AN ABSTRACT OF THE DISSERTATION OF

<u>Thomas S. Sensenig</u> for the degree of <u>Doctor of Philosophy</u> in <u>Forest Science</u> presented on June 12, 2002.
Title: <u>Development, Fire History and Current and Past Growth, of Old-Growth and Young-Growth Forest Stands in the Cascade, Siskiyou and Mid-Coast Mountains of Southwestern Oregon</u>

Abstract approved: John C. Tappeiner II

I evaluated fire occurrence, growth and recruitment and determined the fire history of 21 old and 20 young 8ha stands in Cascade, Siskiyou and mid-Coast mixed conifer and evergreen forests in southwestern Oregon. The rates and patterns of growth were measured and analyzed on 1,079 old-growth and 2,111 young stand trees. I compared stand development among and between young and old-growth stands.

I dated 1,262 fire scars on all sites. There were no significant differences in the number of fire scars among the three forest types (p= .610) and found evidence of only three fires after 1900. The most probable fire frequencies ranged from 7-13yrs in the Cascades, 9-14yrs in the Siskiyous and 9-19yrs in mid-Coast stands. For all sites, fire occurred 66% of the decades from 1700-1900 and conifer trees were recruited in 56% of the decades during the same period. Thus, in all old-growth stands establishment and fires occurred simultaneously. In young stands establishment occurred very rapidly after about 1900 when fires apparently stopped.

In all forest types, current basal area in the old and young stands was not significantly different (p=.444) however, there were significantly more trees in the young stands (p=.002). Agglomerative clustering indicated that the developmental patterns of the old-growth trees was statistically dissimilar to young stand trees in all forest types suggesting that young stands densities are affecting tree growth.

At age 50yrs the diameters of the old-growth trees were significantly greater than that of the largest 50% of the young-growth trees. In old stands, tree size at 250yrs was strongly related to size and growth rate at age 50 (i.e. Cascade r^2= .48), suggesting that early growth rate was a major influence on final tree size.

Height:diameter ratios averaged 51-55 for trees in old-growth stands and 71-79 in the young stands and tree *height:live crown* ratios averaged 56-61 for all trees in old-growth stands and averaged 47-48 in the young stands. This is a further indication of the differences in stand development in these stand types.

These results strongly indicate that the currently abundant young stands are developing on significantly different pathways than that of the historical development of the old-growth stands. The lack of fire has replaced the occurrence of fire as a major factor influencing the development of forest stands. Therefore, in southwestern Oregon young forest stands will likely develop profoundly different and less complex, stand structures and species compositions than that of old-growth stands. Management implications of these results are discussed.

Development, Fire History and Current and Past Growth, of Old-Growth and Young-Growth Forest Stands in the Cascade, Siskiyou and Mid-Coast Mountains of Southwestern Oregon

by
Thomas S. Sensenig

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APPROVED:

Major Professor, representing Forest Science

Chair of the Department of Forest Science

Dean of the Graduate School

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

Thomas S. Sensenig, Author

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DEDICATION

This effort and manuscript is dedicated in honor of my loving parents Robert Charles Sensenig and Pearl W. Sensenig for their relentless pursuit of my well-being, happiness and success.

DEVELOPMENT, FIRE HISTORY AND CURRENT AND PAST GROWTH, OF OLD-GROWTH AND YOUNG-GROWTH FOREST STANDS IN THE CASCADE, SISKIYOU AND MID-COAST MOUNTAINS OF SOUTHWESTERN OREGON

CHAPTER I

INTRODUCTION

This document is organized into six sections, including an introduction, two research chapters, discussion and conclusion, bibliography and an appendix. Chapter I is an introduction of the subject and setting for the research that follows. Chapter II examines the fire occurrence and structural development in old-growth forest stands. Chapter III compares old-growth stand structural development with those of young stands and Chapter IV is the conclusion and discussion of the management implications as a result of the research findings. The bibliography and the appendices follow.

The amount of old-growth forests in the Pacific Northwest has declined markedly since European settlement of the region (Ripple *et al.* 1994). Using detailed forest survey maps drafted by Andrews and Cowlin (1940) for the United States Government, Booth (1991) estimated that 61% of western Oregon's forests were old-growth prior to logging. In 1994, employing geographic information system (G.I.S.) technology, Ripple *et al.* (1994) determined that as much as 71% of western Oregon's forests were old-growth at the turn of the century. Further, he determined that 89% was spatially connected as one patch, meaning that the old-growth habitats were mostly contiguous. Since then, numerous efforts to quantify extant old-growth have been undertaken (Greene 1988, Morrison and Swanson 1988, Ohmann *et al.* 1988, Wilderness Society 1988, Morrison and Swanson 1990, Marcot 1991, Spies *et al.* 1991, Bolsinger and Waddell 1993).

Many of the older forests were harvested to varying degrees leaving a mix of stand conditions (Isaac 1956). Because several large old trees sometimes remain following logging, the quantification and classification of extant older forests is confounded (Franklin and Spies 1991). It is estimated that about 10%-15% of pre-European old-growth remains and much of what does has been fragmented (Harris *et al.* 1982, Rosenberg and Raphael 1986) reducing its habitat effectiveness for old-growth related species (Denison 1979, Harris *et al.* 1982, Lehmkuhl 1984, Morrison and Swanson 1990, Lehmkuhl and Ruggiero 1991, Spies and Franklin 1991, MacArthur and Wilson 1997, Jules *et al.* 1999).

Logging in southwestern Oregon and northern California began in the 1850's. Most of the logging during that period was to clear land for settlement and mining.

By 1892 miners clearing land in search of gold had burned much of the lower elevation forests.

The first railroad to connect the growing communities of Josephine and Jackson counties in southern Oregon began construction in 1880 and was completed in 1890. Soon, sawmills sprang up throughout the region to accommodate the growing demand for railroad ties for the rapidly expanding railroad systems (Mckinley and Frank 1995).

With the advent of the gas-powered chain saw and the advances in transportation systems by the 1940's the logging of Northwest forests was flourishing. Beginning in the 1950's federal land management agencies, tasked with wood production to meet the growing demand for housing after World War II, began the liquidation of the slower growing older forests with the goal of replacing them with faster growing tree plantations.

In recent years forests throughout the southwestern region of Oregon have been observed to be under environmental stress. The climate of southwestern Oregon is among the hottest and driest in the western Cascades (Little *et al.* 1995). Although forests of all ages are exhibiting symptoms of stress, mortality has been most prevalent in older forests among large trees. Many forest stands have lost and are continuing to loose a relatively high proportion of the older trees to what appears to be density related mortality, exacerbated by an extended period of below average precipitation from 1987-1992 (Sensenig *et al.* 1994). Rates of loss of large trees during drought can be high. For example, from 1994 through 1996 more than 50 million board feet of dead and dying overstory trees were removed during salvage operations from Federal land in southwestern Oregon. Many of these trees were old, dominant stand components generally between 160 years and 450 years of age. These trees were clearly capable of surviving previous climatic and ecological variation as evidenced by the fact that they lived to the present. Droughts in this area are common (Douglass 1934, Graumlich 1987). This may indicate that other factors are involved in overstory tree stress and mortality. Overstory tree mortality rates appear to exceed their replacement. If this trend continues a pronounced reduction in old-growth forest ecosystems is inevitable (Lehmkuhl 1991) and may result in a corresponding decline in old-growth forest habitats.

Southwestern Oregon's forests, especially the Siskiyous, exhibit extraordinary species diversity (Detling 1961, Stabbing and Majors 1965, Franklin and Waring, 1979) ranking among the most diverse in northen temperate forests (Nelson 1997, Coleman and Kruckeberg 1999, DellaSalla *et al.* 1999). All western plant formations dominated by trees occur in this area (Whittaker 1961). Because of the relatively dry climate and historically frequent fire events, the plant communities of southwestern Oregon, tend to be delimited into smaller assemblages than found in more mesic environments (Atzet and Wheeler 1989). This is partly due to the fact that resources are often limiting, leading to broad environmental gradients (Atzet *et al.* 1996). Slight variations in aspect and elevation can improve growing conditions sufficiently to influence which vegetative community will persist (Whittaker 1961, Waring 1969). This observation is consistent with those at higher elevations where abrupt shifts in tree species composition are frequently observed. Atzet and others have identified and described >140 distinctive plant associations in southwestern Oregon forests (Atzet *et al.* 1989, 1996). Similarly, another 70 plant associations have been described in tanoak and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] forests in the Klamath Mountains of northern California (Jimerson *et al.* 1996). As a result of these and other factors, the forests in southwestern Oregon tend to exist in patches, varying in size and species composition. Forest patches, although diverse in and of themselves, contribute to the diversity of the broader landscape (White and Pickett 1985, Spies and Franklin 1991, Van Pelt *et al.* 1992), which in aggregate are of major importance to landscape function (Lehmkuhl and Ruggiero 1991). The loss of these older forest components may diminish the ecological productivity of these landscapes in the long-term (Franklin and Waring 1980, Franklin 1989, Thomas *et al.* 1993). In the absence of disturbances such as fires which tend to perpetuate seral diversity (Petraitis *et al.* 1989), forest stands may become more homogeneous in terms of habitat and species richness, resulting in reduced biological diversity within and throughout forest stands (Norse *et al.* 1986).

As old-growth habitats are reduced, there is a growing concern that these reductions may influence the abundance and viability of old-growth associated species (Harris *et al.* 1982, Norse *et al.* 1986, Thomas *et al.* 1993, FEMAT 1994). Also, the possibility that extant old forests may be unique ecosystems that have developed under climatic and disturbance regimes that may never be duplicated has alarmed some biologist (Fritts 1965, 1971, Brubaker 1991, Franklin and Spies 1991, Thomas *et al.* 1993).

