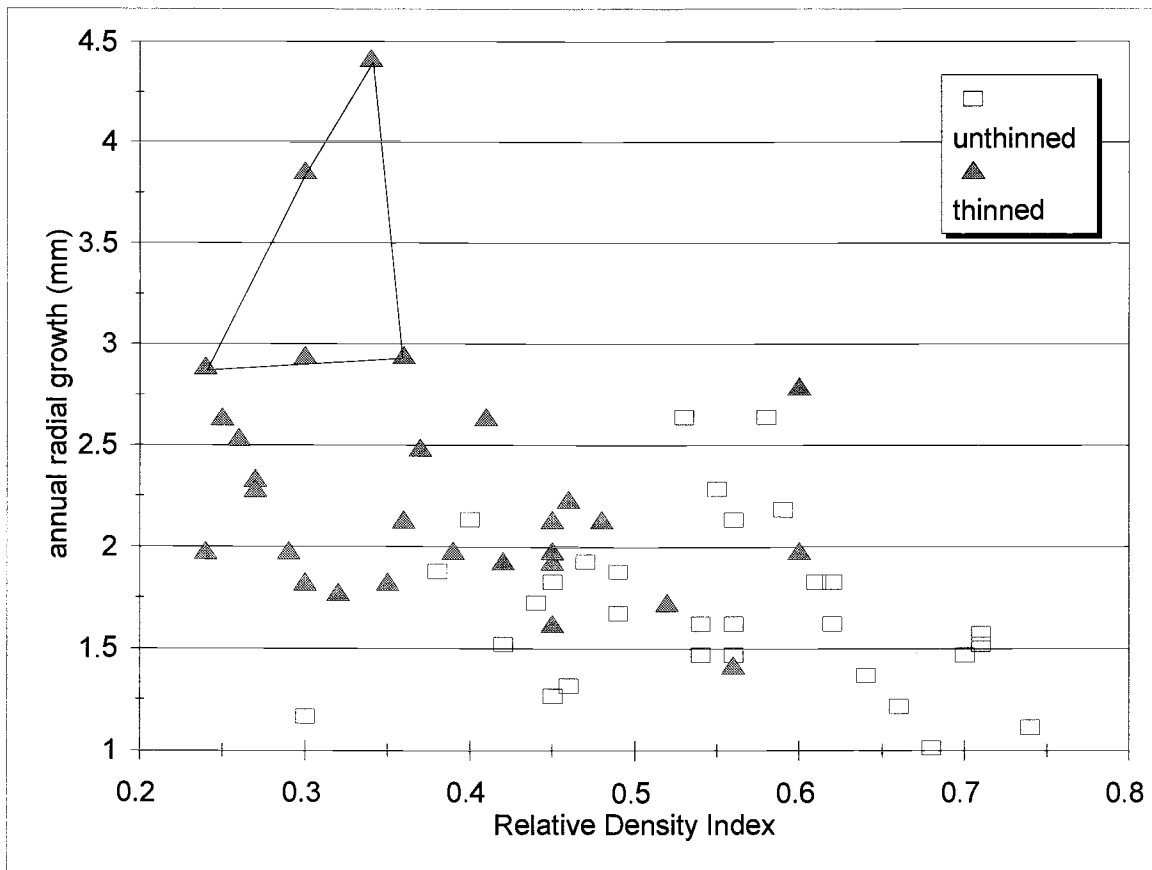


Figure 2.2. Stand-average annual radial growth for all thinned and unthinned stands vs. relative density index (RDI). Five sites with greatest radial growth are delineated.

thinned stands), stand age ($r^2 = 0.10$), and additional variability due to initial stocking, site index and time since thinning. The five stands with the greatest radial growth rates (upper left in the figure, and identified in Table 2.2) were thinnings that removed >50% of standing volume on average, resulting in RDIs of < 0.35 and densities of ≤ 153 trees/ha. Radial growth on those five heavy thinnings and their unthinned paired stands was correlated with live crown ratio (LCR, the proportion of the tree bole having live branches) at $r = 0.49$ and with a combined crown volume estimator (LCR times crown radius squared) at $r = 0.53$. Annual radial growth rate following the year of thinning (a 10- to 25-year time period depending on the pair) was likewise significantly greater in thinned stands ($p \leq 0.0001$). Overstory western hemlock trees, on average, had 54% greater radial growth rate ($p = 0.0050$) in thinned stands. Using basal area growth rates in these analyses did not change these significance levels.

Overstory LCR and crown radius for all species together, not including remnants, were consistently different between the two stand types (Table 2.2). Across unthinned stands, LCR is best predicted by age and site index ($r^2 = 0.54$), but age is not dominant in thinned stands, replaced by thinning intensity and site index ($r^2 = 0.30$). Douglas-fir trees in thinned stands averaged greater LCRs and crown radii in 16 of 32 and 15 of 32 pairs, respectively, and across all 32 pairs at $p \leq 0.0001$ for both variables. These crown differences were especially prominent in: 1) pairs with heavier thinnings which did not quickly return to full canopy closure; and 2) younger pairs in which the unthinned stand were early in the dense, stem exclusion phase of succession (Oliver and Larsen 1990). Overstory western hemlock trees were present in only 15 of the 32 pairs, but had 22% greater LCR ($p = 0.0451$) and 1.0 m greater crown radius ($p = 0.0118$) in thinned stands relative to unthinned stands. The density of western hemlock was lower in those thinned stands ($p = 0.1658$). Overstory hardwood trees were present in 22 of 32 pairs; they were less frequent in thinned stands ($p = 0.0397$) but had greater LCR ($p = 0.0685$) on average. Hardwood crown radius was not significantly different between the stand types.

Old-growth stands were fundamentally different from younger stands in terms of overstory tree density, DBH, LCR, and crown radius (Tables 2.1 and 2.2). The magnitude of differences (e.g., in DBH) was greatest between old-growth stands and the youngest pairs. Old-growth stands had only 20 to 40 large (>90 cm DBH) trees/ha, and 35 to 104 trees/ha >20 cm DBH (95% confidence limits). Only the heavier thinnings in older stands had densities as low as 100 overstory trees/ha (e.g., Marten Ridge in Table 2.1); unthinned stands averaged 400 trees/ha in stands < 100 years and 200 trees/ha in older stands. Unthinned stands had the greatest density (trees/ha and RDI) in 19 of 20 triads ($p \leq 0.0001$ across all 20 triads). Basal area was highest in old-growth stands in 17 of 20 triads ($p \leq 0.0001$). Basal area of western hemlock only was also greatest in old-growth stands at $p \leq 0.0001$.

Increased tree ages and sizes at lower densities corresponded with greater LCR in old-growth stands for 14 of 20 triads ($p \leq 0.0001$), though not significantly different from thinned stands in 8 of these cases. Old-growth averaged greater crown radius in 16 of 20 triads ($p \leq 0.0001$); they were different from thinned stands in all but two of these 16 stands, and from unthinned stands in all but one stand. The LCR, crown radius and radial growth of western hemlock was not different between old-growth and thinned stands. Total canopy LAI was significantly greater in old-growth and/or unthinned stands in 16 of 20 triads (in thinned stand in one triad). Across all 20 triads, old-growth and unthinned stands were not different, but had greater canopy LAI than thinned stands at $p = 0.0055$. Crown closure averaged 91% in old-growth, not different from unthinned stands (88%) but greater than thinned stands (67%) at $p \leq 0.0001$.

Old-growth stands averaged 19 snags/ha of large (≥ 90 cm) soft, well-decayed snags across all 20 triads, greater than either thinned (10 snags/ha) or unthinned stands (14 snags/ha) at $p = 0.0038$. Across all 32 pairs, unthinned stands had greater numbers of snags than thinned stands ($p = 0.0871$). Old-growth stands averaged 7 stems/ha of smaller (≥ 20 cm) hard snags, intermediate of but not different from either thinned (4 stems/ha) or unthinned stands (12 stems/ha). Thinned and unthinned stands differed at

$p = 0.0086$. Across all 32 pairs, thinned stands showed fewer hard snags ($p \leq 0.0001$). There were 18 overstory trees/ha on average showing evidence of natural or human-caused damage to their boles in old-growth stands, not different from thinned stands (14 trees/ha) but greater than unthinned stands (10 trees/ha) at $p = 0.0079$. Across pairs only, the density of damaged trees was greater in thinned than in unthinned stands ($p = 0.0503$), but individual sites ranged from 2 - 40 and 0 - 30, respectively.

Old-growth stands are also distinguishable by the variability of their overstories within stands. Overstory tree heights and diameters in old-growth stands averaged coefficients of variation (CV) of 19 and 14%, respectively. Young stands only exceeded 14% in four unthinned stands and four thinned stands which contained some points dominated by large remnant trees (e.g., Sand Creek). In total, young stands averaged CV of 10% for both variables. Trees/ha and RD also varied most among points within old-growth stands. Coefficients of variation averaged 52 and 34%, respectively. These CV levels were exceeded only in five older unthinned stands (with distinct areas of self-thinning mortality) and seven heavy thinnings. Variability in overstory basal area was not consistently greater in old-growth stands than either young stand type.

Current standing cubic foot volume per hectare (m^3/ha) was lower in thinned than unthinned stands for 28 of 32 pairs given the reduced density of trees. Volume is a function of age and site index in unthinned stands ($r^2 = 0.43$), but years since thinning and thinning intensity ($r^2 = 0.64$) in thinned stands. Lighter thinnings, typically in older stands, showed differences $< 100 \text{ m}^3/\text{ha}$ (e.g., Fawn Creek in Table 2.1) after 20 years. Board foot volume per acre (MBF/ac) was likewise lower in thinned stands in 29 pairs. Both volume estimates were significantly lower in thinned stands across all 32 pairs at $p \leq 0.0001$. Current differences in volumes fade with time, however, particularly for board foot volume. For example, projected MBF accumulation to age 130 is presented for a moderately-heavy thinning on a productive site (Figure 2.3). This site represents the type of data available for reconstructing volume and ORGANON volume growth. Growth trajectories show the assumed development of the single stand prior to harvest, the

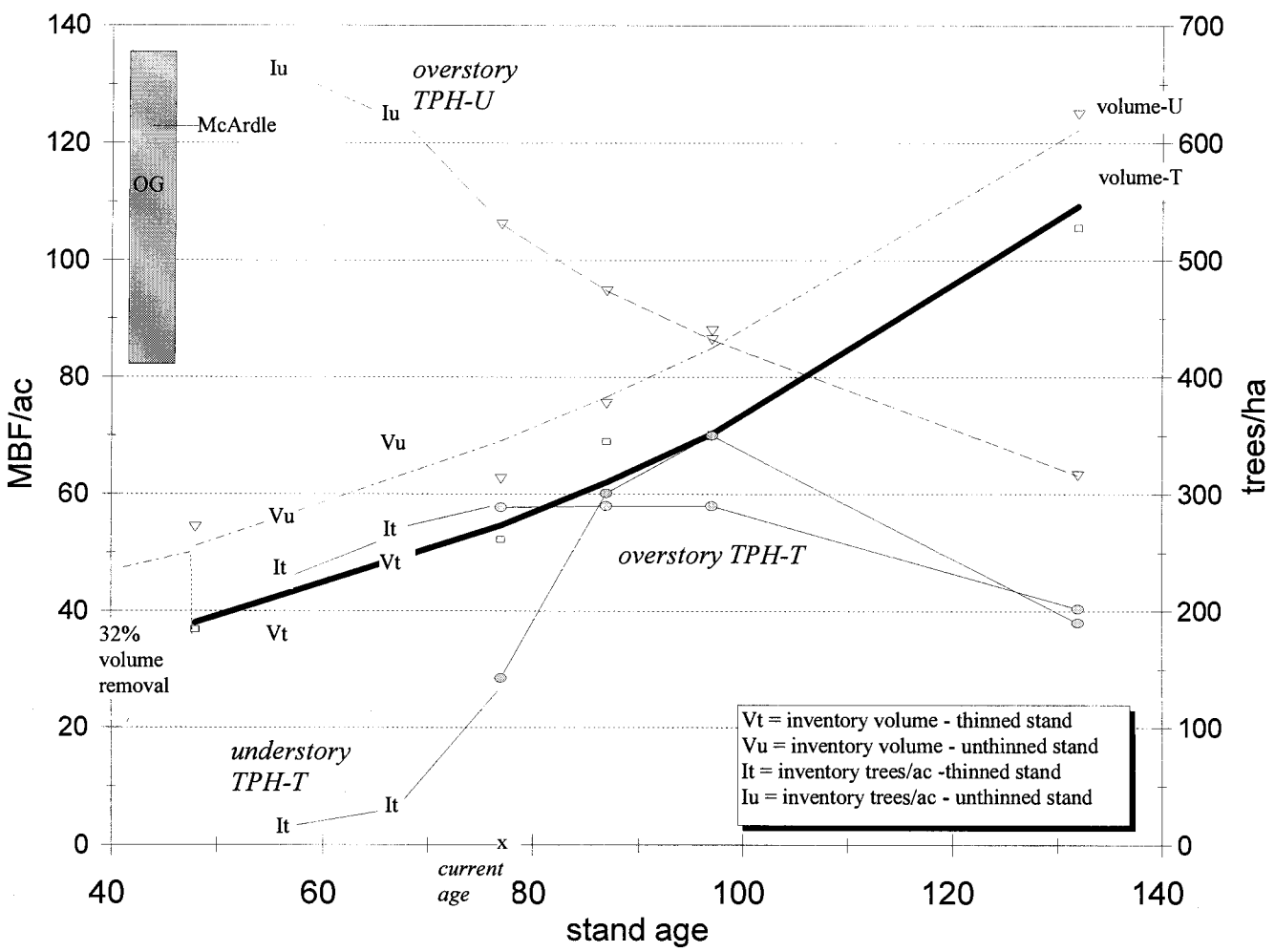


Figure 2.3. Net cubic foot volume accumulation and tree/ha density trajectories for a thinned (T) and unthinned (U) pair -- "Sand Creek". The dashed line prior to age 48 is reconstructed volume from harvest and inventory data points associated with the unthinned stand (I_u); 32% volume removal is shown at age 48. Volume and tree density before age 77 is based on inventory data points (V_t - I_t and V_u - I_u) and beyond age 77 is ORGANON summary and projection. Overstory and understory tree density is separated; understory tree density is negligible in the unthinned stand. Volume expectation based on Bulletin 201 (McArdle et al. 1949) and observed old-growth stand volumes (25 - 75 percentiles across 20 old-growth stands) are graphed for reference.

harvest removal and standing volumes at age 48, data from two permanent inventory points (one each in the thinned and unthinned stand) at two measurements each, current ORGANON volume estimates from our stand exams, and projected growth of the two stands. Stand characteristics at age 130 are included for comparison and reference to observed old-growth stands and volume expectations for well-stocked Douglas-fir using Bulletin 201 (McArdle et al. 1949).

Figure 2.4 shows the influence of stand age and site productivity on three groups of three sites each: 1) 50-yr, highly productive sites ($SI_{50} \geq 130$); 2) 60-yr, lower productivity sites ($SI_{50} \leq 110$); and 3) >100-yr, moderately-productive sites. The observed range of cubic volume in old-growth stands is noted for comparison. Our data suggests that a standing volume of $1200 \text{ m}^3/\text{ha}$ may be the upper asymptote for most sites in western Oregon. These old-growth stands also average $90 \text{ m}^3/\text{ha}$ more in downed wood than unthinned stands on average, and $170 \text{ m}^3/\text{ha}$ more than thinned stands. Young thinned stands on productive ground exceed projected volume in unthinned areas around age 100, beyond age 120 on less productive ground. The removal of growing stock via thinning from stands >100-yr on moderately-productive sites appears to preclude the stand from recovering that volume again within the near future. ORGANON volume projections can exceed the maximum values found in our old-growth stands because it accounts for mortality due only to self-thinning.

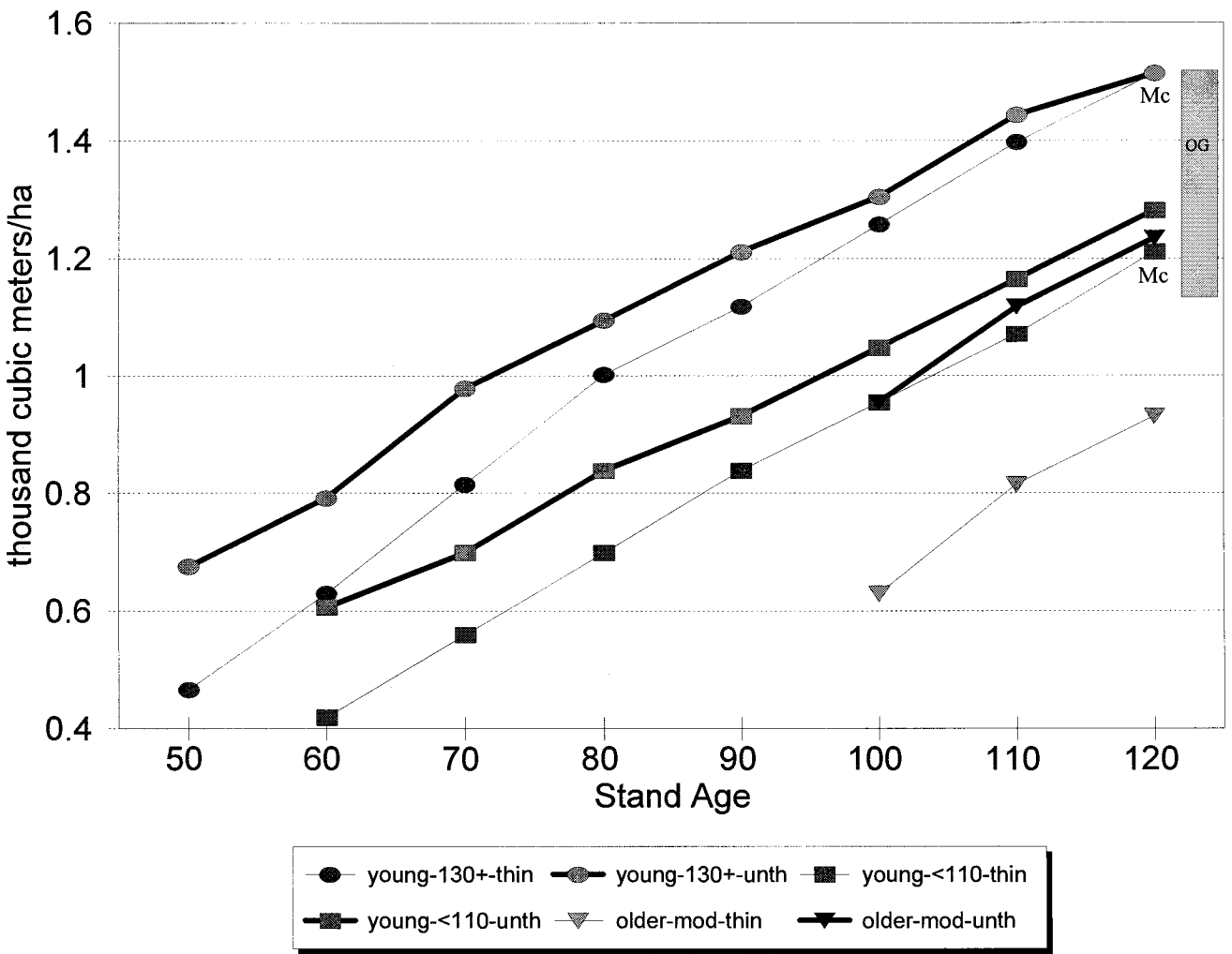


Figure 2.4. Net cubic volume accumulation from current age to age 120 for three groups of three sites each, representing three age classes and site index groups (King's >130, <110, and 110-125) groups, each comparing thinned and unthinned stands. Mean old-growth stand volume \pm one standard deviation is graphed for reference, as is volume expectation based on McArdle et al. (1949) shown with an "Mc".

Intermediate trees

Intermediate trees are defined as individuals between 3 and 20 cm in diameter and below the main canopy. In thinned stands, this stratum was dominated by recently regenerated saplings, with a few intermediate and suppressed trees from the original overstory that were not harvested during thinning. Intermediate tree species varied among sites due to regional- and small-scale differences in seed source availability (e.g., for western hemlock). Intermediate tree structure on northern sites was dominated by western hemlock, and southern/valley-fringe sites were dominated by Douglas-fir. Thinned stands may have had high densities of intermediate trees (e.g., Elliott State Forest, see Table 2.3) given sufficient stand age and thinning intensity ($r^2 = 0.39$). Table 2.3 identifies 12 such pairs with greater intermediate tree density under thinned overstories (250 such trees/ha on average) than in unthinned stands. In these thinned stands, living trees comprised 93% of the intermediates and their LCR averaged 0.63. These sites were thinned relatively heavily (> 30% volume removal) and/or thinned 20+ years ago. Even across all 32 pairs, intermediate tree LCR and the percent of intermediates living were greater in thinned stands ($p \leq 0.0001$). Of the few scattered intermediates and suppressed trees from the original overstory, we saw ample evidence that western hemlock responded to release in terms of radial growth rates and/or crown development. Few Douglas-fir residuals responded to thinning in radial or height growth within the time frame of this study.

Intermediate structure in unthinned stands, in contrast, was comprised primarily of intermediate and suppressed Douglas-fir from the origin cohort, with few young saplings and an increased number of standing dead stems. The density of intermediate trees in unthinned stands is best predicted by stand age alone ($r^2 = 0.39$). Table 2.3 identifies nine pairs with significantly greater numbers of these intermediate trees in unthinned stands (200 such trees/ha on average). In those 9 unthinned stands, only 50% of the trees were living, and their LCR averaged 0.33. Intermediate tree height and diameter were greater in unthinned stands in 18 of 32 and 14 of 32 pairs, respectively, and was significant

Table 2.3. Intermediate tree (3-20 cm diameter) density, percent living, and their live crown ratios (LCR) for each stand type. P-values are tallied at the bottom, followed by averages and standard deviations for each stand types, with associated p-values for testing differences across all pairs and triads.