The resiliency or potential for an ecosystem to recover and restore productivity following disturbance is related to its biological diversity (Ehrlich 1980, Franklin *et al.* 1989, Perry *et al.* 1989, Kelly and Harwell 1990, Frank and McNaughton 1991, Tilman and Downing 1994, Brookes 1996, Chang 1996). Therefore, additional attention has focused on the potential loss of biological diversity throughout northwest forests, due in part to a reduction in old-growth forest ecosystems (Crow 1990, Franklin and Spies 1991a, FEMAT 1994, Wilson 1998).

Factors responsible for species orientation toward old-growth include protection from competitors, food sources, and suitable nesting and reproductive sites (Franklin *et al.* 1981). Because the physical, chemical and biological environments under which old-growth forest ecosystems develop are continually changing, their ecological processes such as nutrient cycling, production of organic matter and down wood are also constantly in a state of transition, resulting in ongoing spatial and temporal variation (Sollins *et al.* 1980, Brinkly and Graham 1981, Franklin *et al.* 1981, Lienkaemper and Swanson 1987, Harmon and Chen 1991). This variation is expressed in many forms including, stand structure, species composition and abundance, soil productivity and many others which in turn results in irregular habitat characteristics facilitating structural and species diversity (Meslow 1978, Mannan and Meslow 1984, Schowalter 1990, Bingham and Sawyer 1991, Franklin *et al.* 1991).

Older forests, typically >200 years of age, are often referred to as late-successional. Late-successional forests are mature forests that are beginning to develop, or currently exhibiting old-growth forest characteristics. The characteristics of old-growth are not precisely defined however, attempts to describe and define the ecological attributes of old-growth have been undertaken (Juday 1976, Franklin *et al.* 1979, Franklin and Waring 1980, Lang 1980, Old-growth Definition Task Group 1986, Hunter 1989, FEMAT 1994). Although the definition of old-growth varies somewhat by the forest vegetation community and location, the consensus is that the definition of old-growth includes more criteria than age alone (Franklin *et al.* 1979, Franklin 1986, Franklin *et al.* 1991). They also include stand attributes such as snags, down wood, vertical structure, canopy layers and large trees (Hunter 1989, Bingham and Sawyer 1996). Old-growth forests may exhibit considerably different structures than younger forests thus creating dissimilar habitats (Franklin *et al.* 1981, Franklin 1988, Franklin and Spies 1991, Tappeiner *et al.* 1997, Poage 2000).

Older forests with large trees are known to provide habitats for many rare organisms (Pike *et al.* 1975, Franklin *et al.* 1981, Thomas *et al.* 1993, FEMAT 1995, Wilson 1998). There is an expectation that as increased tree mortality, logging and fires reduces the amount of older forests, their habitats will be replaced by younger forest stands that will eventually develop old-growth forest characteristics. This assumes that as young stands mature, suitable old-growth habitats will redevelop and old-growth dependent/related organisms will gradually colonize these stands. In the interim, the 1994 "Northwest Forest Plan" which regulates federal forest practices, prescribes temporary protection for more than 600 late-successional and old-growth related, associated or dependent organisms (USDA/USDI 1994).

The Northwest Forest Plan designated a provisional system of spatially connected late-successional reserves (LSRs) with the intention of providing habitat for species that rely on old forest habitats and connectivity to facilitate species dispersion across the landscape.

This plan also prescribes criteria for the retention of snags, down coarse wood and stand canopy closures to provide refugia for old-growth associated and dependent species, long enough for their populations to eventually disperse into proximal stands as suitable old-growth habitats redevelop. This strategy is primarily based on the assumption that the abundant young forests will grow suitable replacement habitats for late-succession associated and dependent species over time. Thus, the fate of late-successional and old-growth forest ecosystems are dependent to a great extent to which this assumption holds true. Thus it becomes critically important to better understand the ecological processes involved in the development of old-growth and the available options for managing young stands toward replacing old-growth and late-successional forest ecosystems.

Currently the preponderance of southwestern Oregon's forests, are approximately <120 years of age. Numerous factors must be determined in order to manage young forests to replace old-growth habitats. For example: How did old-growth forests in southwestern Oregon develop, in terms of growth, species composition, density and stand structure? Did these old-growth forests develop following the patterns of stand initiation, self-thinning and understory re-initiation outlined by Oliver and Larson (1990)? What ecological factors were instrumental in creating the conditions under which old-growth forests developed and did fire play a role in their development? What are the current conditions of young stands in terms of their characteristics and attributes and do these young stands have the capability of being managed to replicate old-growth stand structure and habitat? Will fire, or the lack of fire, explain likely differences in stand developmental patterns?

OVERALL RESEARCH OBJECTIVES

There are two overall research objectives in this study. The first is to characterize the fire regime under which old-growth forests developed, and the establishment of cohorts of old-growth trees in this regime. The second is to determine the density, age distributions, growth rates and crown and stem characteristics of old-growth trees and compare them with contemporary young-growth trees. Understanding the development and growth of young and old-growth stands should provide a basis for managing young stands to produce old-growth characteristics. Specific details of these objectives will be outlined in Chapters II and III.

It is important to note that these studies were conducted at the stand scale on areas of about 8ha. Most previous studies of fire histories have been conducted at large scales with the purpose of characterizing fire regimes for a particular forest type typically >1,000's ha. For example, Bork (1985) studied the fire history of the eastern Oregon region, Agee (1991) the Douglas-fir forests of the Pacific northwest, Madany and West (1980) studied Zion National Park, Taylor (1993) the red fir forests, Willis and Stuart (1999) the forests of northern California, and Teensma (1987) researched the central western Oregon Cascade forests. However, to broaden our understanding of potential fire effects on stand development it is important to characterize the range of fire free intervals as well as the average fire return intervals or frequency. Also, much of the work on stand growth has been done on small plots (<.10ha) however, stand development and especially establishment of large old-growth trees occurs at a scale greater than this.

The following studies involve both old and young-growth stands. The overall objectives in the old-growth studies are to determine the developmental dynamics of old forests at the stand scale. Old-growth forest stands typically exist in patches (Spies and Franklin 1988, 1989, 1990). In southwestern Oregon these patches most frequently range in size from 8-32ha (BLM 1995). Consequently a 8ha plot was chosen to facilitate fire occurrence sampling of a representative old-growth stand. These studies are unique in that disturbance by fire, or lack thereof, and its potential influence on species composition, stand structure and rates of growth is studied at the stand level. Sampling and analyses are stand specific so that the developmental dynamics of individual stands can be determined. This approach has not been previously undertaken. This information will be particularly useful to forest ecologists when evaluating current stand conditions for developing silvicultural options for managing both young and old forest habitats. I chose stands in the Cascades, Siskiyous and mid-Coast forests of southwestern Oregon to study the development of old-growth forests and compare their development with that of young-growth forests growing on comparable sites.

DESCRIPTION OF STUDY AREAS

Location

This study was conducted in forests of three geographic regions in southwestern Oregon including the Cascade Mountains, Siskiyou Mountains and the mid-Coast Mountain region of Oregon's Coast Range Mountains representative of the tanoak understory community (Atzet and Wheeler 1989, Jimerson *et al.* 1996) (Figure 1.1). The locations of the Cascade, Siskiyou and mid-Coast research sites are depicted on Figure1.2.

Cascade Forests Species Composition

Southern Cascade forests are comprised primarily of mixed coniferous stands that vary significantly in composition by elevation.

Major tree species include Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.), white-fir [Abies concolor (Gord. & Glend.) (Lindl. Ex Hildebr.] and incense-cedar (*Calocedrus decurrens* Torr.) and Shasta fir *(Abies magnifica* var. shastensis Lemm.) at high elevations. Minor tree species include sugar pine (*Pinus lambertiana Dougl.)* and western white pine (*Pinus monticola Dougl. ex D. Don).*

Hardwood species include; Oregon white oak (*Quercus garryana* Dougl. Ex Hook.), California black oak (*Quercus kelloggii* Newb.) and Pacific madrone (*Arbutus menziesii* Pursh). The lower elevation mixed conifer forests are generally dominated by ponderosa pine and Douglas-fir. The mid and higher elevations are dominated by Douglas-fir and the highest elevation forests, generally above 1,900 meters, are dominated by white-fir (*Abies concolor),* and Shasta fir (*Abies magnifica*) and infrequently western white pine and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.].

Figure 1.1 General vicinity map illustrating the Cascade, Siskiyou and mid-Coast forests of southwestern Oregon. The perimeter of the box indicates the approximate range of inference of these study areas.

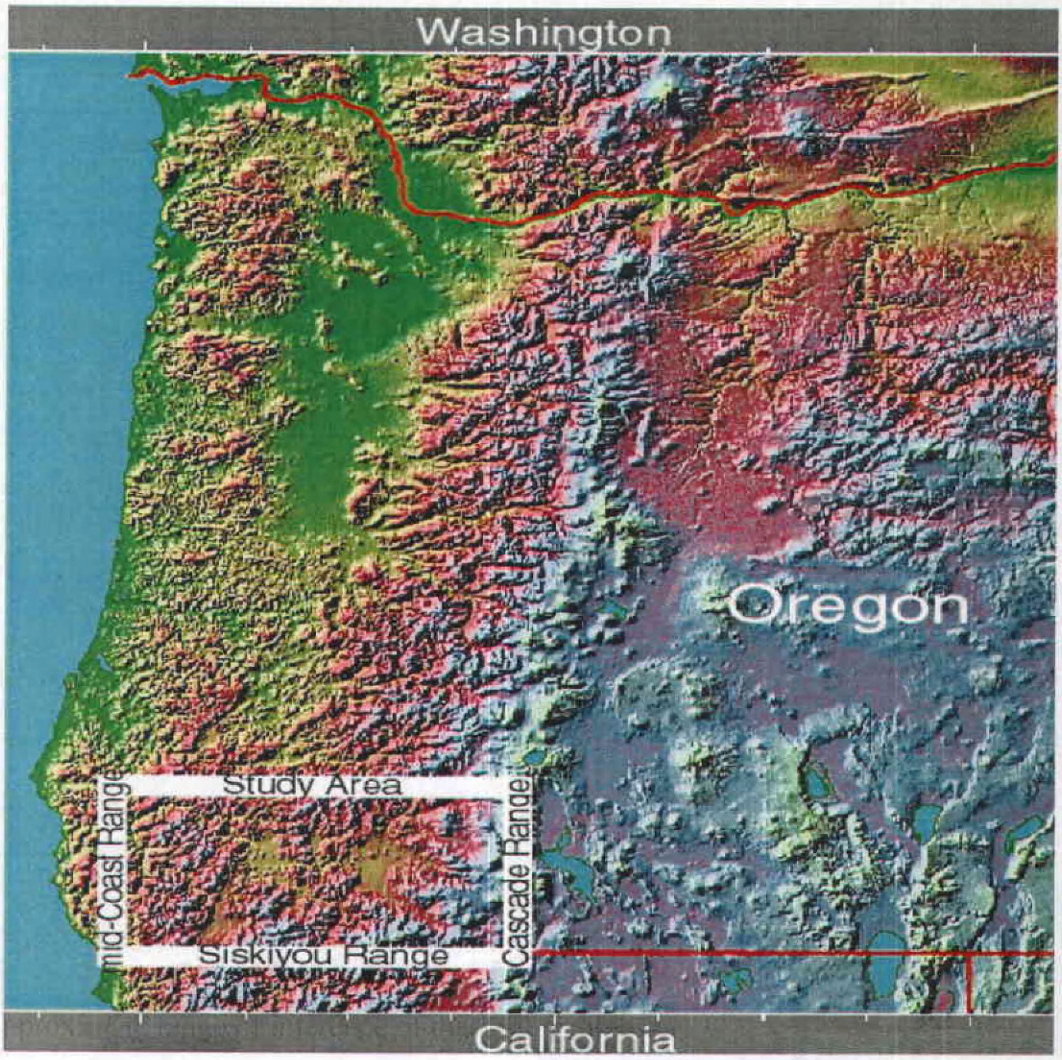


Figure 1.2 Location of Cascade, Siskiyou and mid-Coast research sites in southwestern Oregon

Sugar pines (*Pinus lambertiana* Dougl.) are individually scattered throughout all elevations but are more abundant in the mid and higher elevations. Predominant understory vegetation includes, snowbrush (*Ceanothus velutinus* Dougl.), green-leaf manzanita (*Arctostaphylos patula* Green) and brush-form golden chinkapin [*Castanopsis chrysophylla* (Dougl. A.DC.].

Siskiyou Forests Species Composition

The Siskiyou Mountains of southwestern Oregon and northern California are comprised of Mixed-Evergreen forests (Franklin and Dyrness 1973). Dominant coniferous tree species include Douglas-fir, ponderosa pine, white-fir and incense-cedar. Minor species include, sugar pine, Jeffreyi pine (*Pinus jeffreyi* Grev. & Balf.) and knobcone pine (Pinus attenuata, Lemmon). Hardwood species include; canyon live oak (*Quercus chrysolepis* Liebm.), Oregon white oak (*Quercus garryana* Douglas. Ex Hook.), California black oak (*Quercus* kelloggii Newb.) and Pacific madrone (*Arbutus menzeisii* Pursh).

The understory vegetation includes, buckbrush [*Ceanothus cuneatus* (Hock) Nutt.] green-leaf manzanita (*Arctostaphylos patula* Green) and golden chinkapin [*Castanopsis chrysophylla* (Dougl.) A. DC.].

Mid-Coast Forests Species Composition

The major coniferous tree species of the mid-Coast forests include Douglas-fir, ponderosa pine and incense-cedar. Tanoak [*lithocarpus densiflorus* (Hook. & Arn. Rehd] is a major species in these forests frequently dominating the understory. Minor coniferous species include white-fir and sugar pine. Pacific rhododendrons (*Rhododendron macrophyllum* D. Don), salal (*Gaultheria shallon* Pursh) and golden chinkapin [Castanopsis chrysophylla (Dougl.) A. DC.] are common in the understory. Pacific madrone (*Arbutus menziesii* Pursh) is also very common especially on drier sites.

Southwestern Oregon Climate

This geographic region is characterized by an extended period of hot and dry weather usually beginning in mid May and often lasting through mid October. The summertime weather patterns are dominated by Pacific high pressure cells. These cells move from their southern, winter positions and migrate through the northern Pacific during the summer months influencing moisture and cold air mass movements. During the summer, high energy storms are frequently diverted into the region (Morris 1934b). Daytime humidity remains relatively low, generally <12% throughout most of the summer dry season ranging between 8% and 20% (Waring 1969). However, during the months of July, August, September and sometimes early October, energy latent warm fronts passing through the region result in a rapid increase in humidity. As a result, high (cirrus) clouds are formed followed by dense layers of nimbo-cumulus clouds. These conditions often result in a barrage of violent thunderstorms sparking numerous wildfires (Alexander 1927, Morris 1934b, Burke 1979), (Chapter II, Figure 2.8 p.70).

During these events precipitation is usually sporadic and widely dispersed having relatively little suppression effect on dry available fuels. There is considerable evidence indicating that fire has been an intricate component of the area's forest ecology for perhaps tens of thousands of years (Pyne 1982, Agee 1990, 1993).

Fire is recognized as the predominant natural disturbance process in southwestern Oregon forests (Atzet and Martin 1994). These study areas are also characterized by a prolonged moist or rainy season, particularly in the mid-Coastal Mountains, usually beginning in mid to late November and frequently persisting through February.

Annual precipitation across the study sites ranges from approximately 97-142cm in the Cascades, 9-107cm in the Siskiyous and 91-1381cm in the mid-Coast range (Table 1.1). The physical attributes of each study site are summarized in Table 1.2.

Table 1.1 Average annual precipitation (cm) for each of the eighteen study sites in Cascade, Siskiyou and mid-Coast forests derived from a topographic model for mapping precipitation over mountainous terrain (Daley *et al.* 1994).

Average annual precipitation in the study areas

Cascade					
Deer Creek	Soda Meadows	Hoxie Creek	Buck Divide	Shell Peak	Willow Creek
97 cm	122 cm	122 cm	132 cm	142 cm	132 cm
Siskiyou					
Glade Creek	Skunk Gulch	Woodpecker Springs	Lick Gulch	Wrangle Pass	Yale Creek
107 cm	107 cm	112 cm	97cm	114 cm	102 cm
mid-Coast					
Smith Creek	Rum Creek	Smoked Elk	Dulog Creek	Big Windy Creek	Sourgrass Creek
127 cm	132 cm	191 cm	381 cm	304 cm	208 cm

Table 1.2 Summary of site attributes for 20 old-growth and young stands in southwestern Oregon Cascade, Siskiyou and mid-Coast forests.

Site Attributes

Cascade	Slope %	Aspect	Elevation (m)	Forest Type	Site Index (50yr)[1]	Soil Type [2]
Deer Creek						
Old-growth	30	NE	1,140	*MIX	70	McNull-Medco
Young Stand	15	NE	1,050		61	
Soda Meadows						
Old-growth	23	N	1,542	MIX	65	Medco
Young Stand	23	N	1,476		75	
Hoxie Creek						
Old-growth	3	S	1,526	MIX/WF	80	Farva-Pinehurst
Young Stand	0	S	1,505		75	
Buck Divide						
Old-growth	30	NE	1,706	*WF	75	Rustler Peak
Young Stand	43	N	1,739		72	
Shell Peak						
Old-growth	13	NW	1,509	WF	75	Pinehurst
Young Stand	5	NW	1,516		60	
Willow Creek						
Old-growth	30	E	1,608	WF	65	Farva
Young Stand	7	E	1,739		65	
			Additional Cascade Forest Types			
Sugar Pine						
Dead Indian						
Old-growth	8	W	1,509	*SP	120	Farva
Shasta Fir						
Vulture Rock						
Old-growth	13	N	1,870	*SF	105	Oatman
Young Stand	20	NW	1,837		70	
Griffon Pass						
Old-growth	14	SW	1,673	SF/WF	50	Oatman/Otwin
Young Stand	15	W	1,936		63	

Table 1.2 (continued)

Siskiyou	Slope %	Aspect	Elevation (m)	Forest Type	Site Index (50yr)[1]	Soil Type [2]
Glade Creek						
Old-growth	44	NW	1,180	MIX	75	Vannoy
Young Stand	35	W	1,160			
Skunk Gulch						
Old-growth	50	S	1,214	MIX	77	Vannoy
Young Stand	52	SW	1,247			
Woodpecker Spring						
Old-growth	17	NE	1,378	MIX	75	Vannoy
Young Stand	31	E	1,400		82	
Lick Gulch						
Old-growth	52	NE	1,247	MIX	70	Carris
Young Stand	57	NE	1,214		77	
Wrangle Pass						
Old-growth	45	SE	1,806	MIX	60	Dubakella
Young Stand	52	E	1,903		78	
Yale Creek						
Old-growth	38	N	1,378	MIX	75	Vannoy
Young Stand	46	NE	1,362		76	

mid-Coast	Slope %	Aspect	Elevation (m)	Forest Type	Site Index (50yr)[1]	Soil Type [2]
Smith Creek						
Old-growth	20	SW	984	Tanoak	88	Vermisa-Beekman
Young Stand	16	W	1,148		95	
Rum Creek						
Old-growth	37	SE	1,165	Tanoak	74	Speaker-Josephine
Young Stand	44	NE	984		78	
Smoked Elk						
Old-growth	32	S	525	Tanoak	73	Vermisa-Beekman
Young Stand	22	SW	591		79	
Dulog Creek						
Old-growth	65	SE	1,345	Tanoak	71	Speaker-Josephine
Young Stand	43	E	1,340		66	
Big Windy Creek						
Old-growth	39	SE	1,280	Tanoak	68	Vermisa-Beekman
Young Stand	32	SW	1,378		57	
Sourgrass Creek						
Old-growth	56	NE	1,312	Tanoak	87	Vermisa-Beekman
Young Stand	33	E	1,083		82	

[1](Hann and Scrivani 1987), [2] (USDA 1993), * MIX= Mixed Conifer, SP= Sugar Pine, SF= Shasta Fir, WF= White-fir

THE USE OF TREE RING ANALYSIS IN RESEARCH

Much of the data used in this research effort was obtained through tree ring analysis. The annual growth rings of both young and old trees were measured and their development recreated using the dendrochronology methodology developed by Tappeiner *et al.* (1997). In addition, fire scars on tree rings were analyzed to compute fire occurrence (McBride 1983, Means 1989, Dieterich 1980a, Agee 1996).