SITE	Intermediate trees/ha					% living			Intermediate LCR				
	thin	unth.	p-value	OG	diff.	thin	unth.	OG	thin	unth.	p-value	OG	diff.
Beaver Flat	32	17	0.03	121	O>T>U	68	13	100	0.71	0.37	0.19	0.59	0.26
Blue Ridge 26	106	541	0.00	86	U>T,O	60	41	77	0.41	0.31	0.04	0.52	O,T>U
Blue Ridge 35	35	541	0.00			30	41		0.60	0.31	0.00		
N. Ward Creek	54	40	0.52	74	0.41	58	10	97	0.60	0.26	0.00	0.44	O,T>U
Keel Flat	160	173	0.49	240	0.56	49	32	94	0.62	0.51	0.04	0.59	T,O>U
D-Line Road	119	301	0.06	257	U,O>O,T	66	63	81	0.33	0.29	0.94	0.48	T,O>U
Little Wolf Cr.	294	244	0.79	156	0.39	92	36	94	0.51	0.25	0.00	0.35	T>O,U
Perkins Cr. #1	358	153	0.04	291	T,O>U	78	38	69	0.46	0.54	0.14	0.38	U,T>T,O
Perkins Cr. #2	289	316	0.54			84	60		0.43	0.33	0.41		
Gnome	94	299	0.00	123	U>T,O	93	46	94	0.66	0.30	0.00	0.51	T>O>U
Gordon Creek	67	123	0.05	402	O>U>T	82	42	99	0.74	0.45	0.06	0.57	T,O>O,U
Wildwood Falls	133	299	0.07			61	50		0.39	0.25	0.05		
Sand Creek	62	12	0.03	79	O,T>U	83	22	88	0.67	0.68	0.51	0.59	U,T>T,O
Bald Mtn.	175	64	0.22			89	52		0.49	0.38	0.12		
Clay Creek	291	99	0.06			89	37		0.50	0.44	0.15		
Marten Ridge	77	17	0.02	257	O>T>U	94	41	96	0.60	0.56	0.68	0.54	0.39
Burnt Creek	336	69	0.01	338	O,T>U	96	54	100	0.70	0.63	0.15	0.65	0.21
Windy Ridge	195	341	0.16	580	O,U>U,T	93	62	97	0.71	0.35	0.00	0.44	T>O>U
Big River	237	412	0.03			92	89		0.66	0.54	0.02		
Highpass Rd.	143	212	0.00	121	0.54	63	66	82	0.37	0.37	0.41	0.40	0.31
Eagle's Rest	316	146	0.05	222	T,O>U	96	61	77	0.65	0.35	0.00	0.38	T>O,U
Days Creek	402	94	0.05			96	60		0.75	0.32	0.00		
Bummer Ridge	188	133	0.34			100	81		0.78	0.64	0.30		
Honey Creek	279	165	0.18	200	0.18	100	44	77	0.64	0.39	0.15	0.35	T>U,O
Bear Creek	294	25	0.00	91	T>O>U	98	59	73	0.56	0.81	0.00	0.49	U>T,O
Elliott St. For.	375	32	0.00	254	T>O>U	93	68	94	0.73	0.70	0.75	0.62	0.20
Horse Creek	198	32	0.00			99	81		0.65	0.79	0.03		
Rooster Rock	27	44	0.14	328	O>U,T	92	32	98	0.75	0.43	0.14	0.44	T>O,U
Little River	328	99	0.00			90	70		0.52	0.38	0.03		
Meyer Creek	94	69	0.53			83	55		0.69	0.49	0.02		
Fawn Creek	138	99	0.28			92	85		0.52	0.50	0.53		
Panther Gap	242	210	0.79	353	0.24	100	57	88	0.77	0.25	0.00	0.23	T>U,O
# stands with T>U:			12								20		
# stands with U>T:			9								3		
Avg:	192	169		229		83	52	89	0.60	0.44		0.48	
Std:	111	144		130		17.1	19.1	9.8	0.13	0.16		0.11	
overall p-value:			0.30		0.54						0.0001		0.0001

across all 32 pairs at $p \leq 0.0001$ for both variables. The increased density of standing dead intermediate trees in unthinned stands ($p < 0.0001$ across 32 pairs), increased overstory canopy density, reduced survival rates, and reduced live crown ratios were all consistent with an observed decrease in intermediate tree radial growth in unthinned stands in 4 of 11 pairs with sufficient representation to construct the test. These measurements were taken exclusively from residual trees left since the time of thinning.

Intermediate tree density in old-growth stands was no different ($p = 0.6249$) from either younger stand type, though the character of those trees (i.e., younger and smaller, mix of shade tolerance) were more similar to thinned stands (Figure 2.5). The density of standing dead intermediates and the percent of intermediate trees living was no different between old-growth and thinned stands; unthinned stands had higher densities and lower percentages of living trees across all 20 triads at $p \leq 0.0001$ for both variables. Old-growth stands maintain densities of intermediate, typically shade-tolerant trees comparable to thinned stands despite higher overstory densities than thinned stands. Conversely, old-growth maintains higher survival rates than unthinned stands at the same overstory tree density or basal density. This phenomenon is apparently related to differences in stand age which drives multi-storied canopy development and species composition. Intermediate tree LCR was less in old-growth stands than in thinned stands in 8 of 20 triads. Thinned stands had the greatest intermediate tree LCRs across all triads at $p \leq 0.0001$, with no significant difference between old-growth and unthinned stands. Variability in intermediate tree size (e.g., DBH) and arrangement (e.g., RD) is not consistently different among old and young stand types.

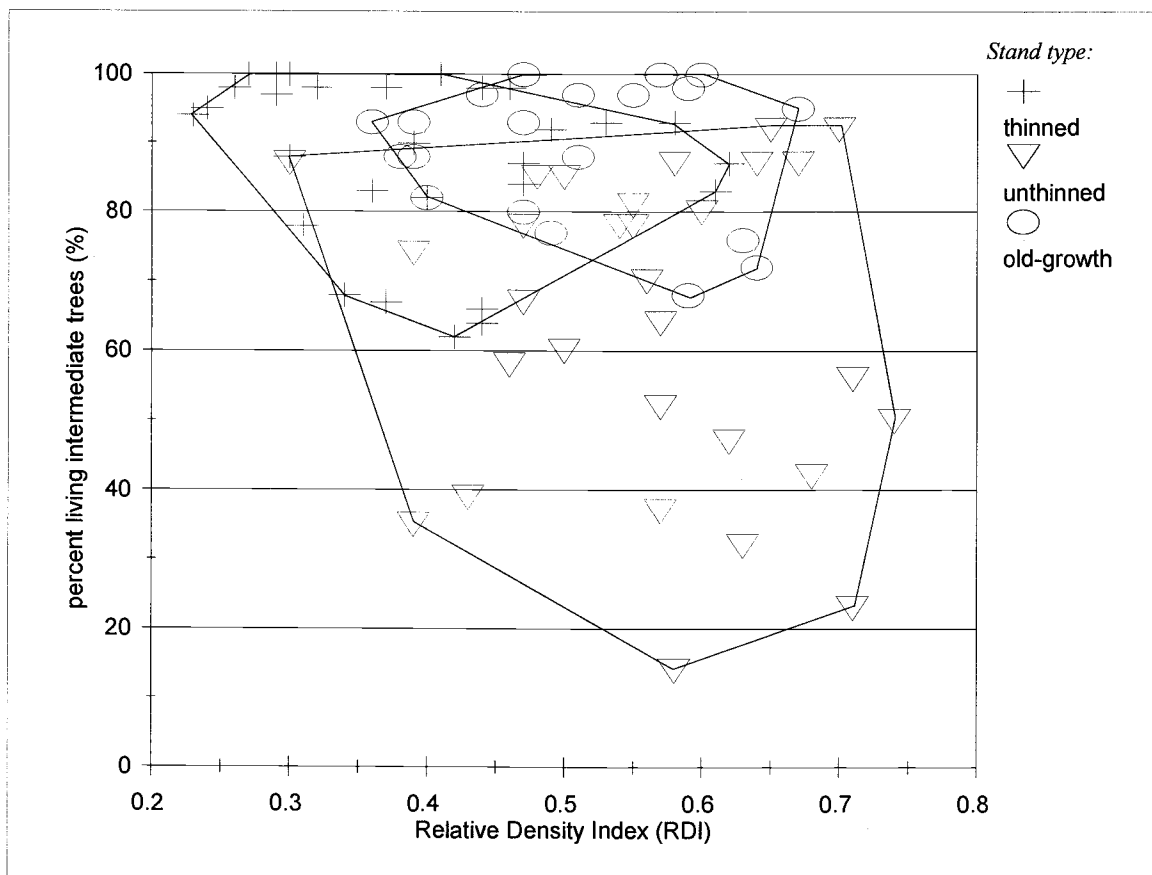


Figure 2.5. Percent of intermediate trees that were alive, by stand type for 32 young stand pairs (thinned and unthinned) and 20 old-growth stands. Stand types are delineated to show the data range for each.

Understory Regeneration and Shrubs

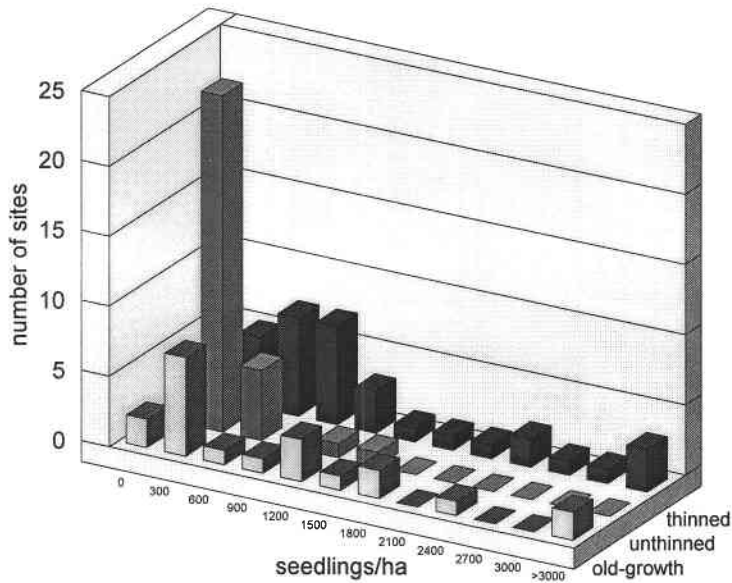
Understory conifer seedling density and frequency was one of the largest and most consistent differences between thinned and unthinned stands measured in this study (Table 2.4, Figure 2.6a). Twenty-four of 32 pairs had significantly higher seedling densities (primarily western hemlock and Douglas-fir) in the thinned stand; no pair had more seedlings in the unthinned stand. Across all 32 pairs, thinned stands had greater seedling density at $p \leq 0.0001$. Conifer seedling density in unthinned stands was best explained by and positively correlated with stand age ($r^2 = 0.20$). Seedling density in thinned stands was best explained by and positively correlated with thinning intensity ($r^2 = 0.10$, Figure 2.7), a poor fit that demonstrates the variability across sites in western Oregon. The 13 heaviest thinnings (which removed $\geq 33\%$ of the volume) averaged 2300 seedlings/ha while their paired unthinned stands averaged 230 seedlings/ha. Compositional changes were as dramatic as density differences. Twenty-nine of 32 thinned stands still had Douglas-fir seedlings in the understory (Figure 2.6b). We found only 7 unthinned stands with Douglas-fir regeneration, all at densities less than 300 seedlings/ha and located in southwestern Oregon or the edge of the Willamette Valley. Shade tolerant western hemlock and cedar comprise nearly all of regeneration in unthinned stands in Figure 2.6a.

Conifer seedling frequency increased from 0.12 on average (typically 0 to 0.2) in unthinned stands to 0.48 (typically 0.3 to 1.0) in thinned stands across all pairs, significant at $p \leq 0.0001$ (Figure 2.8). In unthinned stands, frequency is best explained by stand age ($r^2 = 0.22$), but frequency is best explained by site index and thinning intensity ($r^2 = 0.32$) in thinned stands. The 13 heaviest thinnings in Figure 2.7 averaged a frequency of 0.59; their paired unthinned stands average a frequency of 0.13. In terms of species composition, western hemlock seedlings are most frequent at more northern sites in unthinned stands and lower intensity thinnings. Douglas-fir seedlings predominate at southwestern and Willamette Valley fringe sites in heavier thinnings.

Table 2.4. Understory characteristics for each site and stand type. P-values are tallied at the bottom, followed by averages and standard deviations for each stand type, with associated p-values for testing differences across all pairs and triads. ¹ denotes five stands with fewer seedlings than would be expected given similar sites.

SITE	Seedling stocking (/ha)					Tall shrub stems/ac			Small shrub cover (%)					Total L.A.I. (m2/m2)				
	thinned	unth.	p-value	OG	diff.	thinned	unth.	p-value	thinned	unth.	p-value	OG	diff.	thin	unth.	p-value	OG	diff.
Beaver Flat	916	417	0.02	158	T>U>O	325	247	0.37	80	40	0.00	43	T>O,U	6.2	6.2	0.41	6.8	O>T,U
Blue Ridge 26	830	565	0.49	0	T,U>O	1178	357	0.01	39	5	0.00	16	T>O,U	7.5	8.4	0.02	8.1	U,O>T
Blue Ridge 35	1449	565	0.83			805	357	0.08	46	5	0.00			7.2	8.4	0.04		
N. Ward Creek	477	12	0.00	136	T>O,U	1056	325	0.05	39	29	0.82	34	0.48	5.0	5.7	0.23	6.5	O>U,T
Keel Flat	1027	449	0.03	1032	O,T>U	751	560	0.23	21	21	0.76	23	0.89	7.5	6.6	0.09	7.6	O,T>U
D-Line Road	395	227	0.03	968	O,T>U	719	307	0.01	82	36	0.00	65	T>O>U	6.6	7.2	0.27	7.3	0.29
Little Wolf Cr.	2553	138	0.00	101	T>U,O	900	159	0.00	22	22	0.31	20	0.94	5.8	7.3	0.00	7.1	U,O>T
Perkins Cr. #1 ¹	427	114	0.03	215	T>O,U	481	142	0.07	80	67	0.02	66	T>U,O	7.2	7.2	0.71	8.2	O>T,U
Perkins Cr. #2	227	123	0.59			435	279	0.23	82	47	0.00			7.1	7.7	0.21		
Gnome	820	126	0.03	202	T>O,U	1775	388	0.00	85	24	0.00	73	T,O>U	6.5	7.5	0.10	7.9	O,U>T
Gordon Creek	6714	22	0.00	1615	T,O>U	1291	1275	0.71	42	20	0.00	34	T,O>U	6.3	8.1	0.05	7.6	U,O>T
Wildwood Falls	328	44	0.00			892	508	0.11	75	42	0.00			7.3	8.7	0.00		
Sand Creek	2198	91	0.00	879	T,O>U	239	215	0.81	47	35	0.13	48	O,T>U	6.1	6.1	0.68	7.2	O>T,U
Bald Mtn.	259	27	0.09			1268	572	0.00	78	69	0.18			6.9	7.1	0.59		
Clay Creek	509	126	0.01			229	343	0.09	65	75	0.32			5.8	7.3	0.00		
Marten Ridge	430	0	0.00	3857	O,T>U	1584	1219	0.34	95	81	0.00	55	T>U>O	5.1	6.4	0.14	-	-
Burnt Creek	6714	1163	0.00	3886	T,O>U	64	33	0.51	31	46	0.01	4	U>T>O	7.2	6.6	0.11	6.2	T>U,O
Windy Ridge	2119	188	0.08	1299	T,O>U	125	402	0.08	41	16	0.09	18	T>O,U	4.6	5.5	0.03	5.7	O,U>T
Big River	869	1242	0.49			421	133	0.00	70	43	0.00			7.9	8.4	0.21		
Highpass Rd. ¹	701	126	0.34	0	T,U>O	366	1013	0.03	34	24	0.08	50	O>T>U	5.9	6.0	0.99	6.6	0.22
Eagle's Rest	1978	114	0.00	114	T>O,U	1172	615	0.20	70	79	0.05	52	U>T>O	7.9	6.8	0.06	7.8	T,O>U
Days Creek	4896	62	0.00			371	625	0.53	15	9	0.11			4.3	4.8	0.56		
Bummer Ridge	649	109	0.00			595	350	0.34	90	83	0.16			6.4	7.0	0.60		
Honey Creek	1141	146	0.00	1052	T,O>U	1795	376	0.00	35	24	0.07	25	0.16	8.9	6.3	0.00	7.5	T>O>U
Bear Creek ¹	202	101	0.80	158	0.90	2087	1304	0.10	52	45	0.91	40	0.20	6.6	6.2	0.37	7.3	0.17
Elliott St. For. ¹	281	170	0.31	1615	O>T,U	128	1208	0.00	62	48	0.03	20	T>U>O	7.5	6.3	0.01	8.5	O>T>U
Horse Creek	802	12	0.00			1085	524	0.07	85	50	0.14			7.9	7.1	0.07		
Rooster Rock ¹	141	101	0.22	2360	O>T,U	841	524	0.25	70	60	0.04	45	T>U>O	7.3	6.7	0.23	7.9	O,T>U
Little River	1770	195	0.00			931	588	0.19	27	34	0.31			4.0	5.0	0.06		
Meyer Creek	780	37	0.00			1103	671	0.34	74	85	0.49			9.1	6.6	0.00		
Fawn Creek	452	395	0.47			805	1114	0.12	46	65	0.02			8.8	7.2	0.02		
Panther Gap	2788	240	0.00	553	T>O>U	1205	585	0.07	11	14	0.79	17	0.67	2.6	3.6	0.00	4.0	O,U>T
# stands with T>U:			23					14			19					8		
# stands with U>T:			0					5			3					11		
Avg:	1433	233		1010		844	541		56	42		37		6.6	6.8		7.1	
Std:	1679	292		1149		514	350		24	24		19		1.4	1.1		1.0	
overall p-value:			0.0001		0.0001						3E-04		0.0001			0.32		0.1655

a. all species



b. Douglas-fir only

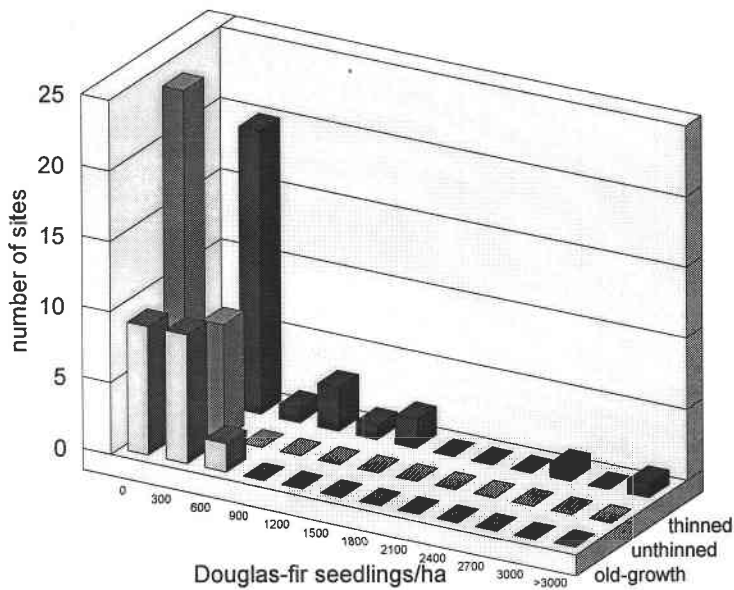


Figure 2.6. Conifer seedling density in three stand types: a. all species (predominantly western hemlock and Douglas-fir), and b. Douglas-fir only. Frequency distributions were constructed from 32 thinned and unthinned stand pairs and 20 old-growth stands. The x-axis label is the upper-most value for each frequency class.

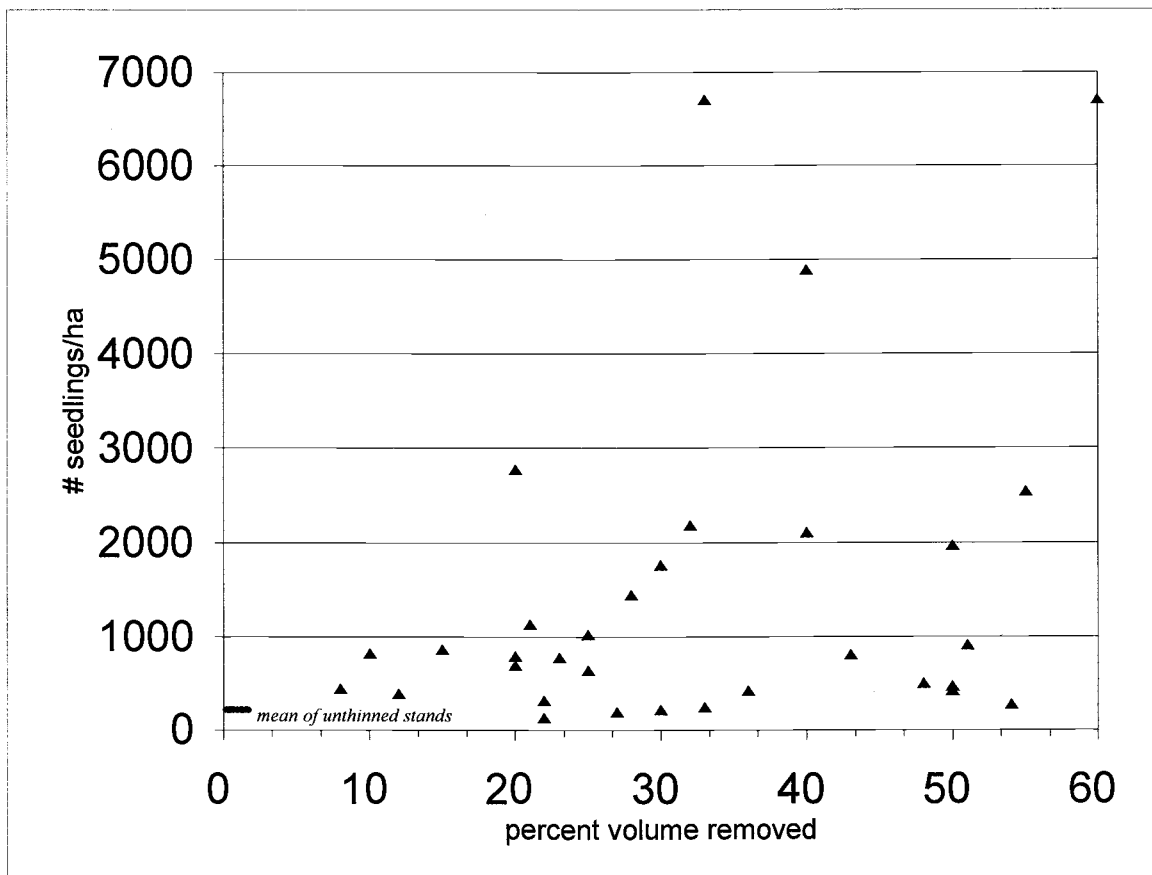


Figure 2.7. Conifer seedling density vs. percent volume removal during harvest (thinning intensity) for each thinned stand. Average density across all unthinned stands is shown for reference on the y axis.