The concentric rings visible in the cross-section of trees have intrigued foresters, naturalists and ecologists for a long time (Douglass 1929, Campbell 1949, Anon 1977). Childs (1882) published the first publication specifically correlating tree growth rings to tree age, illuminating the concept that trees store potentially valuable information about the past. Soon afterwards, scientists eager to discover new ways of uncovering historical information began studying tree ring patterns. By 1905 the United States Weather Bureau recognized that tree ring growth was a reliable tool for determining historic precipitation particularly in dry climates (Bogue 1905). Soon, hundreds of studies were underway throughout the country (Studhalter et al. 1963). In 1924, Bauer published on a newly developed instrument that he termed the increment borer which could extract a core and expose the annual rings from a living tree without harming the tree (Bauer 1924). In 1937 the first comprehensive text on tree ring analysis tilted Principles and Methods of Tree-Ring Analysis was published (Glock 1937). Early researchers began utilizing tree ring analysis to date all sorts of climatic (Douglass 1928, 1934, 1936, 1941, Glock 1955, Fritts 1966, 1971, 1991, Fritts and Shao1992) ecological, archeological (Douglass 1938, Bannister and Robinson 1975) and geologic events including the advance and retreat of glaciers (Lawerence 1950, Cropper and Fritts 1981), the age of beaver ponds (Lawrence 1952), volcanic events (LaMarche and Hirschboeck 1984), the age of soil strata (McGregor 1936, Babbage 1938), forest pest outbreaks (Evenden 1940, Blais 1962, 1965, 1983, Carlson *et al.* 1973, Brubaker and Greene 1979, Alfaro *et al.* 1982, Carlson and McCaughey 1982, Archambault 1983, Fellin *et al.* 1983 Beverridge and Cahill 1984), regional climates (Fritts and Shatz 1975, Hughes *et al.* 1981, Cook *et al.* 1982), porcupine populations (Spencer 1958) seasonal temperatures and precipitation (Fritts 1974, Fritts and Lough 1985) and many more. In 1944 at a much broader scale, minute but consistent variations in tree ring patterns that corresponded to sunspot maxima and minima were detected over thousands of samples (Mosely 1941, Rush 1952, LaMarche and Fritts, 1972). Also, tree ring growth analyses are used in a wide range of scientific fields and are routinely undertaken to date archaeological ruins where wood was used in construction (Dean 1978).

The use of fire damaged tree rings to determine forest disturbance regimens began in about 1921 when Lackmund described the formation of scare tissue on trees as a result of fire. Since then many broad scale fire history studies have been undertaken (Lackmund 1921, Morris 1934a, Randall 1937, Weaver 1951, Cronemiller 1959, McBride and Laven 1976, Arno and Sneck 1977, Laven 1980, Teensma and Dominic 1987, Agee 1990). With the advances in technology, computer programs have been developed that are capable of analyzing voluminous amounts of tree ring data for finding obscure correlations in the patterns of tree growth which corresponds to such variables as annual precipitation, gradual climatic change, river basin water yields and seasonal temperatures over vast areas (Fritts *et al.* 1969, Baillie 1973, Cropper 1979, Graybill 1979, Holmes 1983) and by doing so, scientists are better able to determine meteorological history and perhaps be better equipped to accurately predict future trends.

Tappeiner *et al.* (1996) developed a methodology for analyzing the historical development of forest stands. By analyzing tree stumps, stand histories can be reconstructed that approximate stand density, tree sizes and tree growth by measuring and plotting the 10yr (radial increment cm) growth rates of trees. However, numerous limitations in reconstructing forest development from stumps exist. Information on where and when mortality occurred, the extent to which insects and other pathogens impacted stands, the characteristics of tree crowns, tree vigor, the composition of understory vegetation and stand characteristics prior to the trees reaching stump height remains unknown.

CHAPTER II

FIRE DISTURBANCE AND THE STRUCTURAL DEVELOPMENT OF OLD-GROWTH STANDS IN CASCADE, SISKIYOU, AND MID-COAST FORESTS OF SOUTHWESTERN OREGON

INTRODUCTION

Forest ecologists continually strive to gain a greater knowledge of the complex interrelationships within forest ecosystems. As our knowledge of these relationships advances, so does our capability of predicting how forests are likely to respond when disturbed. Disturbance can be induced by natural phenomena, such as fire, wind, disease or by human activity such as thinning or prescribed fire. An understanding of the type, frequency and influence on stand development by historic disturbances can assist foresters in evaluating potential ecosystem effects and response to various silvicultural treatments (Bailey and Tappeiner 1998). It also provides a basis for developing management options, as well as recognizing when stands are developing on an undesirable/desirable trajectory.

Forests are continually responding to changes in their environment (Whittaker 1960, Ehrilich 1980, Agee 1999). Environmental changes occur at various scales and rates (Franklin *et al.* 1991). Relatively slow environmental changes include factors such as gradual shifts in climate (Douglass 1934, Keen 1937, Whittaker 1960, 1961) alterations in soil structure and nutrient cycling (Fowells and

Stephenson 1934), as well as the continuous effects of root pathogens such as laminated root rot [*Phellinus weirii* (Murr.)Gilbon], Armillaria root disease, [Armillaria ostoyae (Romagon. Herink)] annosus root rot [*Heterobasidion annosum* (Fr.) Bref.] and fir dwarf mistletoes *(Arceuthobium abietium* Engelm.) and (*Arceuthobium douglasii* Engelm.) as stands encounter environmental stress (Pickett and White1985). All of these subtly but incrementally influence forest stand development (Brooks 1996). In addition, disturbances such as windthrow, insect epidemics and lightning ignited wildfire, have been influencing the development of forests for many thousands of years (1965, Means 1982, Pyne 1982, Agee 1990). Of these, wildfires have been identified as an influential disturbance, modifying the development of species composition, stand density, tree growth and stand structure (Ahlgren and Ahlgren 1960, Komarek 1968, Heinselman 1981, Atzet *et al.* 1988, Agee 1990).

Fire has been an intricate process of forest ecosystem dynamics throughout time (Hemstrom 1979, Alexander 1980, Martin 1982, Means 1982, Pyne 1982, Dunwiddie, 1986, Cwynar 1987, Agee 1991). Native forest plant species have adapted to living in fire prone environments (Martin 1982, Kauffman 1990). For example, several tree and many other vascular plant species require heat to germinate their seeds, which are stored in the soil seed-bank (Zavitkowski and Newton 1968, Ingersol and Wilson 1990). Such seeds are termed refractory seeds.

Fire may kill hardwoods if the consumption of the overstory is high. However, hardwood tree species like Pacific madrone, tanoak and bigleaf maple are revitalized by regenerating from sprouts following fire (Griffin 1980). Many conifer species, particularly ponderosa pine and Douglas-fir, develop bark characteristics that enhance their cap to survive low intensity surface fires (Chang 1948, Vines 1968, Nicolai 1977). For example, Douglas-fir trees, develop progressively thicker bark as they grow which is an inefficient conductor of heat (Chang 1954, Vines 1968, Nicolai 1977), which often provides sufficient insulation to prevent mortality during a fire (Fahnestock and Hare 1964). Although some tree species are more resistant to induced mortality than others, smaller trees of all species are more susceptible to fire (Van Wagner 1978, Franklin and Hemstrom 1981). Therefore, the frequency of fire during stand development may influence the size and number of surviving trees (Agee 1990). In the absence of fire, species like white fir which are relatively susceptible to fire, become established and gradually displace the more fire adapted species such as Douglas-fir and ponderosa pine (Parsons and DeBendetti 1979). During extended periods without fire, fire dependent species may decline in abundance and eventually disappear (Kauffman 1990, Kauffman and Martin 1991). Therefore, the lack of fire may result in a shift in relative abundance of both overstory and understory trees, shrubs and herbs, influencing the dynamics of forest succession and stand development. Thus, the lack of fire may alter fire regimens resulting in a shift in stand structure and the habitats that they create

(Ahlgren and Ahlgren 1960). In Idaho and other areas fire suppression has been shown to have altered landscape structure (Baker 1992) and influence forest succession (VanWagner 1978, Barrett 1988). Therefore it is plausible that in time, the lack of fire may well replace the occurrence of fire as the most significant ecological disturbance factor influencing the development of southwestern Oregon's forests.

An ecological overview of historical fire activity throughout the Klamath Geological Province of northern California and southwestern Oregon was presented by Atzet and Wheeler (1982). Utilizing the variables, fuel loading (percent ground cover, total stand basal area), and fuel drying (elevation and aspect) on 997 permanent ecology plots located throughout southwestern Oregon, they developed a weighted ranking of potential fire occurrence for six broad forest vegetation classifications termed vegetation series. Douglas-fir stands recorded the greatest litter build-up and because this variable dominates the ranking, the Douglas-fir series ranked the highest for potential fire frequency followed by White-fir, Port Orford Cedar, Tanoak, Shasta fir and Jeffery Pine series stands.

On average, current stands have developed without fire for a longer period of time than stands developing in prior centuries. Since the initiation of active fire suppression in southwestern Oregon, beginning in about 1900, the average number of hectares burned annually has steadily declined. By annualizing 838 high elevation ecology plots located in older unharvested stands (avg.= 237yrs), Atzet and Wheeler (1991) estimated that in the Klamath Province of southwestern Oregon and northern California, the average historical fire frequency was approximately 42 years. Further, they estimated that on average, the time since last fire was approximately 68 years. Because these stands were unharvested, the detection of fires required the coring of trees which tends to underestimate fire frequency because of the difficulty locating the scare of each fire (Barrett and Arno 1988). Similarly, in a cooperative study with the National Park Service at the Oregon Caves National Monument in the Siskiyou mountains, Agee *et al.* (1990) concluded that "recurrent fire has been a theme of the forests of Oregon Caves for more than 500 years. The 19th century had the most fires, with an average natural fire rotation of 34 years. Since 1921, no major fires have started within the Monument. This has been the longest fire-free period in more than three hundred years."