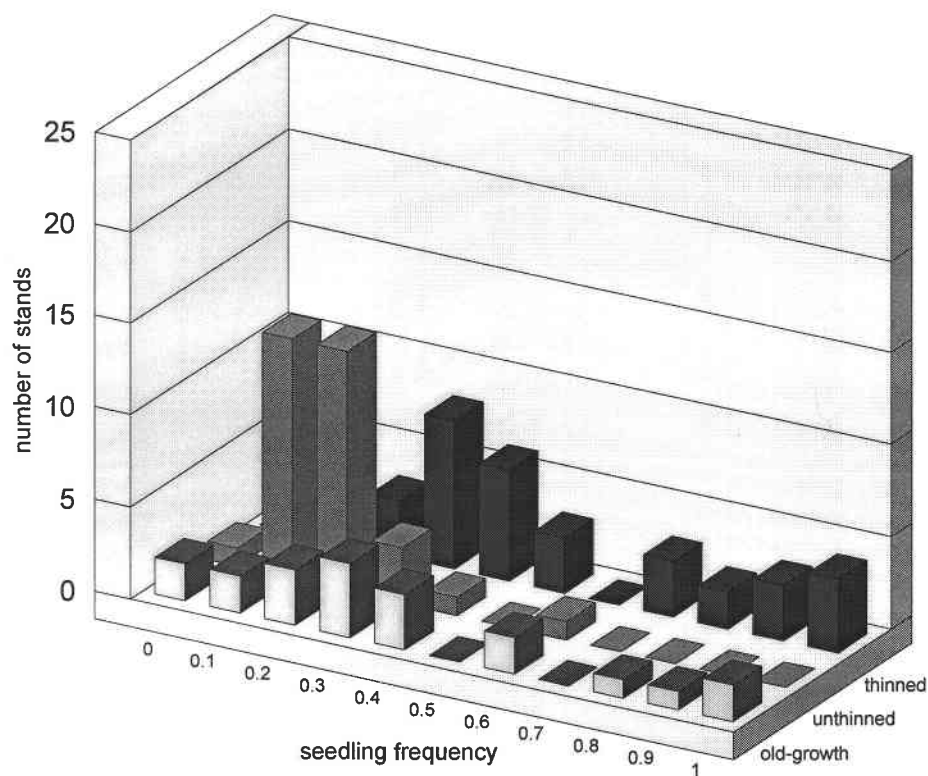


Figure 2.8. Conifer seedling frequency in three stand types for all species (predominantly western hemlock and Douglas-fir). Frequency distributions were constructed from 32 thinned and unthinned stand pairs and 20 old-growth stands. The x-axis label is the upper-most value for each frequency class.

Seedling density and frequency can be viewed as a response to overstory density as described by Reineke's (1933) Stand Density Index (SDI). High frequencies of conifer seedlings were mostly associated with SDI values ≤ 200 (Figure 2.9), which convert approximately to relative density index of 0.35. Low frequencies of seedlings were associated with SDIs > 300 , particularly in smaller-diameter stands (young, unthinned stands).

As with intermediate structure, there were major differences in seedling vigor between stand types. Seedling height growth rates (Douglas-fir only) in unthinned stands typically averaged ≤ 5 cm/yr (Figure 2.10a). In contrast, height growth rates in thinned stands typically averaged ≥ 10 cm/yr. Individual seedling height growth rates from a single area show a more striking difference among stand types (Figure 2.10b). Differences in stand-average height growth rates are best explained by stand age in unthinned stands ($r^2 = 0.12$), and by thinning intensity in thinned stands ($r^2 = 0.42$). Current canopy leaf area (shade producing trees) explained some differences in seedling vigor for Douglas-fir (Figure 2.11). Seedling composition and vigor varied by region (as with intermediate trees), with western hemlock dominant in the northern/mountainous sites and Douglas-fir in southern/valley fringe sites (e.g., Canyonville). Western hemlock is capable of heights (and height growth rates) comparable to Douglas-fir (Figure 2.12) but on average did not obtain as much height at a given age as shown by its regression line. This difference in slope is likely due to the shaded conditions in which western hemlock will persist (more so than Douglas-fir) but grow slowly.

Five thinned stands (e.g., Perkins Creek #1, see Table 2.4) had markedly fewer seedlings than one would expect given similar sites in this study; they are included among the 8 sites showing insignificant differences in seedling densities between stand types. Potential reasons for low densities in these thinned stands include hardwood sprout and shrub competition in these thinned stands. Hardwood sprouting was more dense in thinned stands for 13 pairs, across all 32 pairs at $p = 0.0512$. Across all pairs, hardwood sprouts are younger ($p \leq 0.0001$) and shorter ($p = 0.0643$) in thinned stands reflecting the

Seedling Frequency

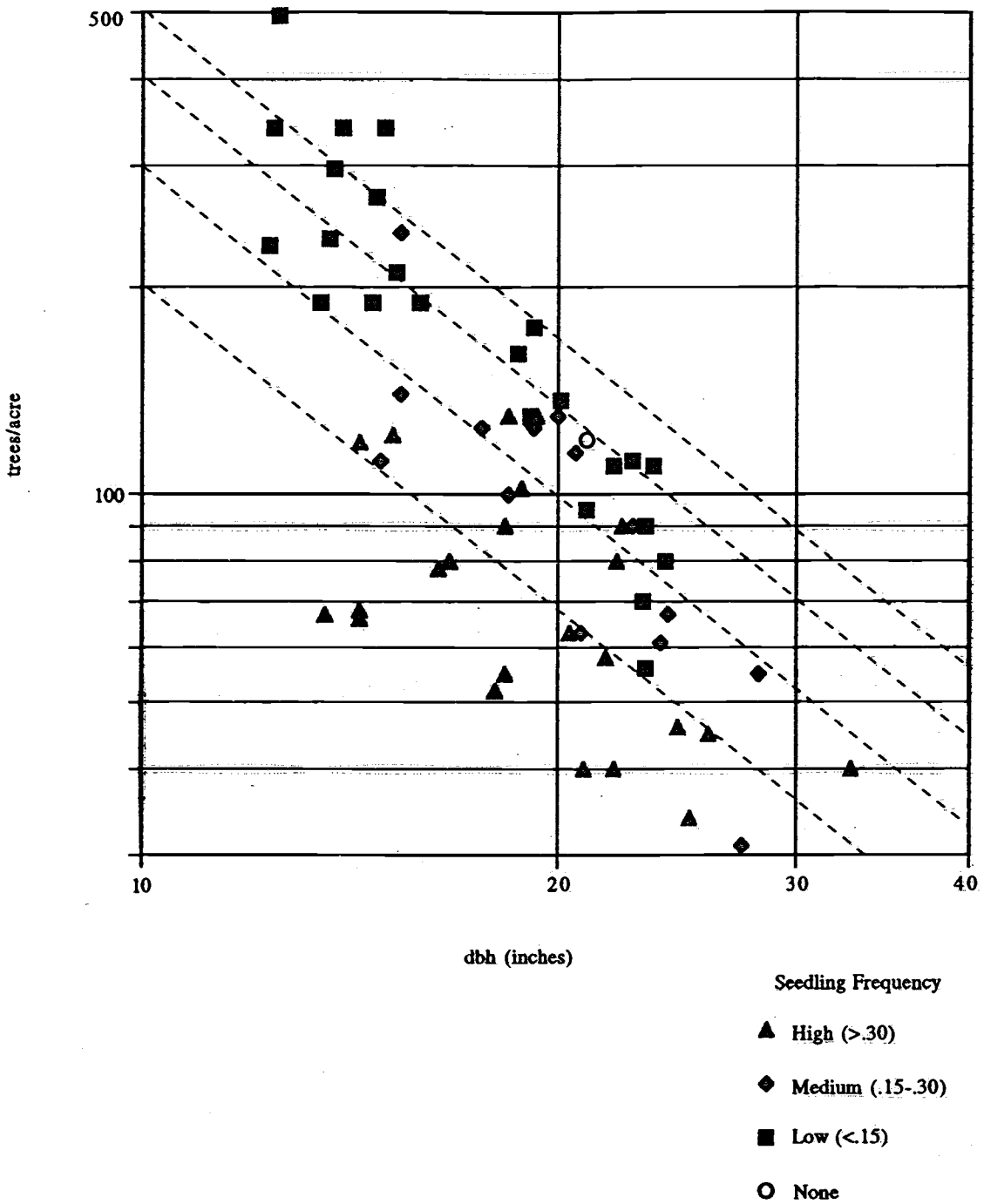
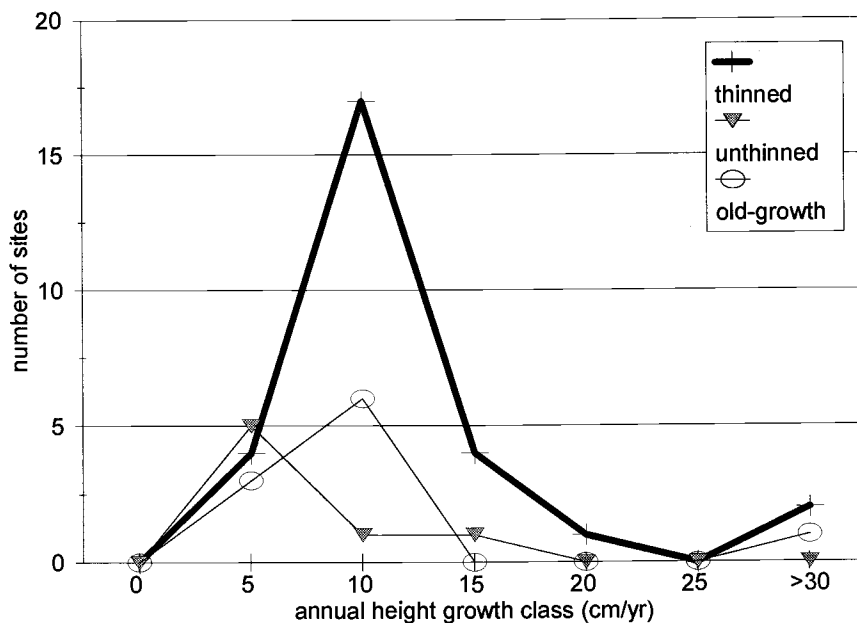


Figure 2.9. Stand-level seedling frequency for thinned and unthinned stands as plotted on a stand density index chart (Reineke 1933), distinguishing stands with high, medium, low and zero frequency. Points are based on reconstructed diameter and density for the year immediately following thinning.

a. stand averages



b. individual seedlings

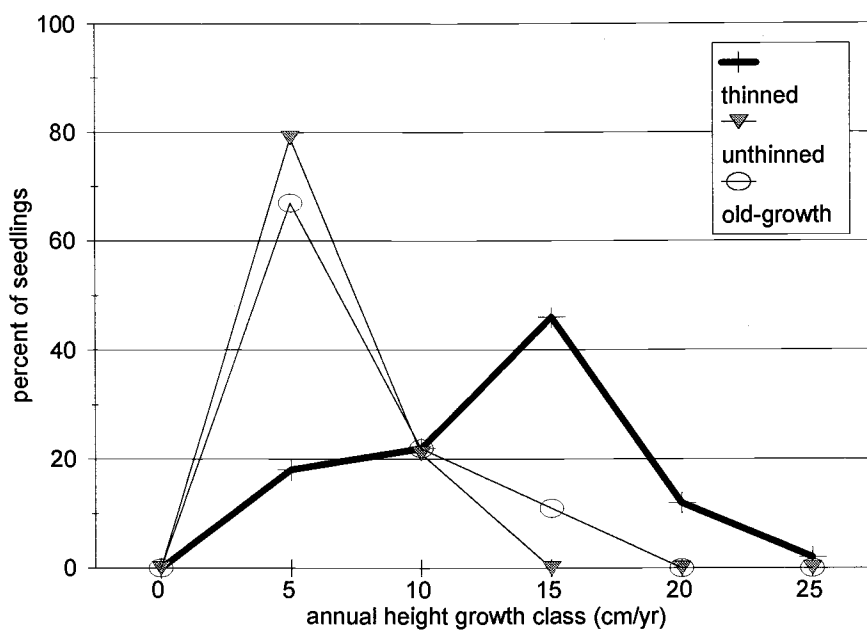


Figure 2.10. Douglas-fir seedling annual height growth (vigor) for three stand types: (a) for all 32 pairs and 20 old-growth stands using stand-level averages; and (b) for all seedlings within a subsample of southwestern Oregon stands which have a high density of Douglas-fir regeneration.

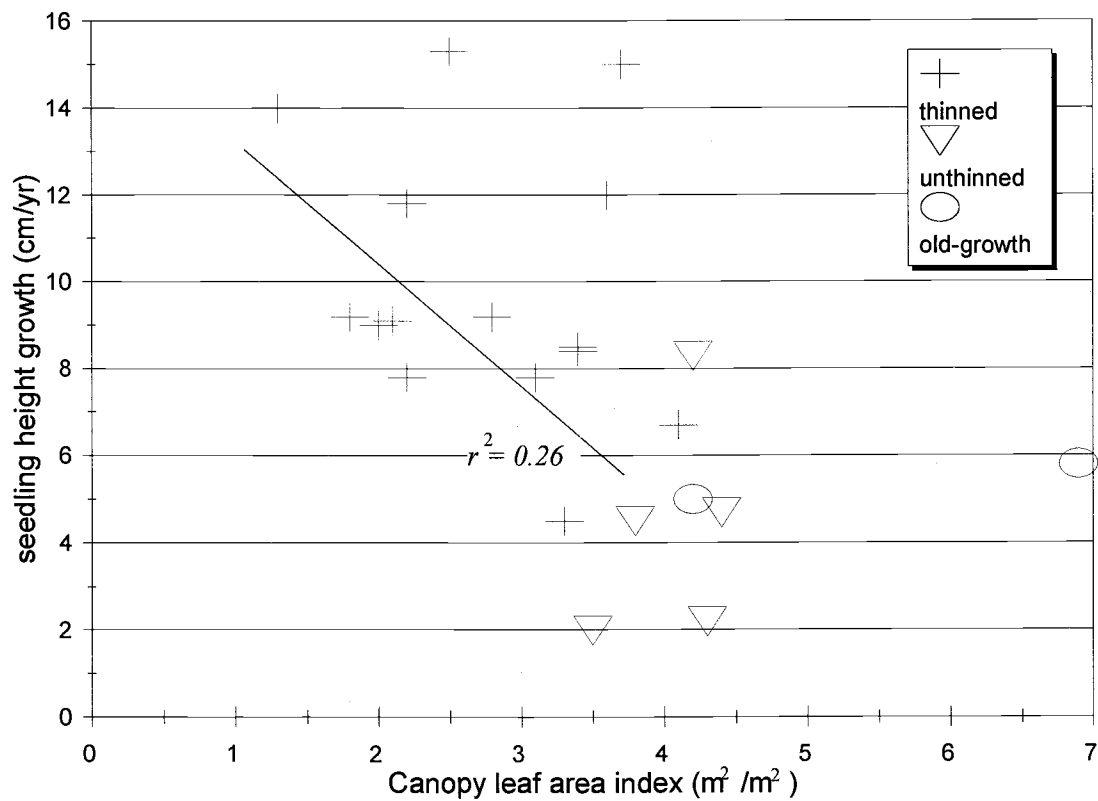


Figure 2.11. Average Douglas-fir seedling height growth (vigor) vs. canopy leaf area index (LAI) for points within a subsample of southwestern Oregon stands (near Canyonville).

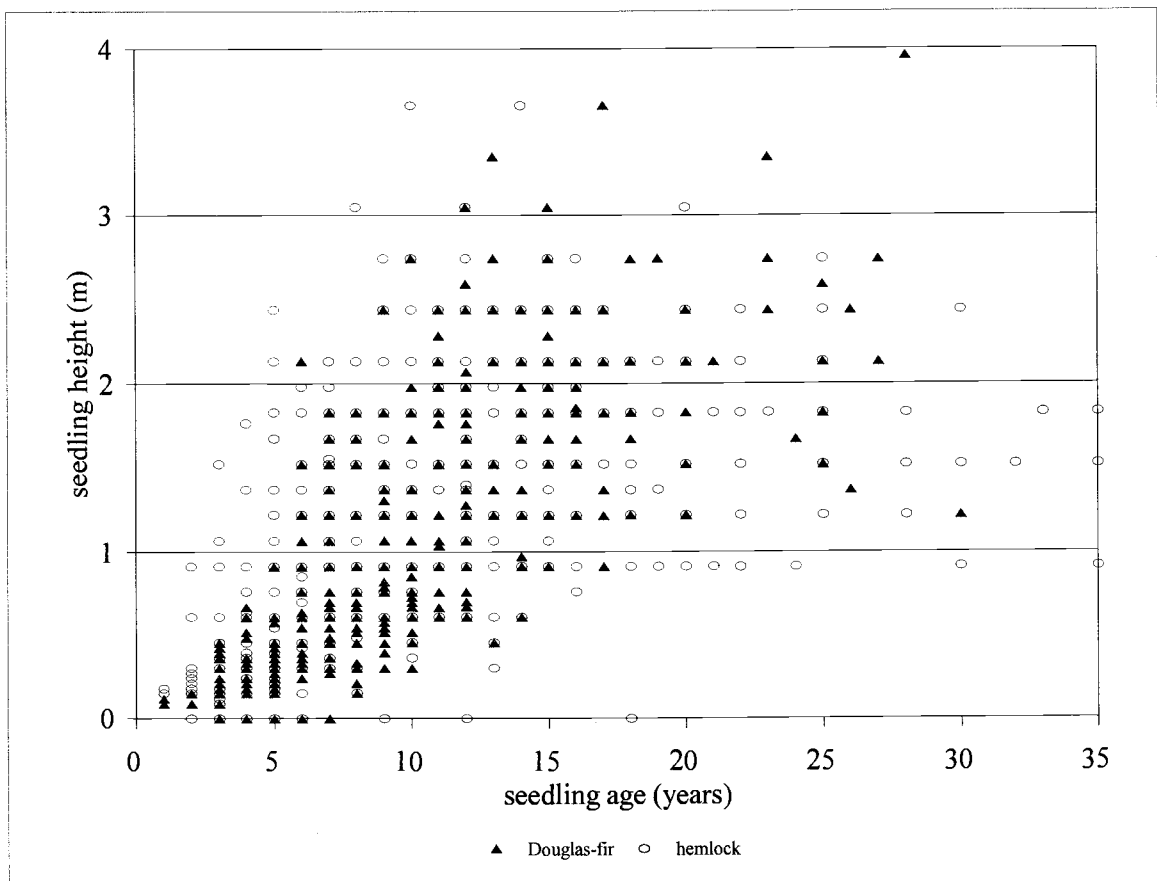


Figure 2.12. Douglas-fir and western hemlock seedling height vs. age for all 32 pairs and 20 old-growth stands.

harvest removal and resprouting since thinning. Tall shrub stem density was also higher in thinned stands in 14 of 32 pairs (lower in 5 of 32 pairs); tall shrub frequency was higher in thinned stands in 21 of 32 pairs (lower in 4 of 32 pairs). Density, LAI and frequency of tall shrubs were significantly greater in thinned stands across all 32 pairs ($p = 0.0021$, 0.0015 and 0.0014 , respectively). Three of the five sites with fewer seedlings than expected had dense communities of hardwood sprouts (averaging > 400 sprouts/ha) and/or dominant tall shrub communities (> 2500 stems/ha and frequencies = 1.0). However, many sites with similar, vigorous hardwood and tall shrub communities also had abundant conifer regeneration.

Low shrub coverage and leaf area also increased consistently with thinning (Table 2.4, and chapter 3). Thinned stands had greater low shrub cover in 16 of 32 pairs, significant across all pairs at $p = 0.0003$. This increase was driven primarily by salal and bracken fern cover. Salal cover was greater in thinned stands for 17 of 32 pairs ($p \leq 0.0001$ across all pairs) and bracken fern for 22 of 32 pairs ($p \leq 0.0001$ across all pairs). Three unthinned stands had greater low shrub cover due to the influences of sword fern and Oregon grape. Sword fern had greatest cover in 6 thinned stands and 8 unthinned stands, and was marginally greater in unthinned stands across all 32 pairs at $p = 0.1539$. Oregon grape was inconsistent, with greatest cover in 3 thinned stands and 6 unthinned stands, and $p = 0.6065$ across all pairs. Low shrub LAI was greater in thinned stands for only 11 of 32 pairs, but across all pairs at $p \leq 0.0001$. Of the five sites with fewer seedlings than expected, one showed extremely high cover of low shrubs ($\geq 80\%$). However, seven other thinned stands with $\geq 80\%$ low shrub cover had ample conifer regeneration.

Old-growth stands were more similar to thinned stands in terms of seedlings and tall shrub communities (like intermediate trees) but more similar to unthinned stands in terms of low shrub communities (Table 2.5). Conifer seedling density and frequency were different among all three stand types at $p \leq 0.0001$, with old-growth stands intermediate among and different from both thinned and unthinned stands (Figure 2.6). On individual sites, seedling density and frequency in thinned stands were not different from old-growth on 7 of 20 triads, though the percentage of shade-tolerant species was higher in old-growth stands. Five-year height growth rates on seedlings in old-growth stands were intermediate to those of thinned and unthinned stands (Figure 2.11). Old-growth had the greatest tall shrub LAI in 4 of 20 triads, thinned stands in 3 of 20 triads, and unthinned stands in one triad. Across all 20 triads, old-growth and thinned stands had similar stand-average tall shrub density, frequency and LAI, greater than unthinned stands at $p = 0.0181$, 0.0107 , and 0.0002 respectively. Low shrub cover and LAI (includes seedling leaf area) were greatest in thinned stands for 11 of 20 and 10 of 20 triads, respectively, across all triads $p \leq 0.0001$ for both. Old-growth and unthinned stands were not different in either measure of total low shrub cover. Cover of individual species did not vary between old-growth and unthinned stands.

Table 2.5. Stand-level average understory characteristics in three stand types: thinned, unthinned and old-growth stands.

Characteristic	thinned stands	unthinned stands	old-growth stands
Tall shrub LAI	0.5	0.2	0.4
Tall shrub density (/ha)	2084	1336	2430
Small shrub LAI	1.4	0.9	0.8
Low shrub % cover (total)	56	42	37
Salal % cover	23	12	10
Sword fern % cover	13	17	14
Bracken fern % cover	7	2	1
Oregon grape % cover	9	10	10
Seedling stocking (/ha)	1432	232	1010
Seedling frequency	0.51	0.14	0.38

Conclusions

This study provides an analysis of the effects of a decades-old BLM thinning program on young Douglas-fir stands, and how those stands have been and can be placed on different developmental trajectories. Foresters before Reineke (1933) have understood the influence of thinning on diameter growth and volume production in residual overstory trees. Similar to other studies mentioned, we found increased diameter growth rates and resultant larger tree boles, as well as increased crown volume to fuel that growth rate. Deeper tree crowns (greater LCRs) in thinned stands ultimately lead to increased canopy LAI as stands re-establish crown closure, as seen in several lighter thinnings in this study which have already exceeded the leaf area in their paired unthinned stand. Heavy thinnings stimulate the greatest crown volume production and leads to the fastest radial growth rates, but they remove much of the growing stock for producing volume at the stand level. Early thinning (including stands < 40 years old) provide the best opportunities to maintain large crown ratios and rapid growth rates in response to thinning. Most previous studies have been experiments conducted on small plots to determine overstory tree responses to stand density. This study verifies that these responses can be expected on operational thinnings in diverse settings.

This study documents important responses in intermediate stand structure and understory development following thinning. Thinning consistently creates conditions for:

- 1) an intermediate tree stratum dominated by released and/or regenerated individuals (as opposed to suppressed individuals common to unthinned stands), dominated by shade-tolerant species where seed sources for such species are available;
- 2) an increase in tall and (particularly) low shrub growth in terms of stem densities, total cover (predominantly salal and bracken fern), leaf area indices and frequencies in thinned stands; and
- 3) an order of magnitude increase in conifer seedling stocking and a doubling of seedling frequency in the understory, including shifts in species composition to greater Douglas-fir density, frequency and increased height growth rates.

These structural differences (e.g., more developed multi-storied canopies) not only influence the current structure and function of these stands, they are fundamental to stand development, species composition, and future structural and functional attributes.

Much of the site-to-site variability that we observed in crown characteristics, understory density, and incremental growth responses can be tied to differences in stand age, site quality, species mixes, and/or individual stand histories. Overstory and understory responses to thinning are most pronounced and consistent in stands ≤ 90 yr old on poorer sites and ≤ 70 yr on productive sites. Heavy understories of shade tolerant species (e.g., western hemlock, western redcedar, and grand fir) were created with $>20\%$ volume removal (assuming available seed sources), but heavy Douglas-fir understories required $>30\%$ removal on these sites. Understory Douglas-fir are unlikely to persist over time except under the heaviest thinnings (i.e., 50% removal). Indeed, the greatest responses in terms of overstory tree diameter growth rates, crown (and branch) sizes, intermediate structure and seedling establishment occurred on sites with $> 50\%$ removal. The histories of individual sites (i.e., the specifics of the original harvest and the thinning, fire regimes, and human settlement) modify all generalities we can make.

Are these young thinned stands on new trajectories to reach "old-growth" conditions sooner than is otherwise expected with natural succession? Our data suggest that thinned stands are already more similar, and becoming more similar, to old-growth stands in terms of:

- 1) lower overstory conifer stocking more consistent with the historical development of old-growth stands in western Oregon (Tappeiner et al., submitted);
- 2) larger overstory tree diameters and growth rates to produce larger trees sooner;
- 3) larger overstory and intermediate tree crown dimensions that has and will improve the multi-storied nature of the stands;
- 4) increased survival and initiation of intermediate trees to enhance future multi-storied development;

- 5) increased tall shrub frequency, density and leaf area to levels more consistent with old-growth stands; and
- 6) stimulation of new regeneration to supply future intermediate and overstory individuals.

However, conifer seedling density often exceeded that associated with old-growth and, perhaps to the greatest detriment to future old-growth-type structure and function, low shrub cover typically exceeded levels found in old-growth stands. Newton and Cole (1996 unpubl. data) have observed that pre-harvest suppression of understory vegetation facilitates regeneration of several species by planting, but that benefit may be restricted to stands with lower overstory densities ($< 20 \text{ m}^2/\text{ha}$ basal area).

The thinned stands we studied reflected traditional stand management practices and policies (i.e., thinning from below to enhance dominant and codominant tree growth). Large remnant trees, overstory hardwoods, soft and hard snags, and large woody debris were also typically removed. Otherwise, these thinned stands could have even more of the characteristics associated with old-growth stands. Thinning objectives in the future may include hardwood release, and actively promote crown development of intermediate and suppressed shade-tolerant species. Some structures will have to be created in young stands, but the potential for their creation (e.g., LARGE snags and woody debris) is greater in thinned stands than in unthinned stands. Though seedling, low shrub, and herbaceous frequency/cover (chapter 3) were often above levels associated with old-growth stands, these communities will likely be reduced in cover/density and frequency as overstory and intermediate canopies close with time. Managers will have to balance the stimulation of understories with volume removals of different intensities at different intervals to create and maintain desired understory structure.

Spatial arrangement of stand structure is an additional consideration when attempting to promote old-growth-type structure in younger stands. Old-growth stands have large overstory variability, with areas of continuous canopy intermixed with areas of

open gaps; indeed, ten points probably did not capture all the variability in our old-growth stands. Young unthinned stands were remarkably homogeneous prior to stem exclusion and reinitiation; light and moderate thinnings typically homogenized overstory tree spacing even further, reducing spatial heterogeneity within the stand. Only in the heavy thinnings was overstory and understory variability created. Managers can therefore purposefully increase stand spatial heterogeneity but only with heavier and/or less-uniform thinning.

Thinning will be an important tool for forest managers charged with promoting or creating old-growth-type structure within all or part of a landscape. But like any tool, thinning will not be appropriate for all stands at all times. Dense stands of young trees are a natural part of the landscape and should be maintained at appropriate levels for those plant and animal species dependent of that type of habitat. Stands with open canopies and existing vigorous shrub growth may not respond to thinning in terms of conifer regeneration without additional management (e.g., vegetation control or planting). Overstory trees with height:diameter ratios greater than 100 may be susceptible to extensive windthrow depending on slope position. However, by varying the intensity and arrangement of thinnings, and how they are interspersed with other treatments, an existing landscape can be manipulated at the stand-level to provide more old-growth-type habitat over time and across a landscape. This type of active management is a preferred alternative to strict preservation given: 1) reduced time to create old-growth-type structures in young forested landscapes lacking such habitat; 2) an ability to emphasize the creation of specific features lacking in a landscape (e.g., large snags); 3) concurrent yield of timber volume to meet societal needs; 4) associated benefits in forest fire fuel reductions or other special programs (e.g., secondary products collection); and 5) a lack of evidence showing negative impacts on plant species composition or long-term productivity following thinning.

Chapter 3

Understory vegetation in old and young managed and unmanaged Douglas-fir forests of western Oregon

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Introduction

Recent concerns over the scarcity of "old-growth" forests in the Pacific Northwest and mandates to protect associated species are prompting development of silvicultural methods which encourage formation of stand structures that mimic old-growth forests. Desired structures include: 1) a multi-storied canopy consisting of a large range of tree species, ages and sizes; 2) large-diameter standing snags and fallen logs, and 3) a diverse understory of many species and a variety of available habitats (Spies and Franklin 1991). While overstory and debris structures are often related to stand age, silvicultural treatments such as partial canopy removal ("thinning") might be used in young stands to hasten their creation. However, understory species development is not as age dependent. Spies (1991) found less than 20% of understory species were more abundant in older forests than in younger unmanaged forests. The effects of stand management for timber production, including thinning, on understory species have been documented on individual sites (e.g., Witley 1975, Halpern 1988), but few have analyzed a collection of sites within a broad geographic area.

Vascular plant richness in Pacific Northwest forests primarily resides within the shrub and herbaceous layers. Richness is high in the stage of forest succession prior to canopy closure and stem exclusion due to survival of disturbance-resistant species and additions of early seral species, including exotics, on disturbed sites (Oliver and Larsen 1990, Franklin and Spies 1991, Halpern 1988). Richness declines as stand density increases, but returns to high levels in mature and old-growth forests as low-intensity disturbances create and maintain openings in the canopy (Alaback and Herman, 1988; Long and Turner, 1975; MacLean and Wein, 1977). This rebound in richness may be explained by the increased number and diversity of microhabitats following such

disturbances (Alaback, 1982). Thinning is also a low-intensity disturbance, creating germination sites and openings in dense canopies and thereby facilitating survival and establishment of some understory species.

Witler (1975) demonstrated that understory biomass was also immediately stimulated by thinning, and the stimulation was increased as overstory cover decreased. Alaback and Herman (1988) studied the response of two coastal Oregon forest types to thinning and saw no immediate difference in vascular plants between forest types nor between thinned and unthinned stands. However, differences in understory composition and cover emerged 17 years after thinning. Variability in percent cover increased with the amount of volume removed during thinning. Understory species composition in Alaska was ultimately unaltered by management, but the duration of the shrub stage following cutting was prolonged while the period of relatively low understory cover was reduced (Alaback 1984).

General increases in understory vegetation richness, frequency and/or cover following thinning do not necessarily translate into the development of late-successional composition as shifts in species composition have been shown to be hidden in richness and diversity indices. Also, competition among and within herbaceous and shrub species can be altered in thinned stands. Expansion of clonal species was encouraged by thinning (Huffman 1992, Tappeiner et al., 1991). For example, *Gaultheria shallon* rhizomes expanded by as much as 23% annually following thinning, creating dense patches which could exclude both herbaceous plants and tree seedlings (Huffman et al., 1994). And some understory species may be mechanically damaged or eliminated during thinning.

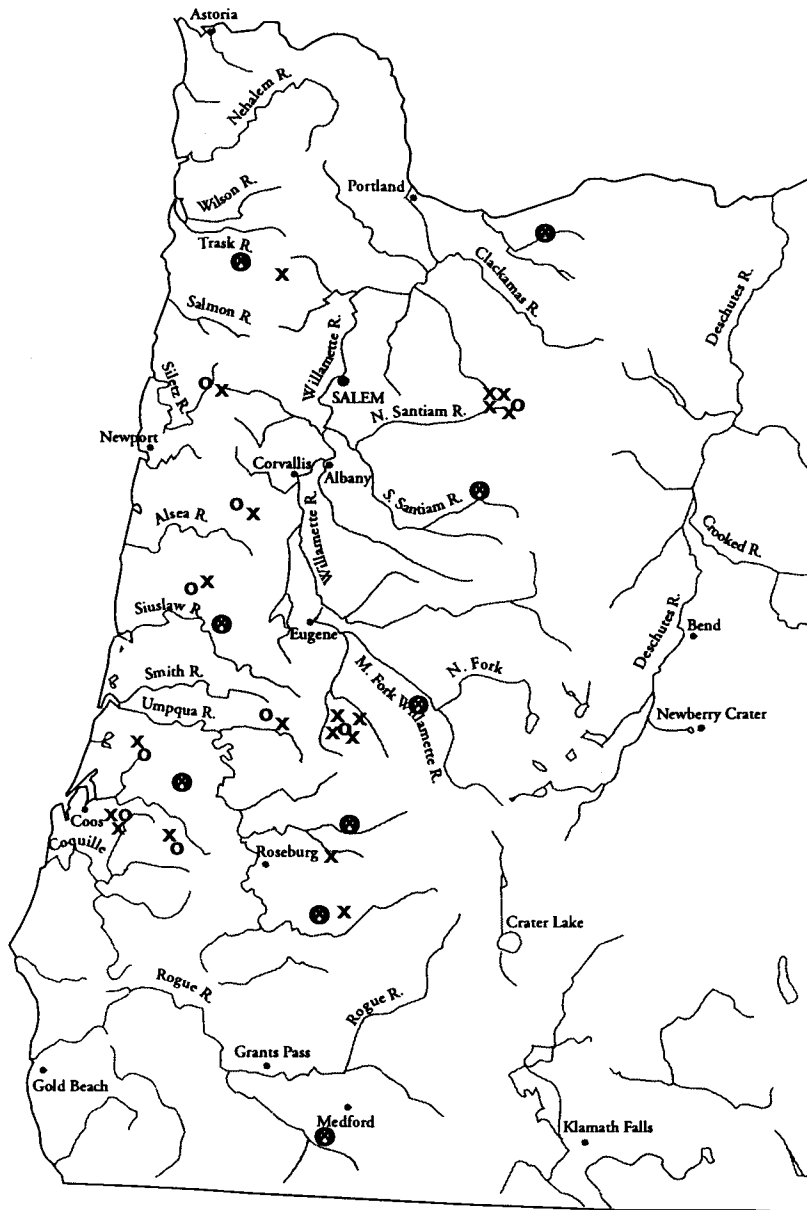
The purpose of this study was to determine if past timber management practices, including both clearcutting of > 50 years ago and thinning of > 10 years ago, had a major effect on native understory plant communities. We examined species richness, cover, frequency and composition in managed and unmanaged stands of different ages, densities and stages of succession. We tested the hypothesis that shrub and herbaceous

communities are no different among three stand types: young (50 - 120 years) unthinned and thinned stands regenerated naturally following logging, and old-growth stands. We analyzed for differences using species grouping and multivariate statistics.

Methods

This research compared shrub and herbaceous vegetation in 28 "pairs" of thinned (T) and unthinned (U) young Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands, and in 18 nearby old-growth (O) stands, to make "triads", distributed across western Oregon (Figure 3.1). Using BLM stand records, we located young stands meeting the following criteria: 1) stand age \geq 50 years; 2) a recorded operational thinning or salvage between 1970 and 1985 in part of the stand; 3) remainder of the original stand untreated but otherwise similar (e.g., slope and aspect); 4) no additional stand treatments (e.g., fertilization) in either the thinned or unthinned portion; 5) location near an older (200+ years) stand exhibiting old-growth structure; and 6) all three stands types contain greater than 10 hectares of interior environment. Thinnings ranged from light (8% merchantable volume removal) to extremely heavy (61% volume removal). The resulting sites spanned a broad range of stand conditions (Table 3.1). Young stands regenerated naturally between 1880 and 1930, usually following cutting and burning associated with railroad logging. They therefore were composed primarily of one age cohort with few large trees or snags remaining from a previous stand (Chapter 2). The older stands had little evidence of disturbance and displayed structures typically associated with "old-growth" as described by Spies and Franklin (1991).

Eighteen triads and 28 pairs (ten without old-growth comparisons) ranged in elevation from 400 to 800 m, with 100 to 300 cm/yr of precipitation and January low temperatures of -2 to 0°C and July highs of 20 to 30°C (U.S. Weather Service). Most sites were in the Western Hemlock Zone (Franklin and Dyrness, 1984) where *Tsuga heterophylla* is considered the climax species. Douglas-fir may be climax at the southern edge of this zone (Spies & Franklin 1991) and is climax in the Douglas-Fir Zone.



Legend

- x thinned/unthinned pair
- o old-growth
- complete triad

Figure 3.1. Location of research sites in western Oregon (map adapted from Franklin and Dyrness 1984). 'X' denotes a thinned-unthinned pair, 'O' denotes an old-growth stand.

Table 3.1. Stand-level average overstory and understory characteristics, by stand type, across 32 pairs of thinned and unthinned young Douglas-fir stands and 18 old-growth stands.

stands	Thinned stands		Unthinned stands		Old-growth	
	Min.	Max.	Min.	Max.	Min.	Max.
Overstory trees/ha	64	289	111	541	42	106
Overstory canopy Leaf Area Index	2.0	7.3	3.4	7.7	3.4	7.5
Tall shrub Leaf Area Index	0.1	1.4	0.0	1.1	0.1	1.1
Small shrub Leaf Area Index	0.1	2.7	0.2	2.1	0.0	1.5
Total Leaf Area Index	2.6	9.1	3.6	8.7	4.0	8.5
Total Small Shrub Cover (%)	11	95	5	85	4	73
Tall Shrubs (per acre)	64	2087	33	1304	191	2059
Tall Shrub Frequency	0.10	1.43	0.03	1.48	.23	1.55

Data collection

Stands were inventoried from mid-June through mid-September in 1993-5, 10 to 25 years after thinning which allowed sufficient time for changes in the understory communities to develop. Pairs and triads were inventoried within days of one another to minimize the likelihood of observing differences in species composition due to time of year. A stand entry location, direction and distance was pre-assigned on each stand map considering boundaries only (points were located 75 meters from any stand edge), ensuring an unbiased sample of an interior area. Six to twelve (typically ten) sample points followed a systematic grid on 50-75 meter intervals depending on total stand size.

Understory plants were divided into three strata after MacLean & Wein (1977): "tall shrubs" (≥ 1.5 meters in height), "small shrubs" (50 to 150 cm), and "herbs". Number, height and average crown radius of individual stems of all tall shrub species (e.g., *Acer circinatum*) were recorded for five 17.6 m² circular plots per point, one at the point center and four plots 15 meters from point center in each cardinal direction. Tall

shrub leaf area index (LAI) was measured at point center only using a LICOR 2000 canopy area meter (LICOR Inc, Lincoln NE). Readings were taken above tall shrub vegetation (for canopy LAI) and compared with readings from below tall shrubs (but above small shrubs). The difference between the two readings represented the amount of leaf area in that stratum.

Percent cover of small shrubs and large ferns (mostly *Berberis nervosa* Pursh., *Gaultheria shallon* Pursh., *Polystichum munitum* (Kaulf.) Presl., *Pteridium aquilinum* (L.) Kuhn.) was visually estimated in 10% classes on these same plots by species. Trace coverage was recorded as 1% for calculation of frequency; cover could total one hundred percent but typically included some empty space or bare ground. We included non-shrub species in this stratum given their size and apparent functional effect. Actual height of the stratum was recorded while measuring small shrub LAI at each point center, by difference readings as with tall shrubs. The lower LAI reading was taken above any herbaceous vegetation.

Herbaceous species cover was recorded for every observed species on 1m² subplots clustered at each point center and surrounding shrub subplot (up to twelve total per point). Percentage cover was estimated visually with the aid of a square-meter reference frame and recorded in 10% classes, with 1% trace coverage and total cover constraints as with small shrubs. Herbs were defined as being without woody, above-ground stems, but some woody plants that were normally less than 50 cm in height in these stands were measured as part of the herb layer (e.g., *Symphoricarpos mollis* Nutt.). Species which occupied multiple strata, through the occurrence of different-sized plants, appear as separate data entries. An individual plant could only occupy one strata. In the rare case that portions of one plant appeared in several strata, it was recorded in the strata where it had the greatest cover. Taxonomic classifications followed Hitchcock and Chronquist (1973).

Data analysis

Observational studies assume that paired subjects were initially identical and that observed differences are due to treatment effects (Cochran, 1983). Every effort was made when comparing adjacent communities to ensure compliance with this fundamental assumption. Detailed pre-treatment data from thinned and unthinned stands establishing their similarity was not available, but the broad classification of habitat type and the aerial-photo-based overstory classification were once identical for every thinned-unthinned pair. The advantage of this type of study was its ability to evaluate changes after long time periods (Mueller-Dumbois and Ellenburg, 1974). This study further evaluates operational practices over large areas. Comparisons of young pairs to old-growth stands ("triads") are presented even though they violate the shared-past assumption (Cochran 1983). This violation is considered minor, however, given that the study question shifts away from one of treatment effect to a simple question of how old-growth stands may differ. Pair-wise t-test comparisons and blocking by triad were both necessary to account for site (regional) differences.

We compared mean density, cover and frequency of individual species and groups of species among stand types within and across 28 pairs and 18 triads. We analyzed individual species which were common across most sites (e.g., *Oxalis oregana* Nutt.). We also were specifically interested in 15 species which Spies (1991) identified as significantly more abundant in old-growth Douglas-fir stands relative to young and mature unmanaged stands (e.g., *Coptis laciniata* Gray). Most shrub and herb species were rare among stands and/or occurred sporadically within stands. Comparisons among stand types were dependent on a species occurring at least on one point in each stand type -- atypical except for the most common 1/4 of our 229 species. Rarity resulted in non-normally-distributed cover and frequency data (i.e., skewed by the predominance of zeros for the vast majority of species, see Figure 3.2) which weakened statistical comparisons. Our data also showed markedly different variances among stand types and individual sites (related to this rarity issue). For such data not meeting the basic assumptions of

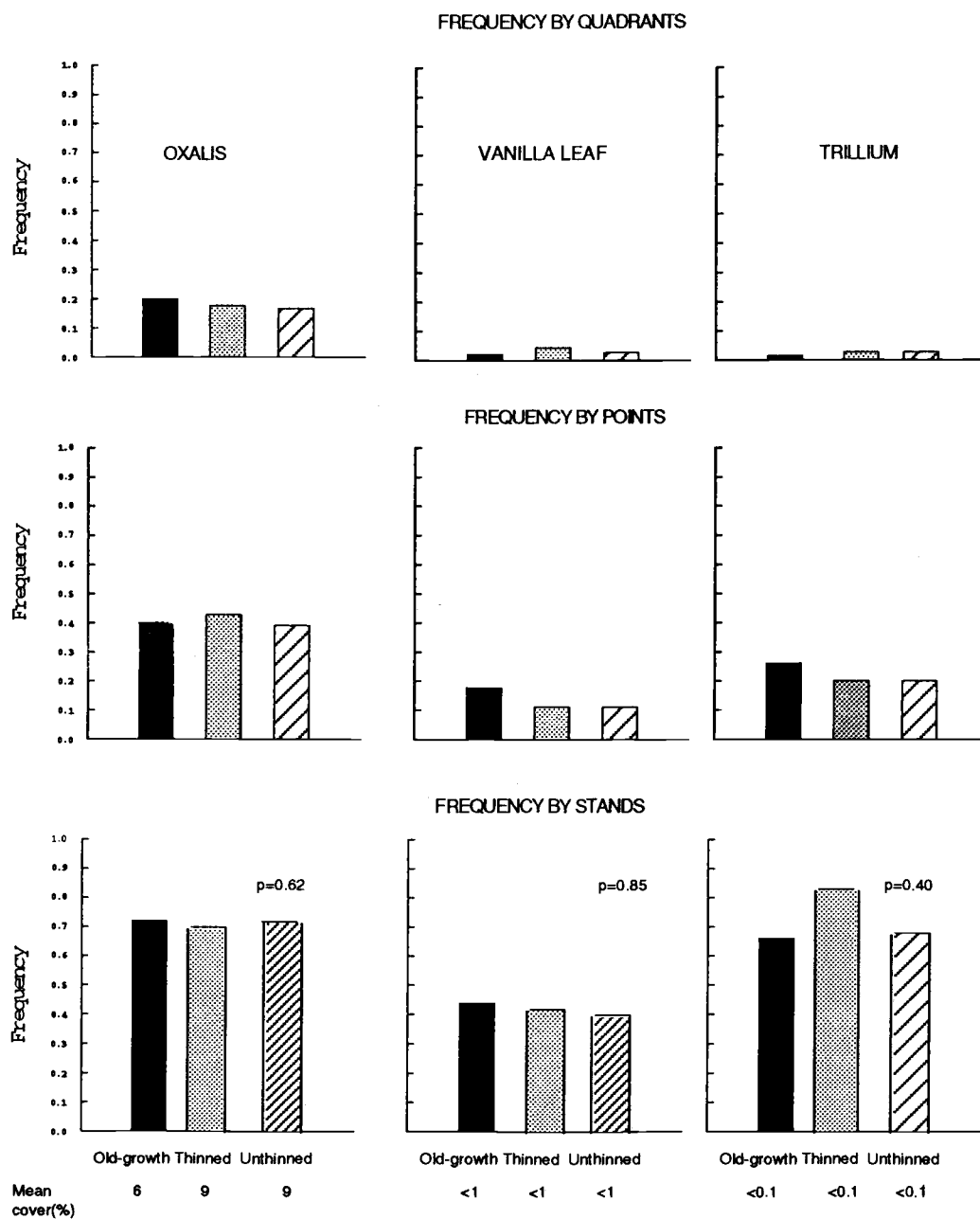


Figure 3.2. Frequency of three native herbaceous species by stand type at three scales: among 1m^2 quadrats, among points (typically 10-12 quadrats), and among stands (typically 10 points). Vanilla leaf, *Achlys triphylla* (Smith) DC., was more common than *Trillium ovata* on quadrats, but less common among stands. *Oxalis oregana* Nutt. was the most common species of 178 herbaceous species at the quadrat and point scales. Mean percent cover by stand type is shown at the bottom, with p-values for testing differences among stand types.

parametric statistics (i.e., normally-distributed, independent data with equal variances), we used Wilcoxon rank-sum test comparisons, and present medians with 25/75 quartiles and p-values from a Kruskal-Wallis chi-square approximation (SAS Institute, Inc).