Throughout the Pacific Northwest most fire history studies have focused on the frequency of fire across broad landscapes such as western Oregon (Dieterich 1980a, Agee 1991, Ripple *et al.* 1994) and the Oregon Coast Range (Teensma and Adrian. 1987) with the intent of broadening our knowledge on the effects of fire frequency on landscape patterns over time. Natural fire rotations of 80-100yrs have been estimated for the Douglas-fir forests in western Washington (Agee and

Dunwiddie 1984). However, the uniqueness of southwestern Oregon's climate precludes extrapolation of these results from other studies. Few studies on fire history and ecology have been undertaken in this area (Atzet *et al.* 1988).

HYPOTHESES

The hypotheses for this study are that:

1. Fire occurred frequently in old-growth stands however, it occurred more frequently in the Siskiyous than in the higher elevation Cascades and the mid-Coast stands which receive more annual precipitation.

2. Seedling recruitment into old-growth stands, closely patterns fire events.

3. Fire killed trees <10cm diameter and that long periods without fire were necessary for seedlings to become established and grow to a diameter of >10cm to survive.

4. Fire modifies densities and growth in old-growth stands.

5. *Null Hypothesis*: Fire suppression efforts were not and did not become effective until technological advances and the use of modernized equipment became available in about 1950-1960.

RESEARCH OBJECTIVES

The objectives are focused at the stand scale. The primary objective was to determine the approximate frequency of fire within particular old-growth stands. I sampled fire scars on six 8ha stands in three forest types so that fire occurrence could be evaluated and its influence on stand development at the stand level could be ascertained. This information will be particularly useful to forest ecologists when evaluating current stand conditions and developing silvicultural options for managing both young and old forest habitats.

The overall objectives of this study are to:

1. Quantify fire occurrence in old-growth forest stands from 1700-1990, through the detections of fire scars in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

2. Compare the frequency of fire occurrence between stands and among these forest types.

3. Determine the length of fire free periods from 1700 -1990 in these three forest types.

4. Compare the frequency of fire with the recruitment of trees during stand development between sites and forest types.

5. Determine stand developmental characteristics including, tree establishment, growth, composition and density of old-growth stands in relation to their fire environment.

The intent of these studies was to determine the approximate fire occurrence in old-growth stands and to establish the disturbance regime within which old-growth stands developed. This work is different from other studies that sought to establish fire histories or chronologies because the intent was not to determine precisely the dates of each fire. This would require cross-dating, a very costly and time-consuming process of comparing patterns of tree growth in known time periods across large populations of trees (Douglass 1941, Stokes and Smiley 1968). In addition, cross-dating requires over 20-times more time than field-counting yet only improves accuracy by 1.73 to 4.44 or approximately 3yrs (Weisberg 1998). Therefore, I felt that errors arising as a result of not cross-dating samples would be more than offset by the increased speed and consequently larger sample size and geographic extent of sampling made possible by not cross-dating. In addition, it is not always possible to accurately date fire scars by cross-dating because fire may destroy scar tissue grown following preceding fires (Douglass 1941, Noel 1968, Stokes 1980). Also, a tree may not produce annual rings for several years if the crown or cambium of a tree is damaged by fire (Craighead 1927, Jordan 1966).

DESCRIPTION OF STUDY AREAS

This study was conducted in three southwestern Oregon forest types, in the Cascade, Siskiyou, and mid-Coast mountains. In southwestern Oregon, the Cascade forests are comprised primarily of mixed coniferous stands that vary in composition by elevation. Major tree species include Douglas-fir, ponderosa pine, white-fir [Abies concolor [(Gord. & Glend.) Lindl. Ex Hildebr.] and incense-cedar and Shasta fir (*Abies magnifica* var. shastensis Lemm.) at high elevations. Minor species include sugar pine (*Pinus lambertiana* Dougl.) and western white pine [*Pinus lambertiana* (Dougl. ex D. Don)]. Hardwood species include Oregon white oak [*Quercus garryana* (Dougl. Ex Hook)], California black oak (*Quercus kelloggii* Newb.) and Pacific Madrone. The lower elevation mixed conifer forests are generally dominated by ponderosa pine and Douglas-fir. The mid and higher elevations are dominated by Douglas-fir and the highest elevation forests, generally above 1,900 meters are dominated by true-firs (*Abies*), including both white-fir and Shasta fir although western white pine and western hemlock [*Tsuga heterophylla*

(Raf.) Sarg.]. Sugar pine (*Pinus lambertiana* Dougl.) trees are individually scattered throughout all elevations but are more abundant in the mid and higher elevations.

The Siskiyou Mountains of southwestern Oregon and northern California consist of mixed-evergreen forests (Franklin and Dyrness 1973). Dominant coniferous tree species include; Douglas-fir, ponderosa pine, white-fir and incense-cedar. Minor species include; sugar pine, Jeffreyi pine (*Pinus jeffreyi* Grev. & Balf.) and knobcone pine. (*Pinus attenuata*, Lemmon). Other hardwood species include; canyon live oak (Quercus chrysolepis Liebm.); Oregon white oak and California black oak. Pacific madrone is common on dry sites. In addition, this study included Cascade, Shasta fir sites and mixed conifer sites that were dominated by sugar pine for comparison, but was a minor part of these studies (see study location map Figure 1.2, p.15).

The mid-Coast forest type is the inland portion of the Coast Range mountains where forests are dominated by mixed evergreen, Douglas-fir and tanoak (Atzet and Wheeler 1989, Atzet *et al.* 1996, Jimerson 1996). The major coniferous tree species of the mid-Coast forests include Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], ponderosa pine [*Pinus ponderosa* (Dougl. Ex Laws.)] and incense-cedar [Calocedrus decurrens (Torr.)]. Tanoak [Lithocarpus densiflorus (Hook. & Arn.)Rehd.] is a major species frequently dominating the understory. Minor coniferous species include white-fir and sugar pine. Pacific rhododendrons (*Rhododendron macrophyllum* D. Don), salal (*Gaultheria shallon* Pursh). Golden chinkapin [*Castanopsis chrysophylla* (Dougl.) A. DC.] are common in the understory. Pacific madrone (*Arbutus menziesii* Pursh) is also quite common especially on drier sites.

METHODS

Point Fire Scar Sampling

Two methods of sampling fire scars are commonly used, point sampling and composite sampling (McBride 1983, Means 1989, Agee 1996, Arno and Sneck 1997). Point sampling, measures the frequency of fire events on an individual tree by dating the intervals between fire scars on the tree or stump. This method estimates the fire occurrence intervals at the precise location of that tree. However, low intensity fires may have burned the tree but did not leave a fire scar.

Because point samples represent only the scars recorded on a single tree, the observed intervals represent the fire history at that particular point and only fires of sufficient intensity to burn through the bark and scar cambial tissue of that tree. Point samples therefore do not necessarily record all the fires that burned within a stand. Point samples estimate the maximum possible fire interval and therefore the minimum fire occurrence at a particular point.

Composite Fire Scar Sampling

Another method of fire history reconstruction is termed composite fire frequency (Dieterich 1980b, Agee 1996). Composite fire frequencies are derived by correlating fire scare dates collected over large areas or landscapes. This method is generally used to determine fire regimes across broad areas of a particular forest type, typically covering 10,000's hectares. When composite samples are compiled without cross-dating each fire, scars as a result of the same fire may fall on slightly different dates, appearing as separate fires. This method yields a narrow fire interval and skews the results toward more frequent fire occurrence. For example, differences could occur in dating as a result of severe physiological damage requiring several years of recovery before xylem rings are produced near the bottom of the tree. Other less damaged trees would have no interruption in xylem growth. Also, a sampling error can result from a misinterpretation of the precise origin of post fire tissue growth. These errors tend to result in counting too few xylem rings. Therefore, composite intervals compiled within a stand can overestimate detectable fire occurrence. Cross dating can help account for missing rings but as previously mentioned has been shown to improve precision by approximately 3.08 years. (Weisberg 1998).

Old-growth forest stands typically exist in patches (Franklin *et al.* 1989, Spies and Franklin 1989). In southwestern Oregon these patches frequently range in sizes from 8-32ha (BLM 1995). Consequently an 8ha plot size was chosen to facilitate fire occurrence sampling of a representative old-growth stand. Because neither point sampling nor composite sampling provides detailed information at the stand scale, I dated fire scars on all of the stumps on each 8ha plot. Eighteen former old-growth stands in three forest types were chosen for the primary of this study; six stands in the mid-Coast Douglas-fir/ tanoak forests, six stands in mixed evergreen forests in the Siskiyou mountains and six mixed-conifer stands in the Cascades. However, because I was also interested in fire occurrence in Shasta fir and sugar pine stands I additionally sampled one sugar pine and two Shasta fir stands in the Cascades for a total of twenty-one stands (Franklin and Dyrness 1973). In southwestern Oregon, sugar pine does not grow as pure stands but rather subsists as a minor component of mixed conifer forests. I found only one stand having sufficient numbers (4.5trees/ha) of harvested sugar pine trees to sample. Also, there were fewer Shasta fir stands to sample since they comprise only a small proportion of the forests growing only at the highest elevations generally above 1,900m (Barbour and Woodward 1985). Both sugar pine and Shasta fir stands are analyzed as special cases, and are not included in the summary statistics except where otherwise noted. Individual site attributes are provided (Chapter I, Table 1.2, p. 20).

Fire Scars Sampling

All stumps within each 8ha clearcut plot were cleaned with a wire brush if necessary and then examined for fire scars. When a fire scar was detected, the growth rings after the fire were counted. To facilitate accurate counting, a pin was inserted into the stump to mark each tenth annual growth ring grown subsequent to the fire. A hand-held magnifier was used to count rings where they were narrow or difficult to delineate. The number of years since harvesting was added to the years of growth subsequent to the fire event and each fire date calculated. Where more than one scare occurred on a stump, each fire was individually dated and a record of the fire interval for that tree was recorded. Where scars occurred on two sides of the same stump which may have resulted from the same fire, both scars were dated for comparison. The stump height diameter at the time each point sample tree survived its first fire was measured in cm on each tree recording multiple fires in order to determine the approximate location to measure growth of the uncut young trees for comparison.

Old-growth Stand Development Sampling Methods

Within each 8ha clear-cut stand, three 0.1ha fixed radius circular plots were randomly established to determine tree ages and growth rates. Beginning at the center of each stump, a pin was inserted into the stump to mark every 10th annual growth ring on the up hillside of each tree. As with fire scare sampling, the stumps were cleared of debris, cleaned with a wire brushed if necessary. If the surface of a stump was damaged, it was resurfaced by cutting a new surface with a chain saw exposing fresh wood if possible. A hand-held magnifier was used where growth rings were narrow or difficult to delineate. Each 10 year growth period was measured in mm for the trees entire life span. In addition, tree species, diameter, stump height, and average bark thickness were measured and recorded for each stump.

DATA ANALYSIS

Fire Occurrence Data Analyses

The dates of all fire scars were calculated and compiled for 8ha plots to produce a composite sample fire history for all eighteen stands. The intervals between each fire record from 1700-1900 were calculated and averaged to establish a composite fire frequency. Composite fire frequencies were compared among stands and between forest types using ANOVA (analysis of variance).

The dates of all fire scars on individual trees recording multiple fires were calculated and compiled for each 8ha plot in all forest types. Each date became a fire record and when compiled formed the point sample fire history for that stand. The intervals between fire scars on individual trees recording multiple fires from 1700-1900 were compiled to establish a point sample fire frequency.

Point sample fire frequency intervals were compared among stands and between forest types using ANOVA.

Fire occurrence derived from point samples (the interval between multiple fires on a single tree) clearly underestimated episodes of fire because proximal trees in the same stand often recorded a single fire that was not detected on an adjacent tree that recorded multiple fires.

Without cross-dating each fire, scars as a result of the same fire may fall on slightly different dates appearing as separate fires and causing overly narrow composite intervals. This likely overestimates detectable fire occurrence, thus more accurate estimates of fire frequencies are likely to fall between the composite and point fire frequencies. Thus, an additional analysis was undertaken to derive a more probable fire frequency for each site. Weisberg (1998) determined that improved accuracy from cross-dating on laboratory prepared slabs, ranged from 1.73 to 4.44 years or 3.08yrs on average. Thus to account for the maximum potential variation of approximately 3yrs, fire scars were grouped (recorded as one fire event) where fires were detected within +/- 3yrs. The intervals between group dates were averaged to derive the most probable fire frequency for each site. I also determined the longest fire free intervals and the percent of the decades recording fire from 1700-1900 (pre fire suppression) for each stand.

Fire and Stand Development

I evaluated stand development on each of the eighteen sites. On three 0.1ha plots per stand I aged each tree by counting xylem rings. I determined the radius of each tree at 10 decade intervals by measuring the distance from the pith to the rings in 10 year increments. Thus I determined the size of each tree at each decade from the time it reached stump height (approximately 45cm) until it was cut.

I evaluated stand development for the period 1700-1990, the period during which about 92% of the trees on the eighteen sites were established (93% Cascade, 99% Siskiyou, 100% mid-Coast). For the three plots combined at each site, I calculated the proportion of the total numbers of trees recruited by 10 year periods by dividing the number of trees reaching stump height (recruitment) by the total number of trees established. I also calculated the proportion of trees on the plots at each decade that were <10cm and <25cm in diameter at stump height. I assumed that if there were large proportions of small trees present, fire intensity was low since small trees are likely to be killed by intense fire (Agee 1993).

Tree recruitment and size data were plotted for each site and compared with fire occurrence data. To further evaluate fire intensity I determined the diameter of each point sample tree when it first recorded a fire.

Old-Growth Stand Development Reconstruction

I used the data from each 0.1ha plot to reconstruct stand development, species composition, rates of 10 year growth and recruitment beginning with the date of when the oldest trees reached stump height until the stand was cut. Recruitment refers to trees becoming established each decade.

The development of the stands with the oldest trees in the Cascades, Siskiyous and mid-Coast were reconstructed and graphed for each stand. They are the stands with the longest developmental history from each forest type (Hoxie Creek, Cascade; Woodpecker Springs, Siskiyous; Big Windy Creek, mid-Coast).

For each tree, its diameter at the end of each 10 year period was calculated. The diameter of each tree in 10 year increments was graphed for each stand. The 10 year growths (mm) of each tree were aligned vertically by the calendar dates (decade) in which the growth occurred. Stand composition and its cumulative stand density were calculated and graphed for each stand. The decades in which fires were detected during stand development, were superimposed on each stand development graph so that recruitment, density, species composition, and tree growth could be compared with the occurrence of fire.

Effectiveness of Fire Suppression from 1920-1990

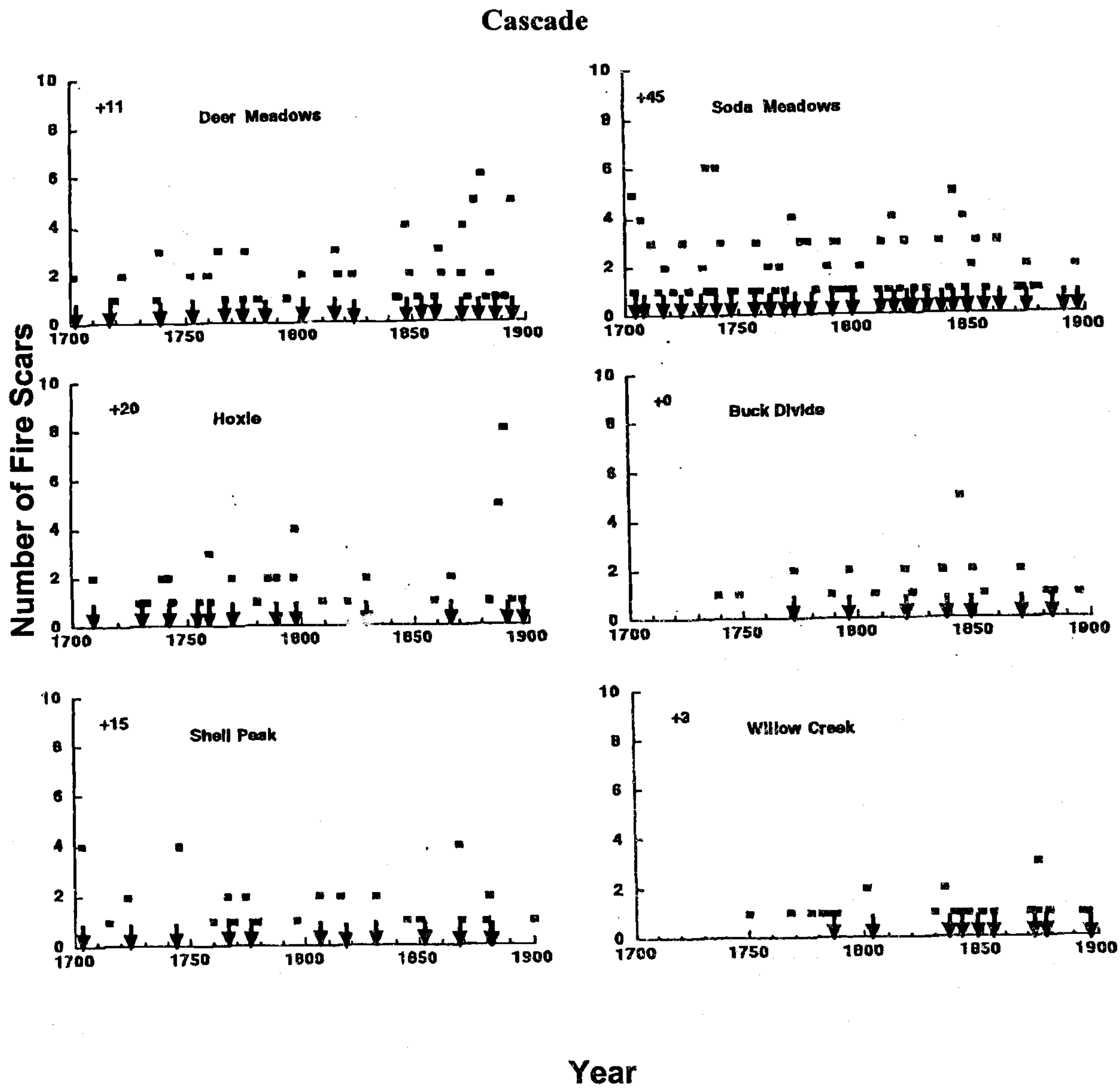
As southwestern Oregon became colonized Euro-American settlers, many fires were suppressed and in about 1900 the active suppression of all fires became policy, however the success and effectiveness of fire suppression is often questioned primarily because of the perception and presumption that the suppression of such a powerful natural force is insuperable. Therefore, to document the effectiveness or possibly ineffectiveness of historic fire suppression efforts, I compiled the analyzed the records provided by the U.S. Forest Service, Bureau of Land Management and the Oregon Department of Forestry on the suppression history of lightning and man caused wildfires within the project area. These records, mostly hand written on note cards, were recovered from old files, archives and suppression reports. These fire records were arrayed by cause, size, location and date and summarized arithmetically.

RESULTS

Fire Occurrence

Fire was common during the development of old-growth stands in all forest types (Figure 2.1). A total of 1,262 fire scars was found on all sites (Cascades mixed-conifer 441; Siskiyou mixed-evergreen, 443; mid-Coast tanoak 319 and 38 on the two Shasta fir stands and 21 on the sugar pine stand), (Table 2.1).