Given the rarity of most species and the ability of related species to function in similar ecological roles across broad landscapes, we aggregated species into groups (Table 3.2) and analyzed aggregate cover and frequency, a concept adapted from Keddy (1992). Grouping increased frequency and cover sufficiently to construct tests for most pairs and triads, and increased our ability to detect cover and frequency differences among stand types. A few comparisons even met the assumptions of parametric statistics, in which case we used t-tests or ANOVA comparisons and present means \pm one standard deviation ($n = 18$) and p-values from the t- or F-statistic. Total (all species) density, cover and/or frequency similarly improved our ability to compare stand types within and across pairs and triads. We excluded our single, most-southern triad from this calculation given the 75 additional species it brought to the list. We did not want our presentation to be susceptible to a single site from a different geographic area.

Multivariate detrended correspondence analysis (DCA) and non-metric scaling (NMS) procedures in PC-ORD (McCune and Mefford 1995) were used to analyze patterns in cover and frequency data. Both methods are used to indicate consistent shifts in species composition across samples. DCA is a standard procedure for viewing ecological data and adequately recovers information along the first axis if additional axes are of minor importance (van Groenewoud 1992). We relativized cover data to equate the respective influence of various species; frequency data were essentially relativized (i.e., all were species 0-1). We also used a "global" NMS ordination (McCune and Mefford 1995) for comparison since DCA axis 1 only captured 42% of the variability in the original full species-by-stand matrix and the original data matrix was replete with outliers which distort ordination space. NMS ordination is not sensitive to outliers or non-normal data and has a more meaningful second axis relative to DCA. The 2 NMS axes had a cumulative coefficient of determination of 0.78.

Table 3.2. Identification and description of six species groups used in this paper, including a brief rationale for their inclusion in the analyses.

Species Groups	Included species
<p>Nitrogen-fixing species:</p> <p>Species capable of fixing nitrogen hold competitive advantages on disturbed sites due to their abilities to establish and prosper on N-depleted soils. They require additional mineral and light resources to exploit this ability. Young stands in this study have disturbance histories; thinned stands include recent disturbance and increased understory resource availability. Thinned stands should contain the greatest abundance of N-fixing species.</p>	<p><i>Ceanothus</i> spp. <i>Cystisus scoparius</i> <i>Lathyrus</i> spp. <i>Lotus micranthus</i>, <i>L. purshiana</i> <i>Lupine</i> spp. <i>Medicago lupulina</i> <i>Swainsona salsula</i> <i>Thermopsis montana</i> <i>Trifolium eriocephalum</i> <i>Vicia cracca</i>, <i>V. americana</i></p>
<p>Tall, cordate-leaved species:</p> <p>Species which display horizontally-oriented, cordate leaves on erect stems are effective light gatherers in heavily-shaded environments where the risk of desiccation is low (Givinish, 1987). These species may therefore be unusually susceptible to disturbance and should be most common in old-growth stands which lack such histories.</p>	<p><i>Actea rubra</i> <i>Asarum caudatum</i> <i>Dicentra formosa</i> <i>Maianthemum dilatatum</i> <i>Mitella caulescens</i>, <i>M. ovalis</i> <i>Tellimia grandiflora</i> <i>Tiarella trifoliata</i>, <i>T. unifoliata</i> <i>Trillium ovatum</i></p>
<p>Grass and sedge species:</p> <p>The presence and thin-leaved grass and sedge species indicates high light environments where desiccation is common. They also possess the ability to spread rapidly via seed into disturbed sites. Thinned stands, with the lowest canopy LAIs and greatest disturbance histories, should contain the most grass and sedge species.</p>	<p><i>Bromus</i> spp. <i>Carex</i> spp. <i>Cynosurus echinatus</i> <i>Elymus glaucus</i> <i>Fescue</i> spp. <i>Holcus lanata</i> <i>Luzula campestris</i>, <i>L. parviflorus</i>, <i>L. spp.</i> <i>Poa</i> spp.</p>
<p>Achlorophyllous species:</p> <p>Species lacking chlorophyll during some part of their life history include: monotropoid, orchidoid, ericoid, and parasitic species. They are unique in how they use shaded, understory environments and are ill-adapted for rapid dispersal given their host specificity and mycotrophic dependency (Luoma, 1995).</p>	<p><i>Corallorhiza maculata</i>, <i>C. mertensiana</i> <i>Goodyera oblongifolia</i> <i>Hemitomes congesta</i> <i>Hypopitys monotropa</i> <i>Monotropa uniflora</i> <i>Pleurocystis fimbriolata</i> <i>Pyrola aphylla</i></p>
<p>Matted Vines:</p> <p>Species with vine-like growth forms are capable of rapid expansion into disturbed sites to capture new resources (e.g light). They often develop thick vegetative mats which may preclude establishment and growth of other species. Thinned stands should have the greatest frequency and cover of these species.</p>	<p><i>Galium aparine</i>, <i>G. oregonum</i>, <i>G. triflorum</i> <i>Nemophila parviflora</i> <i>Rubus ursinus</i> <i>Whipplea modesta</i></p>
<p>Exotic species:</p> <p>This group includes species identified in our sample plots which were established in Oregon after Euro-American settlement (approximately 1900) according to Hitchcock and Chronquist (1973). They possess a combination of regenerative and survival strategies that has enabled their populations to invade and persist with native species. They are potentially assisted by the disturbances associated with young and young, thinned stands in this study.</p>	<p><i>Caucalis microcarpa</i> <i>Chrysanthemum leucanthemum</i> <i>Cirsium arvense</i>, <i>C. vulgare</i> <i>Cynosurus echinatus</i> <i>Cystisus scoparius</i> <i>Digitalis purpurea</i> <i>Epilobium angustifolium</i> <i>Holcus lanatus</i> <i>Lactuca muralis</i> <i>Rubus laciniatus</i> <i>Rumex crispus</i> <i>Senecio jacobea</i> <i>Swainsona salsula</i> <i>Urtica dioica</i> <i>Vicia cracca</i></p>

Both ordination techniques were applied to the full herbaceous stand-by-species matrix: 75 stands and 56 species which were found on at least 5% of the sites (3 sites). That analysis indicated a strong regional signal in the data which prompted analysis of a reduced matrix comprised of 20 northern Coast Range stands and their 42 non-rare species. Only DCA was used to analyze the small shrub stand-by-species matrix (80 stands and 4 common species) since these data better met the assumptions of DCA. We correlated axes with individual species to determine which species might be driving the ordination of sites and stand types. We also correlated axes with a secondary matrix containing mean annual precipitation and temperature records, and stand elevations and aspect (sine transformed). Mayrsohn (1995) conducted similar DCA and correlational analyses on shrub and herb data from a subset of these sites sampled in 1993 only.

Results

Density and Cover

The density/cover of vegetation in each stratum was greatest in thinned stands, consistent with the premise that thinning creates new resources for growth at small spatial scales as a result of the operational disturbance. Total tall shrub density (all species) was greater in old-growth and thinned stands than in unthinned stands ($p = 0.0286$). Thinned stands had greatest density in 14 of 28 pairs, significant across all pairs at $p = 0.0021$. Tall shrub LAI was not significantly different between thinned and old-growth stands, as with density, though unthinned stands had significantly lower LAI ($p = 0.0011$). Tall shrub density for individual species was not consistently different across stand types except for *Rosa gymnocarpas*, which was significantly greater in thinned stands across 28 thinned-unthinned pairs ($p = .0543$).

Total small shrub cover was greater in thinned stands than in either unthinned or old-growth stands ($p = 0.0048$), averaging 13% greater cover. This increase can be attributed to increases recorded in two species: *Pteridium aquilinum* and *Gaultheria shallon*. *Pteridium* cover increased from 0 and 1% in unthinned and old-growth stands,

respectively, to 5% in thinned stands (median values, rank test $p \leq 0.0001$); *Gaultheria* cover increased from 5 and 8% to 23% (median values, rank test $p = 0.0233$).

Polystichum munitum cover was not consistently different across triads ($p = 0.80$), but was marginally greater in 28 unthinned stands relative only to their paired thinned stand ($p = 0.1530$). *Berberis nervosa* cover was not consistently different across pairs or triads. Small shrub LAI was consistently greater in thinned stands ($1.4 \text{ m}^2/\text{m}^2$) than in old-growth and unthinned stands, both $0.8 \text{ m}^2/\text{m}^2$ ($p = 0.0001$). Combining LAI for the two shrub strata and comparing across stand types yields significant differences among all three stand types ($p = .0005$), with thinned stands averaging $1.7 \text{ m}^2/\text{m}^2$, old-growth stands $1.2 \text{ m}^2/\text{m}^2$ and unthinned stands $0.9 \text{ m}^2/\text{m}^2$. This suggested some compensatory interaction between tall and small shrubs, at least in old-growth. Chapter 2 presents additional analysis of shrub cover as it related to overstory conditions and tree regeneration.

Total herbaceous cover was also consistently greater in thinned stands across 18 triads ($p = 0.0280$) and 28 pairs ($p = 0.0054$) relative to both unthinned and old-growth stands. Thinned stands averaged 25% total herbaceous cover $\pm 6\%$, approximately 10-12% greater than either unthinned or old-growth stands. Total herbaceous cover was not significantly different between unthinned and old-growth stands, averaging 13 and 15% total cover, respectively. Cover was not different among stand types for most of the 212 herbaceous species, or even the most common 56 species, given their respective sporadic occurrence among points and stands. None of the 15 old-growth-associated species from Spies (1991) had significantly greater cover in old-growth stands than in either young stand on these sites.

Frequency

Shrub species were significantly more frequent (occurred at more points) than herbaceous species thereby creating opportunities for stand type differences to be expressed. Consistent with cover results, *Pteridium aquilinum* was significantly more common ($p \leq 0.0001$) in thinned and unthinned stands than old-growth forests with median frequencies = 0.9, 0.7, and 0.18, respectively. *Acer circinatum* Pursh. was significantly more common ($p = 0.0752$) in old-growth stands than either thinned or unthinned stands with median frequencies = 0.15, 0.05, and 0.04, respectively. All points on all sites had some small shrub species present and typically contained multiple species. *Gaultheria shallon* and *Polystichum munitum* were the most common of all shrubs, with median frequencies greater than 0.8 across all stands (stand type comparison $p = 0.21$ and 0.95, respectively).

Every point on every site also had some herbaceous cover making a test of frequency using all 212 species meaningless. At the opposite extreme, testing individual species' frequencies produced few significant differences as with cover data. For example, only three of the 15 old-growth-associated species from Spies (1991) showed significantly different frequencies (significance at $p < 0.15$) among stand types for our sites: *Tiarella trifoliata* var. *unifoliata* (Hook.) Kurtz. at $p = 0.07$, *Synthyris reniformis* (Dougl.) Benth. at $p = 0.09$, and *Goodyera oblongifolia* Raf. at $p = 0.06$. *Tiarella trifoliata* frequency was greatest in thinned and old-growth stands; *Synthyris reniformis* frequency was greatest in unthinned stands; and *Goodyera oblongifolia* frequency was greatest in unthinned and old-growth stands. *Rubus ursinus* Cham. & Schlecht. was one of the few individual herbaceous species to show a consistent increase in frequency across stand types ($p \leq 0.0001$), being most frequent in thinned stands.

Table 3.3 shows that differences in herbaceous species frequencies and cover across such a broad landscape can be detected by grouping species as described in Table 3.2. Though aggregate cover of some species groups were still quite low (e.g., nitrogen-fixers), increased frequency has relevance both as an indicator of stand history and as a

Table 3.3. Frequency and percent cover comparisons for each species group across thinned (T), unthinned (U) and old-growth (O) stands. The second and fourth columns show stand means \pm one standard deviation ($n = 18$) for normally-distributed data and stand medians with 25 and 75 percentiles for data requiring ranking (indicated with superscripts for four species groups). The third and fifth columns show p-values for the comparisons and which stand types are different by letter designation. For example, N-fixing species have significantly greater frequency (median = 0.25) than unthinned or old-growth stands at $p = 0.0002$ based on rank-transformed data.

Species Grouping	Point Frequency	Comparisons with p-values	Summed cover (percent)	Comparisons with p-values
Nitrogen-fixing species (ranked)	T = 0.25 (0-0.67) U = 0 (0-0.20) O = 0 (0-0.00)	$p = 0.0002$ a b b	T = 0.20 (0-1.50) U = 0 (0-0.05) O = 0 (0-0.00)	$p = 0.0062$ a b b
Tall, cordate-leaved species	O = 0.42 (.35-.49) T = 0.28 (.21-.35) U = 0.22 (.16-.28)	$p = 0.0094$ a b b	O = 0.25 (.07-.74) T = 0.16 (.03-.46) U = 0.09 (.03-.21)	$p = 0.0759$ a ab b
Grasses and sedges	T = 0.66 (.39-.95) U = 0.49 (.17-.81) O = 0.34 (.09-.59)	$p = 0.0022$ a b b	T = 0.57 (.32-2.5) U = 0.32 (.02-.79) O = 0.12 (.05-.38)	$p = 0.0003$ a b b
Achlorophyllous species (ranked)	U = 0.16 (0-0.3) O = 0.10 (0-0.2) T = 0.09 (0-0.1)	$p = 0.2125$ a a a	U = 0.03 (0-0.04) O = 0.01 (0-0.05) T = 0.01 (0-0.02)	$p = 0.5714$ a a a
Matted vine species (ranked)	T = 1.0 (0.9-1.0) U = 1.0 (0.9-1.0) O = 0.6 (0.4-0.9)	$p = 0.0001$ a b c	T = 8.3 (1.5-10.4) U = 1.6 (1.4-3.30) O = 0.9 (0.3-2.64)	$p = 0.0001$ a b b
Exotic species (ranked)	T = 0.1 (0.1-0.3) O = 0 (0.0-0.1) U = 0 (0.0-0.0)	$p = 0.0001$ a b c	T = 0.08 (.01-.30) O = 0 (.00-.11) U = 0 (.00-.00)	$p = 0.0001$ a b c

potential source of propagules for future stand development. In cases where changes in cover were statistically and biologically significant (e.g., grasses and sedges), there may be immediate relevance to ecosystem function. Though insignificant across 18 triads, achlorophyllous species frequency was greater in unthinned than in thinned stands across all 28 pairs ($p = 0.033$) with medians = 0.11 and 0.08, respectively.

Richness

We recorded 137 herbaceous species across all sites north of Canyonville, Oregon. Total species richness was consistently higher in thinned stands relative to unthinned stands and old-growth forests, presumably based on the increased alpha diversity in the understory environment within thinned stands (Table 3.4). Ten triads analyzed by Mayrsohn (1995) had greatest richness in thinned stands (38 species) whereas corresponding unthinned and old-growth stands averaged 31 species each, significantly less than thinned stands ($p < 0.05$).

Richness of exotic species was greatest in thinned stands, though exotics did not solely account for the increase in total richness seen in thinned stands (Figure 3.3). Nitrogen-fixers and native grasses were also richer in thinned stands, and only two species unique to thinned stands were exotic (Table 3.4). Richness did not, therefore, convey all the information in this data set. For example, old-growth and thinned stands were identical in terms of tall cordate-leaved species richness even though their frequencies were significantly different (Table 3.3). The interpretation of richness within stands, across all stands of one type, and within species groups needs to be integrated with information about frequency and cover, and overall community composition.

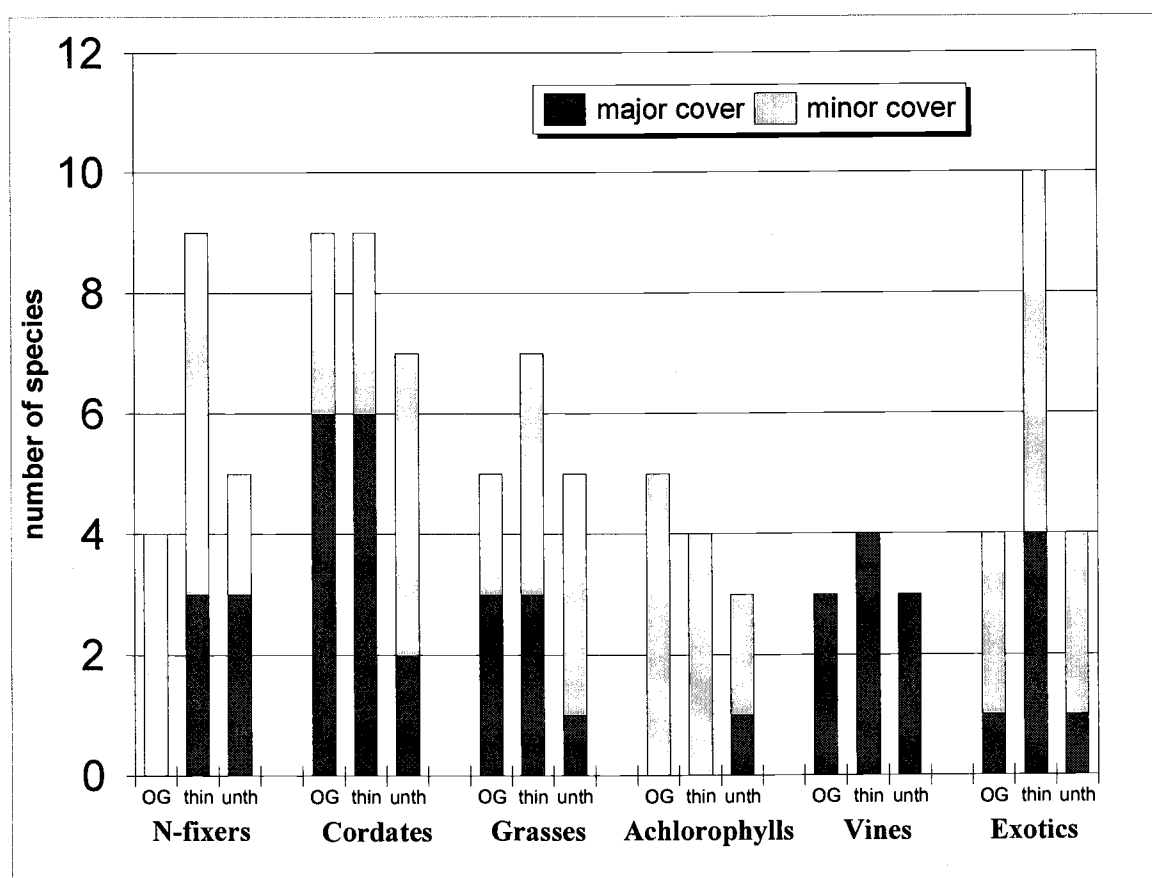


Figure 3.3. Species richness (number of species) by stand type for the six species groups. Major cover (dark bar) corresponds to individual species cover that averaged ≥ 1 percent across 10 1-m² subsamples at any point in any stand; minor cover was that < 1 percent.

Table 3.4. Species richness (number of species) by stand types across 17 old-growth stands and 27 thinned-unthinned paired young stands, identifying species unique to a given stand type. ¹denotes an exotic species; ²is a grass species; ³is a monotropoid; and ⁴is a nitrogen fixing species.

Stand type	Total number of herbaceous species	Species unique to stand type
Old-growth forest	91	(none)
Young unthinned	114	<i>Erechitias minima</i>
Young thinned	133	<i>Anaphalis margaritacea</i> <i>Aralia californica</i> <i>Chrysanthemum leucanthemum</i> ¹ <i>Elymus glaucus</i> ² <i>Epilobium minutum</i> <i>Hypopitys monotropa</i> ³ <i>Hydrophyllum occidentale</i> <i>Lupinus spp.</i> ⁴ <i>Mimulus dentata</i> <i>Oenanthe sarmentosa</i> <i>Rubus laciniatus</i> ¹ , <i>R. leucodermis</i> <i>Senecio triangularis</i> <i>Veratrum californicum</i>

Community composition

The mix of species, based on multi-dimensional ordination of shrub cover and shrub frequency data, produce remarkably similar patterns. Both cover (Figure 3.4) and frequency show site-to-site and stand-type differences. Thinned stands were most distinct from old-growth and unthinned stands particularly along axis 1. Axis 1 correlated positively with *Gaultheria shallon* cover ($r = 0.61$) and negatively with *Polystichum munitum* cover ($r = -0.62$), the dominant shrub and fern species. Heavily-thinned stands ≤ 80 years with dense shrub cover comprise all the stands outside of the polygon defined by old-growth and unthinned stands along axis 1. There does not appear to be any other

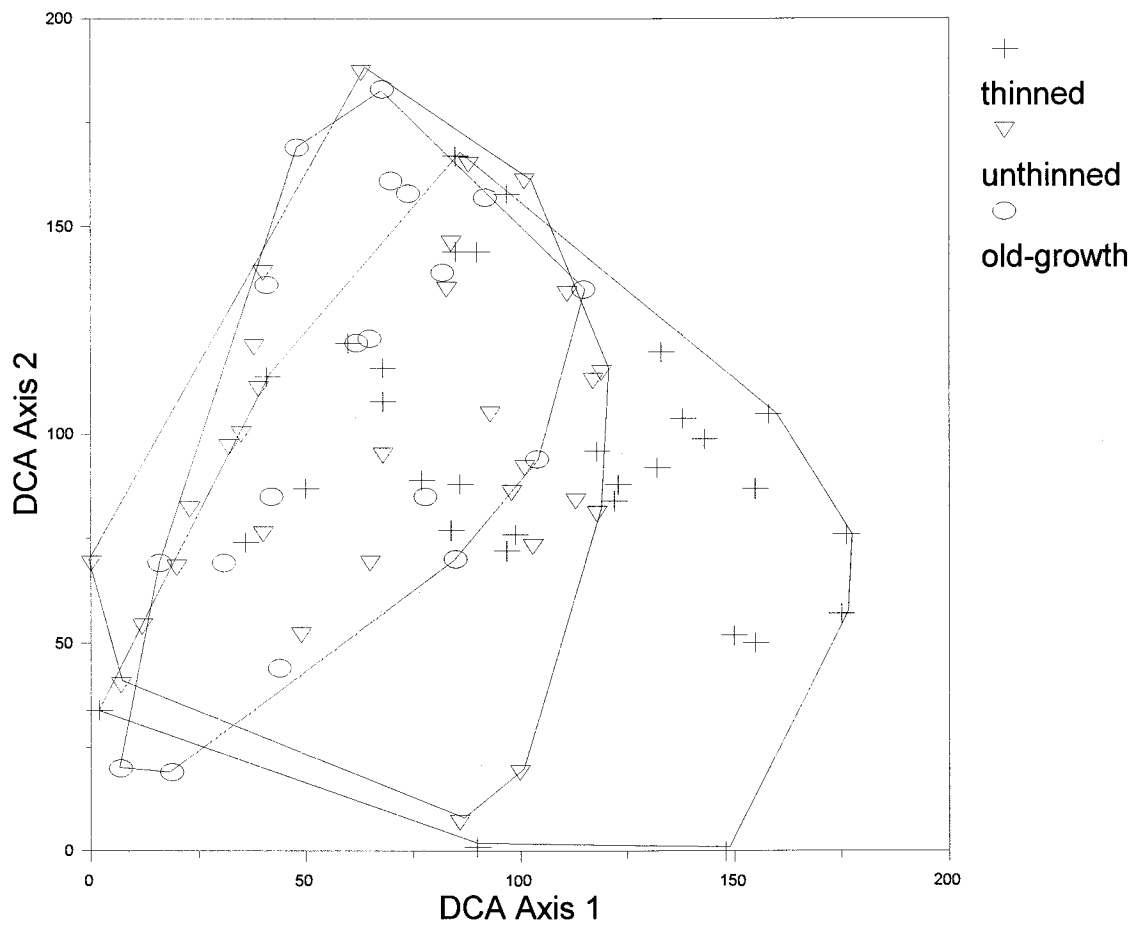


Figure 3.4. Detrended Correspondence Analysis (DCA) ordination of small shrub cover data over the entire range of sites (4 species and 80 stands). Polygon lines delineate the range of data in two dimensions by stand type.

ecological factor (e.g., latitude or climate) associated with axis 1. Similarity in ordinations of frequency and cover data suggests that the ordination of stands was controlled by species frequency within and among stands, which was only slightly modified by differences in percent cover.

Ordinations of herbaceous community data showed much stronger site-to-site differences than stand type differences (Figure 3.5), a result very similar to Mayrsohn (1995). Similar patterns were seen with DCA ordinations with and without smoothing and standardizing procedures. Pairs and triads ordinated closely in 2-dimensions assigned by axes 1 and 2, which captured 78% of the variability in the original data matrix. Southern pairs and triads tended to occupy the lower range of both axes. These pairs and triads had a high frequency of dry-site species like *Whipplea modesta* Torr. ($r = -0.54$ and -0.49 with axes 1 and 2, respectively) and low frequency of moist-site species like *Oxalis oregana* ($r = 0.49$ with axis 1). Correlation with a secondary matrix containing mean annual rainfall produced an $r = 0.67$ and 0.47 for axes 1 and 2 respectively. Pairs ordinated in closer proximity to one another than with their corresponding old-growth stands. In those cases in which all stand types were physically adjacent, their ordinations were typically most proximate to one another as well. The area of 2-dimensional space occupied by each stand type appears greater for old-growth (dominant on axis 1) and unthinned stands (dominant on axis 2) than thinned stands. This suggests that old-growth and unthinned herbaceous communities were more different among themselves than thinned stands.

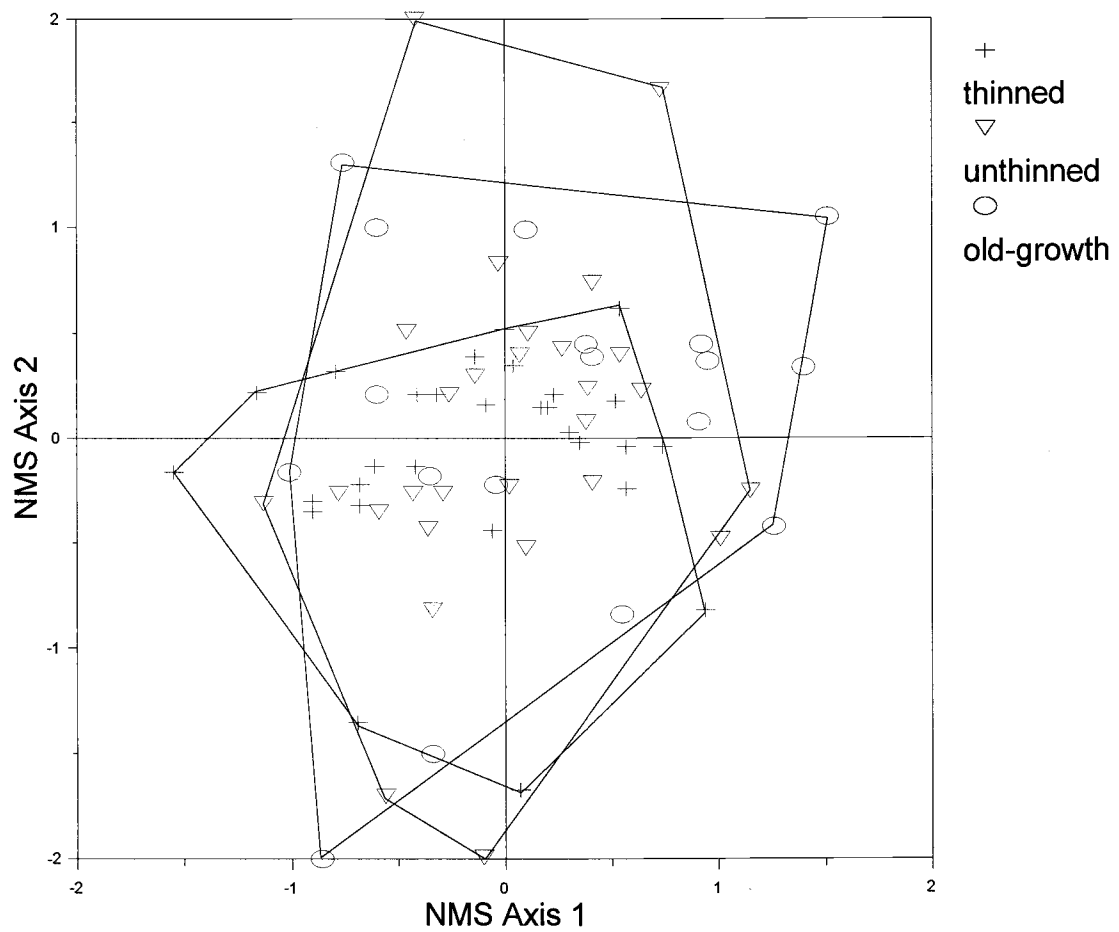


Figure 3.5. Non-Metric Scaling (NMS) ordination of herbaceous species frequency data for 75 sites and 59 species. Polygon lines delineate the range of data in two dimensions by stand type.

A subsample of six northern Coast Range triads, selected to minimize the tendency for ordinations to only distinguish among sites across different vegetation types in western Oregon, still showed that tendency (Figure 3.6). Site-to-site difference was the strongest signal in the herbaceous data matrix. The two primary axes again captured 78% of the variability in the original data matrix. As with the full data set, thinned and unthinned stands were consistently more proximate to each other than to their corresponding old-growth stands, and old-growth herbaceous communities were most variable in the two dimensions. Within this smaller geographic area, the correlation of axes 1 and 2 with rainfall decreased to $r = -0.32$ and -0.48 , respectively.

Discussion

Thinning the overstory canopy of young Douglas-fir stands in western Oregon resulted in consistent stimulation of understory communities relative to their unthinned control stands. Richness, frequency and cover of many species and species groups, including exotics, was increased by thinning. Total herbaceous cover, and shrub LAI and cover, were therefore significantly greater than in corresponding unthinned stands. These changes were likely the result of an increase in small-scale habitat diversity created by low-intensity disturbance across a large area. These thinnings created a range of newly-disturbed environments with increased light and other resources rather uniformly throughout the stand. This stimulation of herbaceous communities was likely less than that seen as the result of complete canopy removal. There was little evidence for competitive interaction between strata. Thinned stands consistently had greater tall shrub, small shrub, and herbaceous cover, frequency, density and/or leaf area than in unthinned stands. Within stand analyses also showed stimulation of multiple strata at one point in the stand. Apparently, most thinned stands provide sufficient resources for multiple strata to develop simultaneously, at least in the near term.

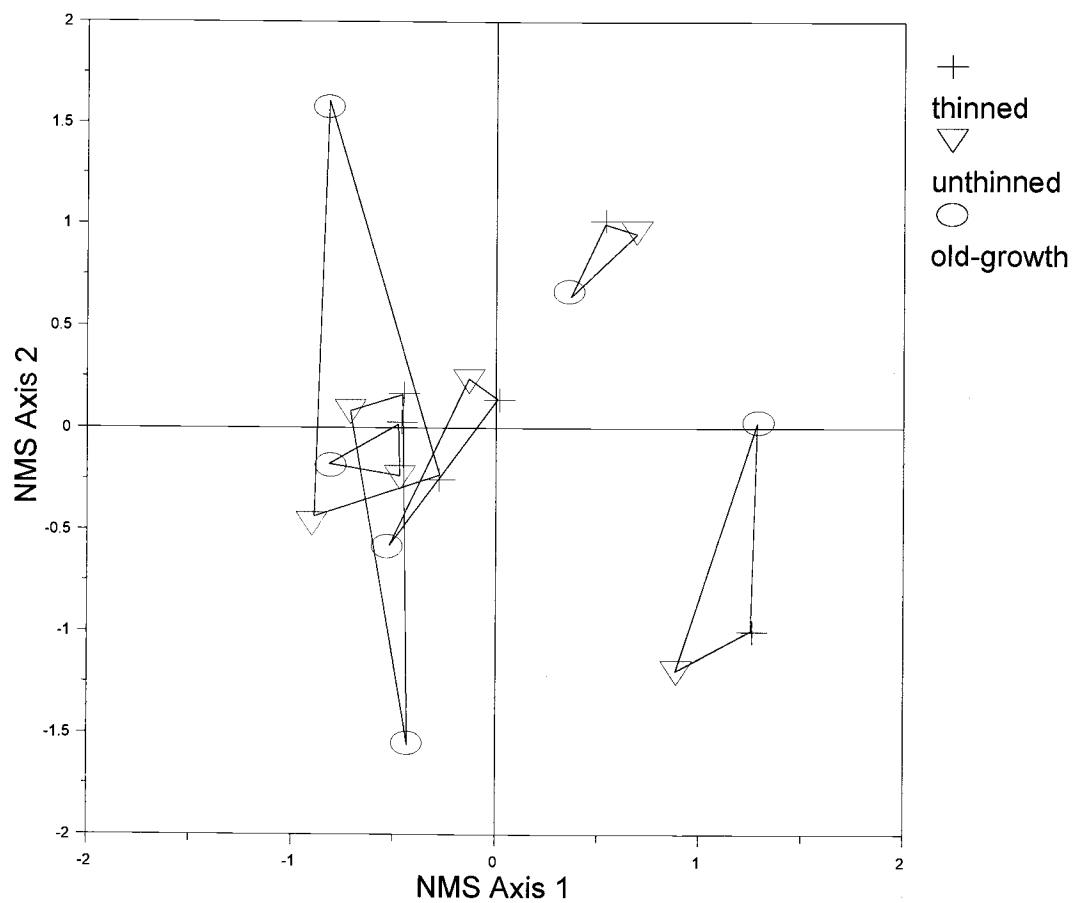


Figure 3.6. Nonmetric Scaling ordination of herbaceous species frequency data over six triads (42 species and 18 stands), showing stand type by symbol and delineating pairs and triads for reference.

Thinned second-growth stands also consistently showed equal or greater richness, frequency and cover of herbs and shrubs relative to nearby old-growth forests. The exceptions to this were the leaf area and density of tall shrubs in total, density of several tall shrub species, and the frequency of tall cordate-leaved, shade-loving species, which was greatest in old-growth stands. The cover of tall cordates, however, was enhanced by thinning such that thinned and old-growth stands were not significantly different. Changes in richness, frequency and cover changes do not automatically result in changes to composition (the mix of species). We found little evidence of consistent compositional shifts among any of the stand types, particularly for herbaceous species.

Site-to-site differences in understory communities dominated any treatment or stand age effect, as demonstrated by multi-dimensional ordination analyses which placed pairs and triads in close proximity to one another, and subregions (e.g., southern Cascades) together. Furthermore, the concept of species grouping, which allows for substitution of species with similar ecological 'roles' across sites, was shown to be highly effective in distinguishing stand types. Finally, blocking by triad was significant in all but a few of the hundreds of comparisons made in this analysis, and pair-wise t-tests were necessary.

For old-growth and unthinned stands, differences among triads (e.g., north and south) reflect changes in climate, soils, and landscape history; differences across thinned stands further include the dynamics of thinning disturbance (intensity of and time since thinning). In this latter case, the frequency of nitrogen-fixing species across thinned stands shows some correlation with thinning intensity (i.e., site disturbance) as measured by the percent volume removed ($r = 0.44$). Such low correlations were due to variations in site history and quality, stand age and time since thinning, as well as our limited selection of sites. The size and design of this study precludes using multiple regressions with all influential factors to predict species cover and frequency. This site-to-site variability has major implications on how we monitor rare species within broad landscapes, and how we look for potential effects of silvicultural treatments. Sampling

with sufficient intensity to construct estimates of cover and frequency that would show differences among stands will be prohibitively expensive when applied broadly.

Similarities in understory vegetation between young stands (particularly unthinned stands) and old-growth stands suggests that native vascular plants in the Coast Range are quite resilient to environmental change. The logging and burning when these stands were harvested around the turn of the century was a severe disturbance, and early successional species probably dominated these stands for two or more decades. Then during the dense stem exclusion stage of stand development (Oliver and Larsen 1990), that flush of early seral growth was suppressed. Despite these extreme environmental fluctuations, species richness, composition, total cover and individual species frequency and cover are indistinguishable 50+ years later. This is consistent with work by Dyrness (1973) documenting the ability of native understory species to survive major environmental change created by clearcutting. As young unthinned stands move through self-thinning and stem re-initiation, they will probably better mimic old-growth forest understory communities. The heaviest thinnings evaluated in this study apparently have over-initiated understory density, cover, frequency and richness in most cases.

Does thinning accelerate the formation of old-growth type understory communities in young, dense Douglas-fir stands? Thinning increased the density, cover and frequency of many species that were suppressed under the light-limiting canopy of unthinned stands to levels found in old-growth stands. For example, tall shrub density and tall cordate-leaved herbaceous cover were stimulated to levels comparable to old-growth stands. And thinning increased total richness (alpha diversity) in the understory community which may have implications for future stand composition. However, old-growth forests did not consistently show maximum richness, nor highest density, frequency and cover of all herbaceous and shrub species. Increases in the frequency and cover of invasive and exotic species in thinned stands may even be counterproductive to the formation of old-growth forest communities. Future thinning operations and other stand management must allow for the over-stimulation of understory vegetation.

Managers can monitor the development of exotic and native species cover to see if it remains high over time. With the development of intermediate conifer and hardwood structure in thinned stands (Chapter 2), herbaceous and shrub cover may return to lower levels more consistent with old-growth stands. Managers could also compensate for the over-stimulation of understory vegetation by varying the intensity of thinning within and among stands, leaving a mixture of open (low LAI) and dense (high LAI) canopies to more closely simulate natural stand re-initiation. Such variable-intensity thinning, which creates within-stand heterogeneity, would enhance both alpha- and beta-diversity (in the broader landscape) and represents an alternative to developing a matrix of evenly-thinned young stands interspersed with other stand types. However, continuous cover of any stand type (particularly young plantations and unthinned mature stands) reduces beta-diversity and should be avoided.

SUMMARY

Silviculturists for the USDI Bureau of Land Management, among other land managers, are interested in the potential for converting young-growth Douglas-fir forests into structurally-older forests in time frames shorter than that of natural succession. The western Oregon landscape is judged by the public to have more young (<80 year old) forests (including plantations) and less older (200+ year old) forests than is thought necessary for some wildlife species such as the northern spotted owl. In addition, much of our landscape is comprised of forests <40 years-old which will be growing into dense stands. The forestry literature is rich regarding the effects of density regulation and thinning for promoting larger, more vigorous and faster growing trees with larger crowns (part of the old-growth 'profile'); however, relatively little work has examined other stand structure.

We conducted a study of overall stand structure in thirty-two (32) paired thinned and unthinned stands, areas that were classified as one large stand prior to operational thinning in part of the stand 10 to 24 years prior to measurement. Thinnings differed in intensity (8 to 60% volume removal) and, thus, degree of site disturbance. Study sites were located across the diverse landscape of western Oregon, and included twenty old-growth stands (200+ yrs) sampled for comparison to 20 of the young-stand pairs (50-120 yrs). This "snapshot" evaluation of a decades-old thinning program, and the associated research in reconstructing and projecting stand development, provided a basis for evaluating thinning impacts on multiple structural layers in young stands. By comparing thinned and unthinned stands to old-growth stands, we assessed whether thinning has resulted in or will likely lead to characteristics typically found in old-growth forests. We further evaluated past harvesting impacts on long-term site productivity and species composition.

Structural differences were described in seven areas, corresponding to vegetation layers or combinations of layers:

- 1) overstory tree density, and resulting tree and crown form;
- 2) overstory tree radial-growth rates, and resulting tree and stand volume growth;
- 3) intermediate (sub-canopy) composition and tree characteristics;
- 4) total tree canopy depth and leaf area;
- 5) tall and low shrub density, cover, frequency and composition;
- 6) conifer and hardwood regeneration density and frequency; and
- 7) herbaceous cover, frequency, richness and composition.

Thinned stands showed effects of increased resource availability (space, light, nutrients and water) in all structural layers:

- 1) larger overstory crowns, fueling accelerated radial growth and larger trees;
- 2) greater density (and growth rates) of living intermediate (a second layer of) hardwood and conifer trees;
- 3) more hardwood sprouts, and expanded shrub/herbaceous communities; and
- 4) initiation of conifer regeneration.

Thinning thus promoted old-growth forest structure in terms of: 1) larger trees at lower densities; and 2) multi-storied and multi-species canopies now and the potential for future contribution. Multiple entries may be needed to maintain desired growth rates in overstory trees, and adequate survival and growth of understory trees and other desired vegetation. Silviculturists can further manipulate thinned stand structure (vertical and horizontal) with well-timed and executed re-entry, including promotion of hardwood species, creation of large snags and downed wood (also typically associated with old-growth).

Old-growth stands of Douglas-fir were characterized by many large-diameter trees with large, long branches occupying half of the trees' boles. In contrast, unthinned stands

had many tall, slender trees with small crowns isolated at the very top of trees. Thinning such stands, particularly early in their lives, provided space and light for: 1) larger diameters for the same tree heights; 2) branch survival lower on trees' boles; and 3) longer and larger branches. This 'growing space' for individual tree branches and crowns is a dominant characteristic of old-growth stands.

Trees in observed old-growth stands averaged nearly 50% live crown ratio (LCR) and 6 m crown radius (or branch length). Unthinned stands averaged 37% LCR and 4 m radius. Thinning dense stands of Douglas-fir dramatically increased LCR and radius, and placed these trees on a new trajectory to old-growth conditions assuming that adequate growing space is maintained in these stands over time. Only with time (i.e., height growth) can LCR increase to that found in old-growth stands; therefore, suppression of lower branches due to shading must be avoided. Heavier thinnings showed greatest LCRs, and promise the greatest future growing space for long branches and deep crowns.

Lower stand densities and larger crowns favored conditions for accelerated tree growth rates following thinning. Most of the inherent ability of the land to produce wood, unaffected in the long-term by either the clearcut harvests of 50+ years ago or the more recent thinnings, is now concentrated in fewer stems. Larger diameter trees produced sooner in the life of the stand have implications on wood product yield, wildlife habitat (living trees and/or snags) and downed woody debris longevity.

Radial growth rates increased 36% on average with thinning, and as much as 105% in the heavier thinnings. Thinning removals greater than 33% yielded 60% increases on average. A 70% increase in diameter growth can compensate for a 30% reduction in growing stock (moderate thin) such that, on productive sites, a stand can exceed standing board foot volume of unthinned stands by age 100. Heavier thinnings and thinnings on less productive sites would require more time to exceed standing merchantable volume. Except in the heaviest thinnings, accelerated diameter growth rates of individual trees were still less than those seen historically in Coast Range old-

growth Douglas-fir stands early in their development. To mimic that kind of tree diameter growth, and associated crown development, will likely require spacings of 100 trees/ha (40 trees/ac) or less.

Neither harvesting activity in the past, clearcutting and burning 50-120 years ago or thinning 10-24 year ago, appear to have impacted site productivity in terms of volume or biomass production. Both unthinned and thinned stands have or will achieve: 1) volumes at or above that of neighboring old-growth stands (including volume in standing and downed dead wood); and 2) volume expectations described in Bulletin 201 (McArdle et al. 1949) for well-stocked Douglas-fir forests. Volume is or will be distributed on a greater number of stems in younger stands, particularly unthinned stands, without additional management. This conclusion is drawn without knowledge of potential influences of changes in climate or other growing conditions (e.g., diseases and pests) over the centuries.

One of the most significant differences between thinned and unthinned stands was the composition and characteristics of intermediate structure (sub-canopy 1-8" diameter trees). Though there were similar densities in many thinned-unthinned pairs, such trees were typically dead or dying in unthinned stands -- being shaded out by the overstory -- with only a small number of shade tolerant species typically neighboring small gaps. Intermediate canopy trees in thinned stands were comprised primarily of new regeneration that started immediately after disturbance and grew rapidly, with some (undamaged) advanced reproduction released by the harvest. Past thinnings typically removed most of the suppressed and intermediate members from the canopy (include many of the shade-tolerant individuals) in favor of the larger overstory trees. Those trees left after thinning typically survived; shade-tolerant species even re-invigorated and grew well. Future thinnings with the objective of promoting old-growth characteristics should favor such shade-tolerant advanced reproduction (including hardwoods) given its potential to contribute to a multi-storied canopy.

Living intermediate trees are a basic requirement for the development of multi-storied old-growth canopies. Eighty-nine percent of intermediate trees were alive in old-growth stands. Thinned stands, with 82% living, approximated this level while, in stark contrast, only 52% was living in unthinned stands. Intermediate structure was most vigorous in thinned stands in terms of live crown ratio and radial growth rates, regardless of species. With fewer overstory trees (more light penetration), intermediate Douglas-fir and western hemlock trees in thinned stands have greater live crown ratios than those in old-growth stands, which are marginally greater than those in unthinned stands. However, intermediate Douglas-fir trees (as with other shade-intolerant species) will likely only persist in the heaviest thinnings or with continued density regulation.

Canopy depth and leaf area are measures that sum overstory and intermediate structure, vegetation that is typically 4 or more meters above the ground surface. Past thinnings typically removed much of this vegetation and, in heavier/more recent thinnings, canopy leaf area was half or less that of adjacent unthinned stands. However, in lighter/older thinnings, canopy leaf area in thinned stands exceeded that in unthinned stands due to the development of deeper, wider tree crowns and (primarily) the development of intermediate structure. Leaf area arranged in a single layer high above the ground does not intercept as much light as deeper, more complex canopies.

Observed old-growth stands carried more leaf area than unthinned stands despite the lack of recent disturbance in either stand type. This observation was likely due to higher species heterogeneity in old-growth stands, with greater proportions of hardwood species and shade-tolerant conifers, which promote deeper, more-diverse canopies. Indeed, without the maintenance of canopy openings in young stands or continual natural gap-phase dynamics in old-growth stands, canopies become sufficiently deep such as to preclude understory density and diversity.

Douglas-fir regeneration is the foundation of future stand structure in Douglas-fir dominated forests, with some contribution from other conifer species. It is also one of the

most prominent differences between the stand types. Thinned stands typically have an order of magnitude (or more) higher density of seedlings, at two- to four-times the frequency found in unthinned stands. Regeneration in unthinned stands is sparse and non-vigorous except in the oldest stands (>100 years) well beyond the stem exclusion stage of development. Heavy thinnings (35% volume removal or more) can initiate regeneration of shade intolerant species like Douglas-fir, though these seedlings are growing quite slowly 10+ years later as the overstory trees expand and intermediate structure develops. Shade-tolerant conifer regeneration that initiates in lighter thinnings and unthinned stands will provide intermediate structure in the near term but will lead to the gradual loss of Douglas-fir from the system (in the absence of other disturbance).