Figure 2.1 Number of fire scars from 1700 to 1900 detected by date on six sites in Cascades, Siskiyou and mid-Coast sites. The number in the upper left of each graph indicates the number of scars with dates prior to 1700. Arrows indicate times where more than one fire was dated within +/-3yrs.



(Continued)

Figure 2.1 Number of fire scars from 1700 to 1900 detected by date on six sites in Cascades, Siskiyou and mid-Coast sites. The number in the upper left of each graph indicates the number of scars with dates prior to 1700. Arrows indicate times where more than one fire was dated within +/-3yrs.

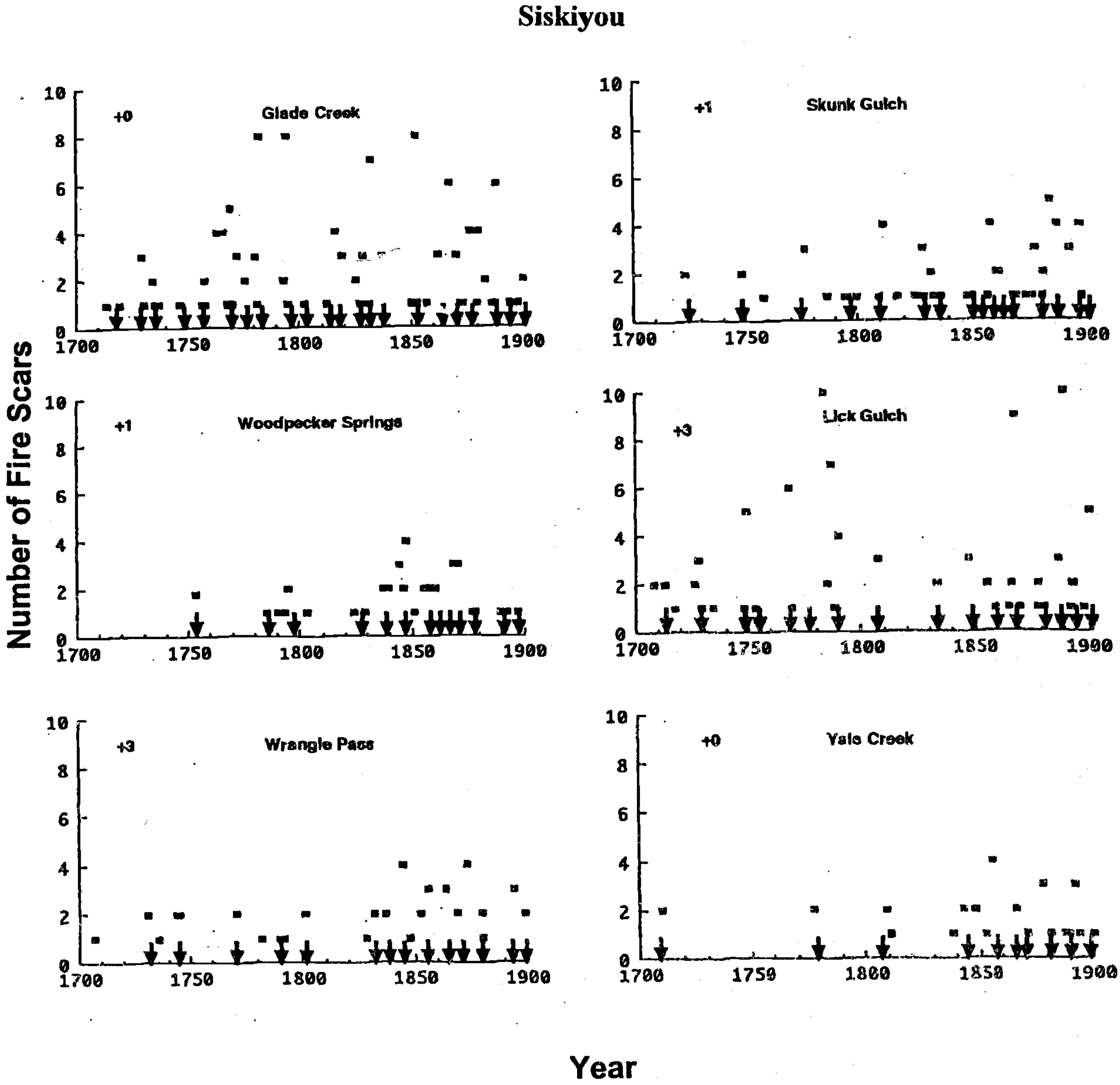


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Figure 2.1 Number of fire scars from 1700 to 1900 detected by date on six sites in Cascades, Siskiyou and mid-Coast sites. The number in the upper left of each graph indicates the number of scars with dates prior to 1700. Arrows indicate times where more than one fire was dated within +/-3yrs.

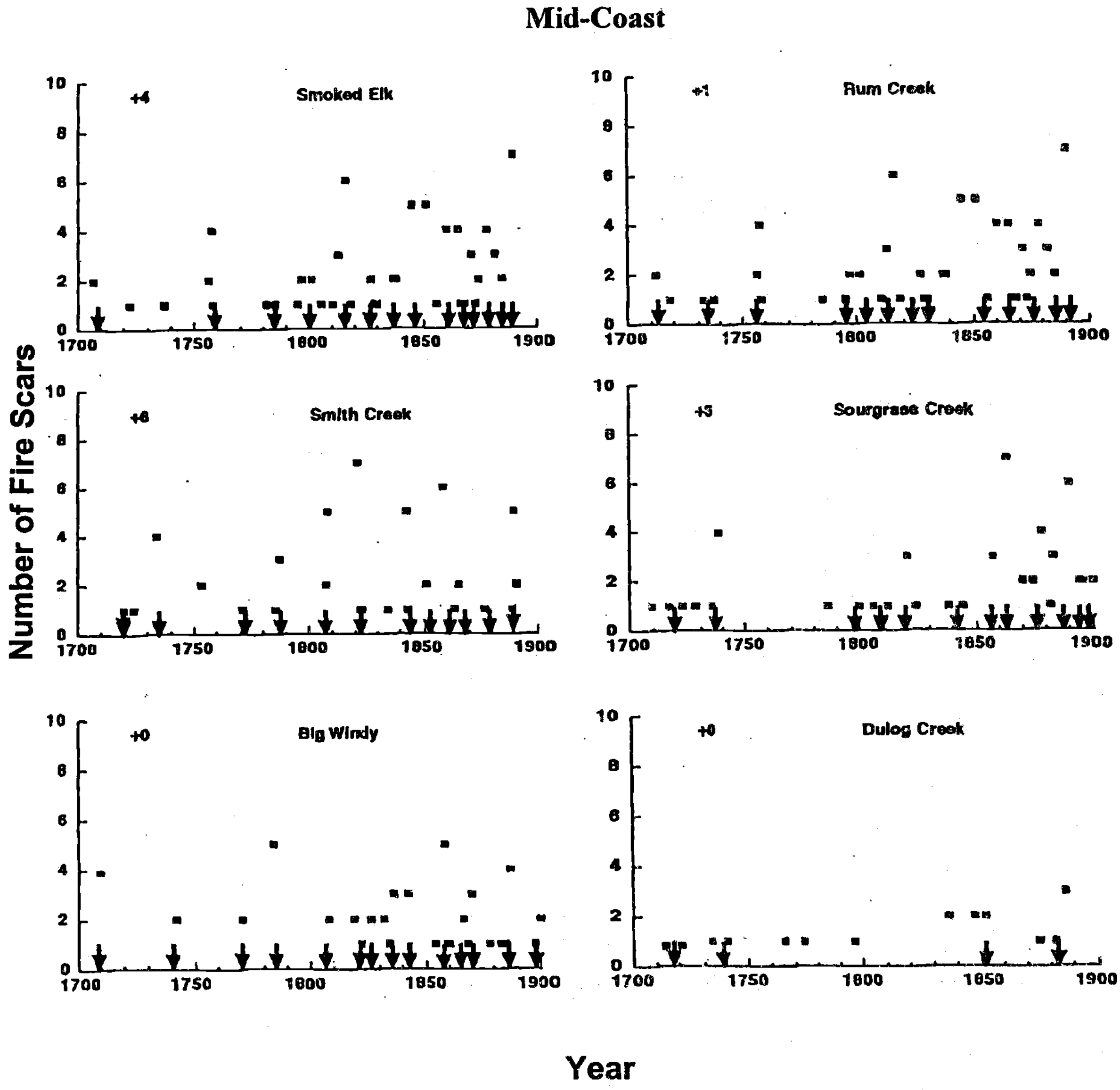


Table 2.1 Summary of fire history and evaluation of fire scar dating on twenty-one, 8ha stands in southwestern Oregon Cascade, Siskiyou and mid-Coast forests.