Conifer regeneration of many species, like intermediate trees, is prominent in observed old-growth stands. Seedling densities are only marginally less in old-growth stands than in thinned stands, and much greater than unthinned stands. However, the species composition is different (particularly in relation to heavier thinnings), and height growth is significantly less than that in thinned stands. These factors reflected an increased amount of canopy leaf area (shade). Regeneration and perpetuation of shade-intolerant species in undisturbed old-growth stands is therefore nearly absent, and often lacking in disturbed old-growth as well. To provide the range of tree ages seen in old-growth Douglas-fir trees (hundreds of years) will require stand densities < 100 trees/ha (or large gaps/stand replacement events) in young and old-growth stands to allow the perpetuation of Douglas-fir over long time scales.

The density of tall shrubs (e.g., vine maple) was highly variable across all sites; however, average stem density and frequency (all species) is typically greater in thinned stands than unthinned stands -- consistent with the concept that increased resources are available for sub-canopy vegetation. The greatest difference is in leaf area reflecting the fact that tall shrubs in thinned stands are growing vigorously. Old-growth stands had high densities and frequencies of tall shrub species, equal to that found in thinned stands (and with equal leaf area index). The physiology and reproductive strategies of certain

tall shrubs (e.g., huckleberry or vine maple) must make them particularly well suited to old-growth conditions. Hardwood sprouts are consistently more numerous and common in thinned than unthinned or old-growth stands, due to recent thinning activities.

Low shrub and fern cover and leaf area was dramatically higher (33%) in thinned than unthinned stands after 10+ years, due primarily to the expansion of bracken fern and salal. Oregon grape decreased marginally in thinned stands due potential to mechanical damage, change in microclimate and/or vigorous spread of other species. Given this uneven response across species, multivariate ordinations showed that thinned stands (particularly those heavily thinned) have a different mix of shrub species relative to unthinned (and old-growth) stands.

The leaf area, cover, frequency and composition of shrub and fern species in old-growth is similar to that of unthinned stands, including that of the individual species named above. Thinning therefore shifted these stands, at least temporarily, away from old-growth conditions with respect to low shrubs. However, given that old-growth stands developed at low tree densities, they likely supported shrub (or herbaceous) communities of similar or greater cover than that of thinned stand when they were younger. As thinned canopies develop and deepen, low shrub cover and leaf area will likely decrease.

Total herbaceous cover and the frequency/cover of some species groups (grasses and sedges, nitrogen-fixing species, vines, and exotic species) were stimulated by thinning after 10+ years. Despite these increases and other potential shifts at species or species-group levels, multivariate analyses show no compositional changes (i.e., changes in the mix of species) between the stand types. Multivariate ordinations using DCA and NMS procedures showed that most variability in herbaceous community data was due to variability among sites. Species richness was greatest in thinned stands; thirteen species were unique to thinned stands and one species was unique to unthinned stands.

Like shrub communities, old-growth herbaceous communities were very similar to unthinned stands in terms of total cover, species richness, and the cover/frequency of individual species and species groups. This shows the resilience of herbaceous species to disturbance associated with either past harvests. The fact that thinning has not dramatically affected the overall composition of species, in the near term, further demonstrates this resilience.

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APPENDIX

Low shrub and large fern species list

Listing of 'common' species which comprised columns in the multivariate ordinations, having some cover at 3 or more of the 32 pairs or 20 old-growth stands. Other less frequent species were included in all other analysis (¹ denotes species tallied as "grass" after year 1). Listing of sites of sites with summarized stand-level average data.

Ordination species:

Berberis nervosa
Gaultheria shalon
Polystichum munitum
Pteridium aquifolium

Other less-frequent species:

Berberis aquifolium
Ceanothus spp.
Rhus diversiloba
Ribes bracteosum, R. sanguineum
Symphocarpus alba, S. mollis

Herbaceous species list

Ordination species (59 total):

Actaea rubra
Achlys triphylla
Adenocalon bicolor
Anemone deltoidea
Anaphalis margaritacea
Asarum caudatum
Carex spp.
Campanula scouleri
Chrysanthemum leucanthemum
Chimaphila menziesii
Cornus canadensis
Collinsia grandiflora
Collomia heterophylla
Coptis laciniata
Cystisus scoparius
Dicentra formosa
Disporum hookerii
Digitalis purpurea
Epilobium angustifolium
Equisetum telmatiea
Fragaria vesca

Galium triflorum
Goodyera oblongifolia
 Grass (*Bromus*, *Festuca*, *Luzula*, *Poa*, and *Eleocharis* spp.)
Hieracium albiflorum
Iris tenax
Lactuca muralis
Linnaea borealis
Listera cordata
Lonicera hispidula
Maianthemum dilatatum
Madia madiodes
Montia sibirica
Monotropa uniflora
Nemophila parviflora
Osmorhiza chilensis
Oxalis oregana
Prunella vulgaris
Pyrola picta
Rubus laciniata, *R. nivalis*, *R. ursinus*
Sanicula crassicaulis
Satureja douglassii
Senecio jacobea
Smilacina racemosa
Synthyris reniformis
Tellima grandiflora
Thermopsis montana
Tiarella trifoliata, *T. trifoliata* var. *unifoliata*
Trientalis latifolia
Trillium ovata
Vancouveria hexandra
Vicia americana, *V. cracca*
Viola glabra
Whipplea modesta
Xerophyllum tenax

Other less-frequent (non-ordinated) species:

Acillea millefolium
Adiantum pedatum
Agroseris grandiflora
Anemone lyalli
Apocynum androsaemifolium
Aquilegia formosa
Aralia californica
Arnica cordifolia
Arenaria macrophylla
Aster radulinus
Athyrium filix-femina

Blechnum spicant
Boykinia major
Boschniakia stobilaea
Brodiaea congesta, *B. hendersonii*
Bromus spp.
Cardamine angulata
Caucalis microcarpa
Castilleja pruinosa
Circaea alpina
Cirsium arvense, *C. remotifolium*, *C. vulgare*
Clarkia rhomboidea
Clintonia uniflora
Corallorhiza maculata, *C. mertensiana*, *C. striata*
Convolvulus spp.
Crypantha minima
Cynorsrus echinatus
Cynoglossum grande
Cystoperus fragilis
*Dactylis glomeratus*¹
Disporum smithii
Dodecatheon hendersonii
Dryopteris arguta
Dryopteris expansa
Eburophyton austiniiae
*Elymus glaucus*¹
Epilobium minutum
Eriophyllum lanatum
Erechites minima
Festuca spp.
Galium aparine, *G. oregana*
Grindelia spp.
Gymnocarpium dryopteris
Habenaria unalacensis
Hemitomes congestum
Heuchera micrantha
*Holcus lanatus*¹
Hydrophyllum occidentale, *H. tenuipes*
Hypericum perforatum
Hypochaeris radicata
Hypopitys monotropa
Iris chrysophylla
Lathyrus spp.
Lilium columbianum
Lithophragma parviflorum
Lonicera cilliosa
Lotus micranthus, *L. purshianus*
Lupinus spp.
*Luzula campestris*¹, *L. parviflora*¹, *L. spp.*
Lysichiton americanum
Madia minima

Marah oreganus
Medicago lupulina
Mimulus dentata, *M. kelloggi*, *M. moschatus*
Mitella caulescens, *M. ovalis*
Montia perfoliata
Oenanthe sarmentosa
Osmorhiza purpurea
Oxalis suksdorfii
Petasites frigidus
Pityrogramma triangularis
Pleuricospora fimbriolata
Polypodium glycyrrhiza
Psoralea physodes
Pyrola aphylla
Ranunculus occidentalis, *R. uncinatus*
Rubus leucodermis
Rumex crispis
*Scirpus acutus*¹, *S. microcarpus*¹
Senecio triangularis
Sidalcea oregana
Smilacina stellata
Solidago spp.
Sonchus arvensis, *S. oleraceus*
Stachys cooleyae, *S. mexicana*, *S. rigida*
Stellaria jamesiana
*Stipa califorca*¹
Streptopus amplexifolius
Swainsona salsula
Tolmeia menziesii
Trapopogon dubius
Trifolium eriocephalum
Urtica dioica
Veratrum californicum
Veronica serpyllifolia, *V. spp.*
Viola sempervirens

Listing of thinned/unthinned pairs

BLM District and legal location, stand age, year of commercial thinning (CT), percent volume removed in that thinning (%VL), and site index (King 1966; base age 50).

SITE	DISTRICT	T-R-S	AGE	CT	%VL	SI50
Beaver Flat	Salem	13s-6w-19	50	1974	51	130
Blue Ridge 26	Coos Bay	26s-12w-26	50	1976	10	127
Blue Ridge 35	Coos Bay	26s-12w-35	50	1982	28	127
N. Ward Creek	Roseburg	20s-5w-23	50	1985	50	130
Keel Flat	Salem	12s-1e-23	60	1971	25	141
D-Line Road	Eugene	18s-7w-25	60	1972	12	121
Little Wolf Cr.	Roseburg	25s-8w-3	60	1980	55	102
Perkins Cr. #1	Eugene	21s-2w-27	60	1981	36	134
Perkins Cr. #2	Eugene	21s-2w-27	60	1981	30	115
Gnome	Eugene	16s-8w-1	60	1983	43	120
Gordon Creek	Salem	1s-5e-11	60	1985	60	118
Wildwood Falls	Eugene	21s-1w-33	65	1981	22	121
Sand Creek	Salem	8s-7w-31	70	1971	32	128
Bald Mtn.	Salem	3s-6w-17	70	1976	33	120
Clay Creek	Eugene	19s-7w-29	70	1980	48	119
Marten Ridge	Eugene	17s-3e-6	70	1981	50	127
Burnt Creek	Coos Bay	27s-9w-5	80	1975	33	117
Windy Ridge	Roseburg	29s-2w-19	80	1977	40	115
Big River	Eugene	23s-2w-18	80	1977	15	130
Highpass Rd.	Eugene	16s-6w-1	90	1971	20	114
Eagle's Rest	Eugene	20s-1w-1	90	1974	50	90
Days Creek	Roseburg	30s-3w-3	90	1977	40	117
Bummer Ridge	Salem	17s-7w-6	95	1976	25	98
Honey Creek	Roseburg	26s-2w-3	100	1971	21	98
Bear Creek	Salem	3s-7w-17	100	1972	27	134
Elliott St. For.	ODF	23s-10w-19	100	1973	54	131
Horse Creek	Salem	7s-3e-21	110	1971	20	82
Rooster Rock	Salem	7s-4e-19	110	1971	22	114
Little River	Roseburg	27s-2w-7	110	1978	30	96
Meyer Creek	Salem	8s-3e-35	120	1970	23	106
Fawn Creek	Salem	8s-4e-25	120	1972	8	110
Panther Gap	Medford	39s-5w-12	120	1981	20	78

Min:	50	1970	8	78
Max:	120	1985	60	141
Avg:	80	1976.41	32.2813	115.938
Std:	22.53	4.53362	14.1205	15.1615

Listing of thinned/unthinned pairs

Stand-level averages for overstory (>8" DBH) tree and stand variables, for thinned (-T) and unthinned (-U) pairs: trees per acre (tpa), crown radius (crad), basal area in square feet per acre (BA), current relative density index (RD), live crown ratio (LCR), and canopy leaf area index (CLA).

OVERSTORY													
tpa-t	tpa-u	crad-t	crad-u	BAT	BAU	RDT	RDU	LCRT	LCRU	CLAT	CLAU		
61	131	15	11	140	222	0.34	0.58	0.47	0.32	5.0	5.8		
93	181	13	11	153	188	0.60	0.54	0.47	0.35	5.7	7.5		
66	181	13	11	123	188	0.37	0.54	0.38	0.35	4.9	7.5		
62	96	16	14	119	146	0.3	0.39	0.43	0.28	3.3	4.7		
60	117	14	13	168	218	0.40	0.56	0.52	0.41	6.0	6.2		
74	157	12	11	180	210	0.44	0.57	0.38	0.35	4.9	6.2		
58	118	12	9	95	136	0.25	0.38	0.51	0.38	4.8	6.5		
79	105	11	10	114	162	0.31	0.43	0.48	0.34	5.2	5.8		
91	146	11	11	132	178	0.35	0.49	0.48	0.40	5.1	6.3		
59	200	11	8	88	212	0.23	0.61	0.37	0.31	3.8	7.1		
49	118	13	12	122	204	0.29	0.53	0.56	0.50	3.8	7.4		
102	219	11	12	158	264	0.42	0.73	0.43	0.41	6.4	7.7		
117	168	13	10	240	272	0.60	0.71	0.36	0.29	4.7	5.4		
59	101	12	10	200	235	0.45	0.57	0.44	0.44	4.9	5.1		
73	102	14	12	158	230	0.39	0.57	0.42	0.35	3.6	5.1		
24	110	16	12	108	285	0.23	0.68	0.41	0.36	2.0	4.4		
31	62	15	15	134	206	0.29	0.47	0.46	0.46	5.5	5.6		
71	157	13	11	142	240	0.36	0.66	0.49	0.38	3.4	4.9		
71	105	15	13	224	256	0.52	0.62	0.46	0.37	6.3	7.5		
54	65	16	14	196	195	0.44	0.45	0.40	0.35	4.7	5.0		
31	59	16	12	106	183	0.24	0.42	0.48	0.45	5.9	5.4		
28	98	17	13	122	236	0.26	0.57	0.49	0.35	2.5	4.1		
45	72	14	13	185	263	0.40	0.59	0.34	0.35	3.9	5.3		
52	80	13	13	124	190	0.30	0.46	0.42	0.36	6.6	5.7		
52	54	15	14	204	200	0.45	0.45	0.43	0.48	4.7	4.5		
49	93	14	12	158	304	0.36	0.70	0.55	0.42	5.1	4.1		
62	76	16	11	192	231	0.44	0.54	0.37	0.34	5.0	4.5		
66	74	14	13	253	280	0.56	0.62	0.38	0.38	5.2	5.7		
44	110	11	12	137	256	0.32	0.63	0.42	0.38	3.0	4.3		
51	109	13	10	204	302	0.45	0.71	0.45	0.34	6.9	5.4		
34	45	18	16	244	235	0.48	0.49	0.43	0.37	7.3	5.4		
40	63	14	11	111	118	0.26	0.30	0.35	0.25	2.0	3.4		
24	45	11	8	88	118	0.23	0.30	0.34	0.25	2.0	3.4		
117	219	18	16	253	304	0.60	0.73	0.56	0.50	7.3	7.7		
59.625	111.625	13.772	11.88	157.313	220.156	0.37813	0.54875	0.43844	0.37094	4.753	5.6094		
21.0353	43.9444	1.861	1.691	44.8626	45.4293	0.10276	0.10455	0.05574	0.05479	1.322	1.1201		

Listing of thinned/unthinned pairs

Stand-level averages for overstory tree (>8" DBH) and stand variables, for thinned (-T) and unthinned (-U) pairs: average diameter at breast height (DBH), density of dead trees per acre (#D), density of large, decomposing snags per acre (sn), density of damaged trees (dam), density of remnant (or "legacy") trees from an earlier stand (rem), and 5-year radial growth rate in inches (5yr).

OVERSTORY TREES													
DBHT	DBHU	#DT	#DU	sn-T	sn-U	dam-T	dam-U	rem-T	rem-U	5yr-T	5yr-U	rem-T	rem-U
20.6	17.6	0	5	0	0	13	3	2	2	0.87	0.51	2	2
22.4	13.8	6	5	0	5	6	5	0	0	0.38	0.29	0	0
20.7	13.8	3	5	3	5	4	5	0	0	0.48	0.29	0	0
18.8	16.7	0	9	4	0	3	6	5	1	0.59	0.42	1	1
22.6	18.5	4	6	2	0	10	10	3	8	0.52	0.46	3	8
21.4	15.7	0	0	1	6	5	10	1	9	0.37	0.41	1	9
17.4	14.6	0	2	1	3	3	1	3	10	0.50	0.37	3	10
16.2	16.8	0	2	5	6	4	3	0	1	0.45	0.34	0	1
16.3	15.0	0	5	0	0	3	4	0	0	0.35	0.33	0	0
16.6	13.9	4	2	8	7	9	0	0	1	0.55	0.35	0	1
21.3	17.8	0	2	0	1	2	4	0	1	0.76	0.52	0	1
16.9	14.9	4	1	6	1	1	2	0	10	0.37	0.22	0	10
19.4	17.2	0	8	3	4	16	0	0	2	0.53	0.31	0	2
25.0	20.7	2	6	5	7	11	1	8	5	0.32	0.28	1	5
19.9	20.4	3	5	1	7	11	2	2	3	0.39	0.31	2	3
28.9	21.8	5	1	0	0	1	0	0	2	0.39	0.19	0	2
28.1	24.6	7	6	4	15	8	7	5	5	0.39	0.39	5	5
19.2	16.8	3	4	5	7	10	8	1	9	0.42	0.24	1	9
24.1	21.1	1	3	5	29	5	2	0	6	0.33	0.31	0	6
25.8	23.4	0	2	0	0	6	2	10	5	0.39	0.35	10	5
25.1	23.9	3	7	1	4	2	2	7	17	0.52	0.30	7	17
28.2	21.0	0	1	2	4	2	12	3	1	0.45	0.31	3	1
27.6	25.8	1	4	1	16	5	6	0	3	0.52	0.43	0	3
20.9	20.9	0	6	15	7	5	8	8	15	0.36	0.27	8	15
26.7	26.2	2	20	4	21	4	2	0	2	0.43	0.25	0	2
24.3	24.4	3	9	13	2	12	5	5	1	0.58	0.29	5	1
23.8	23.6	0	16	8	8	8	5	1	2	0.42	0.32	1	2
26.4	26.4	0	2	0	2	5	3	2	3	0.29	0.36	2	3
23.7	20.7	0	0	2	1	9	3	12	9	0.34	0.27	12	9
27.2	22.5	2	5	8	17	3	2	3	3	0.43	0.30	3	3
36.2	31.0	1	3	18	6	3	6	2	2	0.41	0.37	2	2
22.7	18.5	0	1	1	1	4	6	3	4	0.44	0.23	3	4
16.2	13.8	0	0	0	0	1	0	0	0	0.29	0.19	0	0
36.2	31	7	20	18	29	16	12	12	17	0.87	0.52	12	17
22.95	20	1.69	4.78	3.94	6.00	5.78	4.22	2.69	4.44	0.454	0.33	2.69	4.44
4.41298	4.31205	1.99	4.23	4.45	6.70	3.71	3.03	3.21	4.27	0.121	0.08	3.21	4.27

Listing of thinned/unthinned pairs

Stand-level averages for understory or "intermediate" (1-8" DBH) trees, for thinned (-T) and unthinned (-U) pairs: total density per acre (#/ac), density of dead (dead) and living (live), calculated percent living (%lv), and their live crown ratio (iLCR).

INTERMEDIATES										
#/ac-T	#/ac-U	dead-T	dead-U	live-T	live-U	%lv-T	%lv-U	iLCR-T	iLCR-U	
19	55	6	48	13	7	68	13	0.71	0.37	
72	528	29	309	43	219	60	41	0.41	0.31	
47	528	33	309	14	219	30	41	0.60	0.31	
38	159	16	143	22	16	58	10	0.60	0.26	
134	219	69	149	65	70	49	32	0.62	0.51	
73	193	25	71	48	122	66	63	0.33	0.29	
129	276	10	177	119	99	92	36	0.51	0.25	
185	165	40	103	145	62	78	38	0.46	0.54	
140	214	23	86	117	128	84	60	0.43	0.33	
41	262	3	141	38	121	93	46	0.66	0.30	
33	119	6	69	27	50	82	42	0.74	0.45	
88	242	34	121	54	121	61	50	0.39	0.25	
30	23	5	18	25	5	83	22	0.67	0.35	
80	50	9	24	71	26	89	52	0.49	0.38	
132	109	14	69	118	40	89	37	0.50	0.44	
33	17	2	10	31	7	94	41	0.60	0.56	
142	52	6	24	136	28	96	54	0.70	0.63	
85	221	6	83	79	138	93	62	0.71	0.35	
104	188	8	21	96	167	92	89	0.66	0.54	
92	130	34	44	58	86	63	66	0.37	0.37	
134	96	6	37	128	59	96	61	0.65	0.35	
169	63	6	25	163	38	96	60	0.75	0.32	
76	67	0	13	76	54	100	81	0.78	0.64	
113	153	0	86	113	67	100	44	0.64	0.39	
121	17	2	7	119	10	98	59	0.56	0.81	
163	19	11	6	152	13	93	68	0.73	0.70	
81	16	1	3	80	13	99	81	0.65	0.79	
12	56	1	38	11	18	92	32	0.75	0.43	
147	57	14	17	133	40	90	70	0.52	0.38	
46	51	8	23	38	28	83	55	0.69	0.49	
61	47	5	7	56	40	92	85	0.52	0.50	
98	149	0	64	98	85	100	57	0.77	0.25	
12	16	0	3	11	5	30	10	0.33	0.25	
185	528	69	309	163	219	100	89	0.78	0.81	
91.19	141.91	13.5	73.281	77.7	68.63	83.1	51.54	0.59906	0.4325	
46.73	126.44	15.091	76.932	45.1	58.33	17.1	19.13	0.12541	0.1514	

Listing of thinned/unthinned pairs

Stand-level averages for understory vegetation, for thinned (-T) and unthinned (-U) pairs: density of tall shrubs per acre (S/A), frequency among subplots (FTS), tall shrub leaf area index (TSL), seedling density per acre (#SD), and frequency of seedlings among subplots (FSD).

TALL SHRUBS				SEEDLINGS					
S/A-T	S/A-U	FTS-T	FTS-U	TSLT	TSLU	#SDT	#SDU	FSDT	FSDU
325	247	0.46	0.44	0.2	0.1	371	169	0.62	0.18
1178	357	0.85	0.36	0.3	0.0	336	229	0.23	0.20
805	357	0.82	0.36	0.4	0.0	587	229	0.38	0.20
1056	325	0.83	0.40	0.1	0.0	193	5	0.41	0.02
751	560	0.88	0.53	0.5	0.0	416	182	0.40	0.14
719	307	0.86	0.35	0.2	0.0	160	92	0.26	0.10
900	159	0.78	0.27	0.2	0.1	1034	56	0.82	0.12
481	142	0.61	0.26	0.3	0.0	173	46	0.39	0.16
435	279	0.64	0.36	0.2	0.5	92	50	0.20	0.16
1775	388	1.37	0.55	0.4	0.2	332	51	0.33	0.16
1291	1275	1.26	1.18	0.4	0.3	2719	9	0.84	0.04
892	508	1.28	0.44	0.2	0.4	133	18	0.28	0.06
239	215	0.44	0.32	0.4	0.1	890	37	0.84	0.10
1268	572	1.22	0.60	0.6	0.5	105	11	0.22	0.05
229	343	0.22	0.50	0.2	0.1	206	51	0.34	0.10
1584	1219	1.32	1.08	0.4	0.3	174	0	0.26	0.00
64	33	0.10	0.03	0.7	0.0	2719	471	0.94	0.34
125	402	0.16	0.49	0.1	0.0	858	76	0.66	0.22
421	133	0.56	0.22	0.2	0.1	352	503	0.50	0.54
366	1013	1.38	0.83	0.2	0.3	284	51	0.30	0.18
1172	615	0.84	0.57	0.7	0.1	801	46	0.72	0.09
371	625	0.31	0.40	0.7	0.1	1983	25	1.00	0.11
595	350	0.93	0.50	0.3	0.2	263	44	0.70	0.14
1795	376	1.43	0.36	0.8	0.1	462	59	0.75	0.10
2087	1304	1.16	1.32	1.4	0.9	82	41	0.14	0.10
128	1208	0.22	1.48	0.2	0.6	114	69	0.28	0.14
1085	524	1.00	0.51	1.0	0.5	325	5	0.42	0.02
841	524	0.70	0.51	0.3	0.3	57	41	0.15	0.07
931	588	0.90	0.53	0.2	0.0	717	79	1.10	0.24
1103	671	1.06	0.76	1.1	0.4	316	15	0.26	0.07
805	1114	0.82	1.03	0.7	1.1	183	160	0.32	0.28
1205	585	0.96	0.33	0.5	0.0	1129	97	1.11	0.16
64	33	0.10	0.03	0.1	0.0	57	0	0.14	0.00
2087	1304	1.43	1.48	1.4	1.1	2719	503	1.11	0.54
844.4	541.2	0.82406	0.55844	0.44063	0.22813	580.188	94.2813	0.50531	0.14344
513.8	350	0.37171	0.32588	0.30604	0.26837	680.174	118.119	0.28724	0.1034

Listing of thinned/unthinned pairs

Stand-level averages for understory vegetation, for thinned (-T) and unthinned (-U) pairs: percent low or "small" shrub cover (SSC), small shrub leaf area index (SSL), and the percent cover of salal (gash), sword fern (pomu), bracken fern (ptaq), and Oregon grape (bene).

SMALL SHRUBS													
SSCT	SSCU	SSLT	SSLU	gashT	gashU	pomuT	pomuU	ptaqT	ptaqU	beneT	beneU		
80	40	1.0	0.3	27	6	15	12	27	7	9	8		
39	5	1.5	0.9	31	3	4	2	2	1	3	1		
46	5	1.9	0.9	14	3	25	2	1	1	7	1		
39	29	1.6	1.0	6	1	16	11	5	1	11	15		
21	21	1.0	0.4	2	3	13	13	1	1	4	4		
82	36	1.5	1.0	42	20	6	4	14	3	17	11		
22	22	0.8	0.7	10	8	5	10	6	1	1	4		
80	67	1.7	1.4	35	5	29	57	4	1	7	4		
82	47	1.8	0.9	46	20	5	13	18	3	11	8		
85	24	2.3	0.2	50	10	1	5	18	2	3	1		
42	20	2.1	0.4	22	13	16	7	3	1	1	1		
75	42	0.7	0.6	60	20	3	10	7	1	1	12		
47	35	1.0	0.6	1	0	20	21	21	10	1	3		
78	69	1.4	1.5	31	14	27	43	6	4	3	4		
65	75	2.0	2.1	38	39	5	26	22	5	3	5		
95	81	2.7	1.7	30	30	16	14	14	4	20	33		
31	46	1.0	1.0	1	0	11	34	3	2	15	10		
41	16	1.1	0.6	27	11	11	3	4	1	1	2		
70	43	1.4	0.8	33	6	14	24	3	1	28	12		
34	24	1.0	0.7	0	1	19	15	7	5	0	0		
70	79	1.3	1.3	25	36	26	7	2	1	14	30		
15	9	1.1	0.6	4	0	7	8	2	0	3	2		
90	83	2.2	1.5	36	17	31	47	1	0	18	18		
35	24	1.5	0.5	26	17	4	4	4	1	2	2		
52	45	0.5	0.8	5	3	43	39	0	1	1	6		
62	48	2.2	1.6	37	4	11	32	9	1	7	11		
85	50	1.9	2.1	31	12	11	34	3	1	24	21		
70	60	1.8	0.7	19	12	4	5	5	1	41	40		
27	34	0.8	0.7	15	13	6	17	3	1	2	1		
74	85	1.1	0.8	33	47	5	5	3	1	28	25		
46	65	0.8	0.7	3	9	21	30	2	1	17	24		
11	14	0.1	0.2	0	0	0	0	0	0	0	0		
11	5	0.1	0.2	0	0	0	0	0	0	0	0		
95	85	2.7	2.1	60	47	43	57	27	10	41	40		
55.9688	41.9688	1.4	0.9125	23.125	11.9688	13.4375	17.3125	6.875	2	9.46875	9.96875		
24.0514	23.567	0.57987	0.49228	16.1821	11.8044	10.0403	14.753	7.0788	2.15058	10.0374	10.4716		

Listing of thinned/unthinned pairs

Stand-level averages for stand variables, for thinned (-T) and unthinned (-U) pairs: total volume of downed wood debris in cubic feet per acre (tot), volume of decay class 4 and 5 material (rot), volume of decay class 1-3 material (hrd), and summed leaf area across all vegetation layers (TOTL).

DOWN WOODY DEBRIS				-LEAF AREA-			
tot-T	tot-U	rot-T	rot-U	hrd-T	hrd-U	TOTLT	TOTLU
5526	6595	4943	3827	283	2768	6.2	6.2
1951	24438	1290	22483	661	1954	7.5	8.4
3712	24438	3557	22483	916	1954	7.2	8.4
5401	4914	3724	3749	1677	1165	5.0	5.7
13021	8389	8604	4793	4417	3596	7.5	6.6
954	4915	592	4300	363	615	6.6	7.2
2556	2956	1380	2460	1177	496	5.8	7.3
2947	6080	1930	5527	1017	553	7.2	7.2
2424	3206	1811	2350	613	856	7.1	7.7
3422	4738	2902	3411	520	1327	6.5	7.5
4400	8911	3407	7826	993	1085	6.3	8.1
3186	2591	2558	2513	628	78	7.3	8.7
3638	3360	3227	2001	411	1359	6.1	6.1
3647	3311	2980	2487	667	824	6.9	7.1
5599	2202	2950	1337	2648	865	5.8	7.3
1262	867	967	623	295	245	5.1	6.4
5333	7764	4753	6096	580	1668	7.2	6.6
4943	2266	4411	2066	532	200	4.6	5.5
8807	11922	8505	10787	302	1135	7.9	8.4
750	1745	659	1605	91	140	5.9	6.0
9095	2090	8987	2004	108	86	7.9	6.8
2346	3662	2031	3437	315	225	4.3	4.8
2895	3355	2784	3113	111	242	6.4	7.0
4271	4691	3514	1703	757	2988	8.9	6.3
4234	4523	3777	3763	456	760	6.6	6.2
1520	2440	1254	2202	266	238	7.5	6.3
1954	5108	1680	3314	274	1793	7.9	7.1
898	802	790	436	108	366	7.3	6.7
1994	1794	1219	747	775	1047	4.0	5.0
4485	1864	4157	1286	328	578	9.1	6.6
5301	9090	4949	7744	351	1346	8.8	7.2
3938	902					2.6	3.6
750	802	592	436	91	78	2.6	3.6
13021	24438	8987	22483	4417	3596	9.1	8.7
3950.31	5497.78	3235.23	4595.9	730.323	1050.06	6.59375	6.75
2553.11	5552.88	2194.52	5209.09	843.314	875.21	1.43024	1.09573

Listing of thinned/unthinned pairs

Stand-level averages for overstory tree and stand variables from ORGANON, for thinned (-T) and unthinned (-U) pairs: tree density per acre (TPA), basal area in square feet per acre (BA), current relative density (RD), average live crown ratio (LCR), estimated canopy closure (CC), thousand board feet per acre (MBF), thousand cubic feet per acre (CFVol), and percent of basal area comprised of hardwoods (%hwd).

ORGANON															
TPAT	TPAU	BAT	BAU	RDT	RDU	LCRT	LCRU	CCT	CCU	MBFT	MBFU	CFVol-T	CFVol-U	%hwdT	%hwdU
98	168	146	227	0.41	0.66	0.53	0.30	61	86	29.7	43.5	6.5	9.9	0	0
214	708	260	290	0.77	1.06	0.44	0.32	97	100	50.0	38.4	11.1	10.0	0	0
95	708	156	290	0.43	1.06	0.39	0.32	63	100	28.4	38.4	6.5	10.0	2	0
93	139	127	151	0.37	0.46	0.46	0.25	39	66	21.6	25.6	5.2	6.1	5	2
139	224	179	240	0.52	0.73	0.56	0.43	72	93	36.4	50.1	7.9	10.8	0	1
146	330	190	257	0.55	0.83	0.35	0.31	75	100	39.3	46.9	8.7	10.9	5	6
192	244	109	172	0.38	0.57	0.50	0.31	43	77	17.3	29.1	4.4	7.6	10	11
263	188	128	169	0.45	0.53	0.47	0.41	65	73	15.9	28.9	4.3	6.9	4	3
226	329	142	200	0.48	0.68	0.45	0.34	68	88	17.9	23.4	4.7	6.8	2	13
137	398	129	245	0.40	0.83	0.46	0.33	60	100	21.5	37.6	5.1	9.4	1	1
82	201	124	214	0.35	0.65	0.62	0.48	48	85	21.2	32.3	4.9	7.6	0	1
202	455	170	333	0.54	1.08	0.38	0.34	74	100	26.7	41.0	6.6	11.6	1	14
175	215	242	278	0.70	0.81	0.41	0.29	90	100	52.3	62.6	11.4	13.5	1	1
151	180	237	266	0.66	0.77	0.45	0.38	86	97	49.6	57.5	10.6	12.2	4	2
208	176	167	241	0.54	0.69	0.45	0.35	74	88	35.2	60.1	7.7	12.5	5	4
67	155	111	289	0.31	0.78	0.53	0.36	25	96	38.5	79.4	6.8	15.7	1	3
187	128	153	221	0.49	0.61	0.66	0.54	69	79	42.4	57.2	7.9	11.8	0	9
161	354	148	284	0.46	0.91	0.59	0.36	66	100	26.6	43.4	6.2	10.8	1	5
235	367	230	301	0.71	0.96	0.60	0.47	91	99	49.5	68.3	10.3	14.2	1	0
398	173	245	202	0.83	0.60	0.33	0.37	100	80	37.6	43.1	9.4	9.2	1	5
170	164	129	298	0.42	0.81	0.61	0.43	62	100	26.8	67.6	5.6	14.0	1	8
198	177	137	243	0.45	0.70	0.70	0.31	65	90	32.9	54.4	6.5	11.6	1	4
131	165	192	273	0.55	0.76	0.59	0.43	74	93	49.0	73.5	9.5	14.4	1	7
301	160	152	219	0.53	0.63	0.59	0.35	73	83	29.0	48.1	6.4	10.5	1	13
226	84	215	213	0.67	0.55	0.52	0.57	85	72	59.8	65.8	11.6	12.3	5	0
220	128	178	309	0.57	0.80	0.67	0.45	77	99	37.2	74.6	8.0	15.1	5	0
155	126	199	237	0.58	0.64	0.51	0.36	77	83	50.8	64.0	10.3	12.6	4	1
98	149	259	296	0.66	0.79	0.42	0.40	85	99	64.4	67.2	12.8	13.8	0	5
269	232	195	284	0.64	0.84	0.49	0.37	84	100	32.8	62.4	7.6	13.2	10	2
119	194	220	322	0.60	0.89	0.57	0.36	78	99	59.6	79.5	11.4	16.1	1	1
128	118	258	250	0.69	0.66	0.50	0.42	85	83	91.8	76.6	16.1	14.0	4	1
254	174	134	137	0.47	0.44	0.53	0.24	45	64	27.2	16.7	5.8	4.5	3	8
67	84	109	137	0.31	0.44	0.33	0.24	25	64	15.9	16.7	4.3	4.5	0	0
398	708	260	333	0.83	1.08	0.70	0.57	100	100	91.8	79.5	16.1	16.1	10	14
179.313	240.969	176.906	248.469	0.53688	0.74313	0.51	0.3734	70.5	89.75	38.09	51.79	8.05625	11.2375	2.5	4.09375
70.7798	148.762	46.6023	48.9228	0.12702	0.16102	0.092	0.0741	16.79	10.86	16.21	17.4	2.77544	2.87399	2.6101	4.17103

Listing of old-growth stands

Stand-level averages for overstory (>8" DBH) tree and stand variables: location, tree density per acre (TPA), basal area in square feet per acre (BAPA), relative density index (RDENS), live crown ratio (LCR), canopy leaf area index (CLAI), diameter at breast height (DBH), crown radius (CRAD), 5-year radial growth rate (5YRGR), and the density of dead overstory trees or "hard snags" (#DEAD), decaying snags (#SNAGS), and damaged trees (#DAM).

SITE	DISTRICT	T-R-S	OVERSTORY										
			TPA	BAPA	RDENS	LCR	CLAI	DBH	CRAD	5YRGR	#DEAD	#SNAGS	#DAM
Gordon (BRW)	Salem	1s-5e-24	34	292	0.55	0.41	6.3	39.9	17.9		3	22	9
Little Wolf Cr.	Roseburg	25s-8w-3	21	184	0.35	0.58	5.5	39.7	15.7		1	10	6
High Pass Road	Eugene	16s-6w-11	20	212	0.39	0.45	4.9	43.7	17.4	0.23	2	0	3
N. Ward (Lorane)	Eugene	20s-5w-23	22	236	0.43	0.57	4.6	44.1	17.3		0	3	4
Gnome (Big Iron)	Eugene	15s-7w-29	26	248	0.46	0.44	6.0	41.9	10	0.23	7	7	9
Honey Creek	Roseburg	26s-2w-3	22	204	0.38	0.47	6.4	41.1	17.3		3	7	12
Sand Cr. (VOTG)	Salem	8s-8w-7	22	284	0.50	0.49	6.4	48.4	18.2	0.27	3	14	9
Keel Mountain	Salem	12s-1e-23	17	215	0.38	0.58	5.7	47.8	18.4		0	0	7
Blue Rg (Morgan)	Coos Bay	26s-12w-1	25	264	0.48	0.56	6.5	44.4	17.1		3	8	11
D-Line Road	Eugene	18s-7w-25	31	236	0.46	0.60	6.4	37.5	16.3	0.41	0	3	4
Beaver Flat (CW)	Salem	12s-7w-23	19	268	0.46	0.56	4.6	51.3	18.3		1	1	6
Marten (He-He)	Eugene	17s-3E-35	28	270	0.50	0.46	6.9	42.5	16.3		2	6	9
Perkins (Blue Mtn)	Eugene	21s-2w-33	43	292	0.58	0.48	6.9	35.5	17.2	0.24	7	8	8
Eagle's Rest	Eugene	20s-1w-1	39	324	0.62	0.42	6.9	38.9	12.1	0.37	6	6	13
Bear Creek	Salem	3s-7w-17	33	348	0.63	0.44	6.3	44.3	15.8	0.23	7	18	8
Rooster (Copper)	Salem	8s-4e-7	28	329	0.58	0.41	7.2	46.7	17.6	0.24	1	24	10
Elliott State For.	ODF	24s-11w-12	42	352	0.67	0.52	7.5	39.1	17.4		3	9	6
Burnt Mountain	Coos Bay	27s-9w-24	25	340	0.59	0.47	5.7	50.0	17.6		0	5	15
Panther Gap	Medford	39s-5w-12	36	176	0.37	0.38	3.4	30.0	14.4	0.29	5	1	6
Windy Ridge	Roseburg	29s-2w-19	28	300	0.54	0.46	5.1	44.6	18.4		6	4	5
Min:			17	176	0.35	0.38	3.4	30.0	10.0	0.23	0	0	3
Max:			43	352	0.67	0.60	7.5	51.3	18.4	0.41	7	24	15
Avg:			28.05	268.70	0.50	0.49	5.9	42.6	16.5	0.28	3.0	7.8	8.0
Std:			7.49	52.89	0.09	0.06	1.0	5.0	2.1	0.06	2.45	6.72	3.08
thinned:			60	161	0.38	0.44	4.8	23	13.8	0.45	2	4	4
unthinned:			112	220	0.55	0.37	5.6	20	11.9	0.33	5	6	3

Listing of old-growth stands

Stand-level averages for understory trees and vegetation: density of intermediate (1-8" DBH) trees per acre (#INTS), density of those dead (#DEA) and living (#LIV), their live crown ratio (LCR) and average height (AVHT), and calculated percent of intermediates living (%livin); density of tall shrubs per acre (#ST/AC), frequency among subplots (TSFR), average height (TSHT), and leaf area index (TSLAI); and seedling density per acre (#SD/AC), frequency among subplots (fSD) and average age (SDAGE).

INTERMEDIATES				TALL SHRUBS				SEEDLINGS				
#INTS	#DEA-I	#LIV-I	LCR-I	AVHT-I	%livin	#ST/AC	TSFR	TSHT	TSLAI	#SD/ac	fSD	SDAGE
168	6	162	0.57	15	96	1391	1.44	6	0.4	654	0.58	17
90	23	67	0.35	28	74	1941	1.54	8	0.6	41	0.16	10
49	9	40	0.40	26	82	632	0.62	8	0.4	0	0	7
35	6	29	0.44	22	83	1542	1.32	11	0.7	55	0.1	15
50	3	47	0.51	22	94	1556	1.32	8	0.6	82	0.3	8
138	57	81	0.35	31	59	755	0.96	9	0.2	426	0.26	6
32	4	28	0.59	22	88	1551	1.49	6	0.1	356	0.31	16
120	29	91	0.59	16	76	2059	1.55	8	1.1	418	0.3	9
67	40	27	0.52	27	40	1382	1.02	8	0.9	0	0	13
104	20	84	0.48	20	81	275	0.44	6	0.1	392	0.89	10
49	0	49	0.59	18	100	847	0.92	10	0.7	64	0.16	15
104	4	100	0.54	14	96	709	0.75	7	0.4	1562	0.98	11
118	37	81	0.38	25	69	769	0.94	7	0.2	87	0.34	6
90	21	69	0.38	19	77	453	0.44	10	0.5	46	0.14	12
37	10	27	0.49	18	73	732	0.66	7	0.2	64	0.98	13
133	2	131	0.44	13	98	1246	1.29	6	0.1	1574	0.78	4
126	29	97	0.62	20	77	339	0.60	6	0.5	224	0.24	15
137	0	137	0.65	15	100	563	0.50	8	0.1	526	0.37	10
241	97	144	0.23	22	60	746	0.54	5	0.1	0	0	4
265	38	227	0.44	22	86	191	0.23	8	0.1	1574	0.98	17
32	0	27	0.23	13	40	191	0.23	5	1.1	409	0.38	10.94
265	97	227	0.65	31	100	2059	1.55	11	0.29	465	0.31	3.72
107.65	21.75	85.90	0.48	21	80	984	0.93	7.60	0.44	580	0.51	
62.33	23.41	51.61	0.11	4.82	15.25	541.67	0.41	1.53	0.22	94	0.14	
85	8	77	0.6		89	844	0.82					
105	37	64	0.44		64	541	0.56					

Listing of old-growth stands

Stand-level averages for understory vegetation and downed wood debris: total percent low or "small" shrub cover (SSCOV) and percent cover of salal (gash), sword fern (pomu), bracken fern (ptaq), and Oregon grape (bene), small shrub leaf area index (SSLAI); total volume of downed wood debris in cubic feet per acre (TOTAL), volume of decay class 4 and 5 material (ROTTN) and volume decay class 1-3 material (HARD); and summed total leaf area index across all vegetation layers (TOTLAI).

-----SMALL SHRUBS-----				-----DOWNED WOOD-----			-LAI-	
SSCOV	gash	ptaq	bene	SSLAI	TOTAL	ROTTN	HARD	TOTLAI
34	19	4	0	10	10048	6067	3981	7.6
20	9	9	1	2	4797	3960	838	7.1
50	10	36	3	2	868	730	138	6.6
34	11	13	1	11	4993	2584	2409	6.5
73	30	25	0	16	7257	5541	1715	7.9
25	18	3	1	5	9126	5368	3758	7.5
48	5	12	4	5	17185	17000	185	7.2
23	3	16	0	3	12244	10977	1267	7.6
16	1	16	1	0	7388	6512	876	8.1
65	7	34	3	14	5562	3478	2084	7.3
43	19	8	0	17	3643	2747	896	6.8
55	9	18	0	18	10069	5079	4990	
66	25	12	0	27	2293	1869	424	8.2
52	5	12	1	33	1557	1416	141	7.8
40	5	31	0	1	7330	6975	355	7.3
45	7	2	0	12	7731	4105	3626	7.9
20	2	15	1	4	5471	3878	1593	8.5
4	0	1	1	4	12260	9111	3149	6.2
17	0	1	0	10	5960			4
18	12	6	1	1	2332	1754	578	5.7
4	0	1	0	0	868	730	138	4
73	30	36	4	33	17185	17000	4990	8.5
37.40	9.85	13.70	0.90	9.75	6906	5218	1737	7.15
18.83	8.20	10.39	1.14	8.80	3998	3779	1466	1.02
56	23	13	7	9.5				1.4
42	12	17	2	10				0.9

Listing of old-growth stands

Stand-level averages for overstory and stand variables from ORGANON: density of trees (TPA), basal area in square feet per acre (BAPA), relative density index (RDENS), live crown ratio (LCR), estimated crown closure (CC), thousand board feet per acre (MBF), thousand cubic feet per acre (CFVol), and percent of basal area comprised of hardwood species (%HDW).

-----ORGANON-----										
TPA	BAPA	RDENS	LCR	CC	MBF	CFVol	%HDW			
280	301	0.91	0.55	98	94.9	15.7	0			
136	192	0.55	0.41	75	53.1	9.8	4			
96	216	0.56	0.43	76	64.4	12.2	9			
98	237	0.61	0.55	81	65.4	12.1	1			
107	258	0.66	0.51	86	78.3	14	1			
166	218	0.63	0.39	83	55.9	10.7	8			
87	289	0.7	0.53	79	104.2	16.8	0			
192	222	0.66	0.61	90	46	8.7	1			
117	270	0.7	0.58	90	67.3	12.8	3			
217	259	0.77	0.56	105	59.1	11.8	10			
114	274	0.71	0.57	91	91.7	15.9	4			
197	281	0.8	0.5	100	88.4	15.3	1			
235	304	0.89	0.43	100	72.2	14.3	1			
184	331	0.9	0.42	99	78.2	15.5	3			
159	353	0.93	0.45	97	116.7	20.4	1			
306	341	1.02	0.44	92	118.4	19.3	0			
223	361	1.01	0.61	102	154.2	25.1	0			
250	351	1.01	0.62	91	135.5	22	0			
256	201	0.65	0.25	85	47.7	9.7	5			
369	331	1.04	0.46	100	101.9	18.1	2			
87	192	0.55	0.25	75	46	8.7	0			
369	361	1.04	0.62	105	154.2	25.1	10			
189	280	0.79	0.49	91.00	84.68	15.01	2.70			
76	53	0.16	0.09	8.84	29.23	4.24	3.03			