Forest Type	Total Fire[1] Records	Total Fire[2] Scars	Trees Recording Single Scars	Trees Recording Multiple Scars	Composite[3] Fire Interval From Total Scars	Grouped Composite[4] Fire Interval From Total Scars Grouped +/- 3yrs	Point Frequency[5] Fire Interval From Individual Trees w / Multiple Scars	3 Longest Fire Free Periods From Total Scars Grouped +/- 3yrs	% of Decades Recording Fire From Total Scars Grouped +/- 3yrs
Cascade - mixed conifer	Complete History	Complete History	Complete History	Complete History	From 1700	From 1700	Complete History	From 1700	From 1700
Deer Creek	44	92	55	13	5 (1-20)	10 (6-18)	50 (22-114)	20,15,15	75
Soda Meadows	86	170	99	19	3 (1-16)	7 (5-16)	43 (19-155)	16,11, 9	100
Hoxie Creek	42	70	42	8	8 (1-30)	10 (5-30)	79 (33-203)	30,17,14	65
Buck Divide	16	26	22	2	10 (3-24)	13 (5-24)	44 (40-47)	24,17,16	65
Shell Peak	34	54	32	6	9 (1-22)	13 (5-24)	54 (20-103)	22,19,16	65
Willow Creek	24	29	23	3	9 (1-29)	12 (5-29)	146 (106-180)	29,19,18	35
total	246 avg. 41 SE 10.0	441 avg. 73 SE 21.8	273 avg. 45 SE 11.8	51 avg. 8 SE 2.6	avg. 7yrs SE 1.1	avg. 11yrs SE 0.9	avg. 69yrs SE 16.2	Range 9 to 30	avg. 67 SE 8.5
Siskiyou - mixed evergreen									
Glade Creek	55	134	78	17	4 (1-13)	9 (7-12)	45 (12-309)	15,12,12	55
Skunk Gulch	39	79	53	6	5 (1-25)	9 (4-25)	46 (17-98)	25,18,17	75
Woodpecker Springs	26	42	32	4	6 (1-32)	10 (3-22)	25 (14-53)	22,21,13	75
Lick Gulch	37	107	72	9	5 (1-26)	10 (4-26)	34 (15-82)	26,20,19	40
Wrangle Pass	26	50	44	3	5 (1-27)	10 (5-27)	39 (25-47)	27,27,24	90
Yale Creek	18	31	21	4	6 (2-27)	14 (5-35)	43 (22-72)	35,29,13	75
total	201 avg. 35 SE 19.8	443 avg. 73 SE 16.5	300 avg. 50 SE 9.1	43 avg. 9 SE 2.2	avg. 5yrs SE 0.7	avg. 10yrs SE 0.8	avg. 39yrs SE 3.2	Range 12 to 35	avg. 68 SE 7.3
Mid-Ccast - tanoak/Douglas-fir									
Duiog Creek	11	16	12	2	17 (4-42)	19 (7-51)	30 (20-39)	51,21,22	45
Big Windy Creek	25	51	33	7	8 (1-38)	16 (4-38)	56 (17-161)	38,22,14	65
Sourgrass Creek	28	56	19	3	7 (1-50)	9 (4-50)	80 (5-152)	50,16,14	70
Smith Creek	27	65	37	7	7 (1-20)	11 (5-19)	31 (17-49)	19,18,18	65
Rum Creek	38	48	35	14	5 (1-21)	9 (4-21)	45 (11-140)	21,15,11	55
Smoked Elk	35	83	57	12	6 (1-28)	9 (5-28)	63 (15-145)	28,20,19	80
total	164 avg. 27 SE 3.9	319 avg. 53 SE 9.0	193 avg. 32 SE 6.4	45 avg. 7 SE 1.9	avg. 9yrs SE 1.8	avg. 12yrs SE 1.8	avg. 51yrs SE 7.9	Range 11 to 56	avg. 63 SE 4.9
Three Forest Types	avg. 34 SE 4.6	avg. 67 SE 10.0	avg. 43 SE 5.4	avg. 8 SE 1.2	avg. 7yrs SE 0.8	avg. 11yrs SE 0.7	avg. 53yrs SE 6.5	Range 9 to 56	avg. 66yrs SE 3.9
sub-total	611	1,203	766	139					
Cascade- shasta fir, sugar pine									
Shasta fir, Vulture Rock	8	13	11	1	25 (6-89)	26 (26-89)	63	89,23,17	30
Shasta fir, Griffin Pass	16	25	23	1	11 (2-66)	18 (5-56)	28	56,50,14	40
total	24 avg. 12 SE 3.0	38 avg. 19 SE 6.0	34 avg. 17 SE 6.0	2 avg. 1 SE 0.0	avg. 18yrs SE 7.0	avg. 22yrs SE 4.0	avg. 46yrs SE 17.5	Range 14 to 89	avg. 35yrs SE 5.0
Sugar Pine	15	21	15	3	9 (1-26)	14 (5-28)	72 (42-96)	28,16,16	40
All Study Sites Total	650	1,262	815	144					

1 Fires that left only one scar and fires with two or more dates
2 Total number of fire scars detected including those that recorded the same fire
3 The average interval between the dates of all fire records
4 The average interval between the dates of all fire records grouped +- 3 years
5 The average interval between fire dates from all trees recording more than one fire

Of the1,262 fire scars detected, 612 dated the same fires, thus a total of 650 separate fires were recorded. In the Cascade, Siskiyou and mid-Coast stands 52%, 76% and 67% respectively were dated to precisely the same year.

Apparently there were few fire on these sites after 1900. Of the 650 fires detected on 21 sites, only three were detected after 1900, including one in the Cascades at Shell Peak in 1901, one in the Siskiyous at Yale Creek in 1909, and one in a mid-Coast in 1903 on Big Windy Creek. The earliest fires detected in the three forest types occurred in 1432, 1623 and 1604 on Hoxie Creek in the Cascades, Skunk Gulch in the Siskiyous and Rum Creek in the mid-Coast respectively.

The largest number of fire scars ranged from the 170 at Soda Meadows in the Cascades, 134 at Glade Creek in the Siskiyous and 83 at Smoked Elk in the mid-Coast stands. The fewest fire scars were detected at Buck Divide (26), Yale Creek (31) Dulog Creek (16) in the Cascades, Siskiyous and mid-Coast forests respectively. The two highest elevation Shasta fir stands, Vulture rock and Griffin Pass had only 13 and 25 fire scars. The sugar pine stand had 21 fire scars (Table 2.1). There were no significant differences in the number of fire scars detected in 8ha stands among the three forest types ($p= 0.610$). Additionally, stand elevation did not account for differences among sites in any forest type (Cascade $p= 0.440$, Siskiyou $p= 0.267$, mid-Coast $p= 1.000$), or between forest types ($p= 0.710$).

Point Sample Fire Frequency

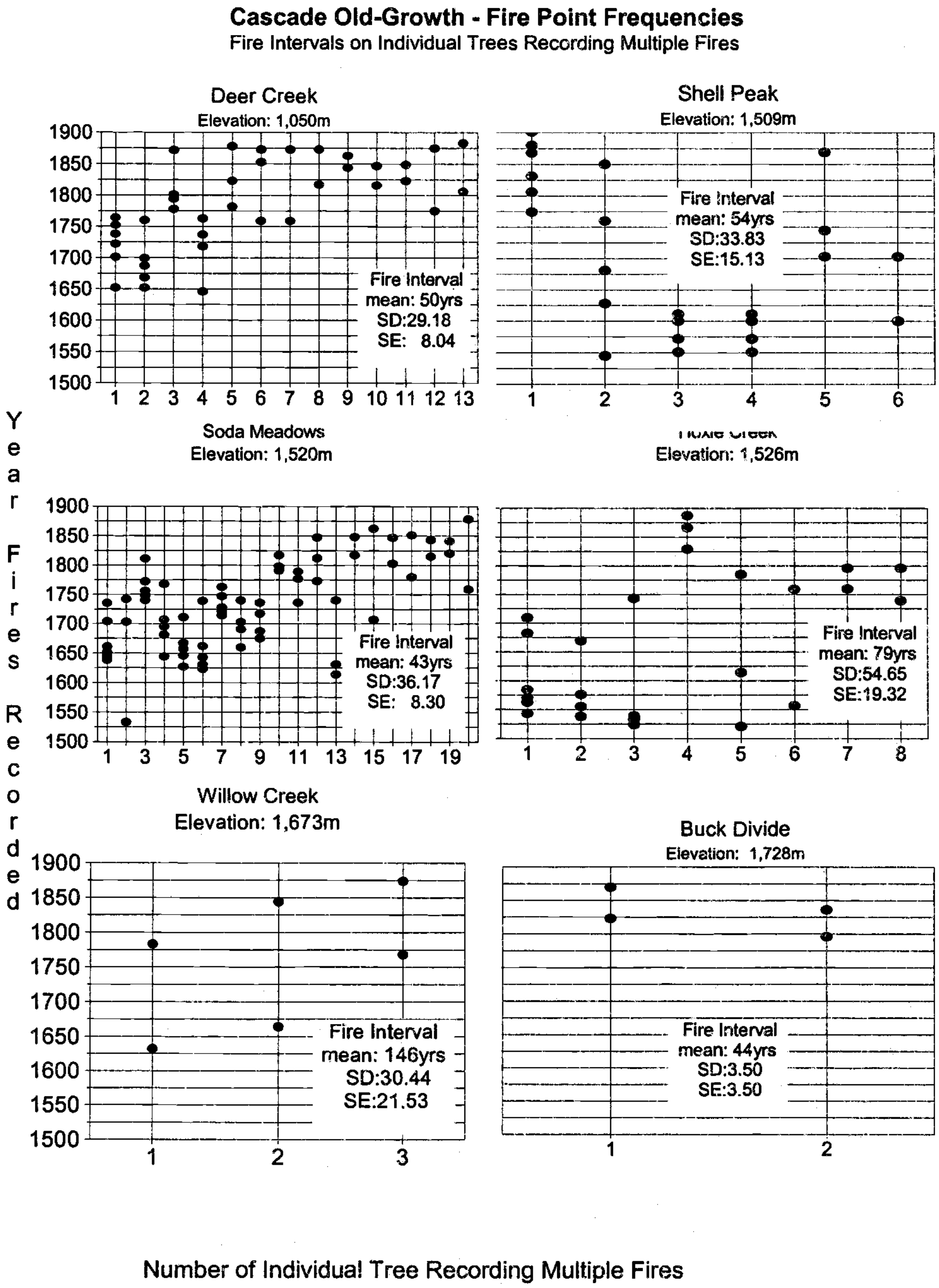
The number of trees recording multiple fires varied considerably among sites. In the Cascades for example, there were only 3 at Willow Creek but 19 at Soda Meadows (Table 2.1).

Similar to the variability in the Cascades, there were 3 trees that recorded multiple fires at Wrangle pass to 17 at Glade Creek in the Siskiyous and 2 at Dulog Creek to 14 at Rum Creek in the mid-Coast. Only one tree recording more than one fire was located in each of the two Shasta fir stands and sugar pine stand.

Point sample frequency intervals were much greater than intervals determined from all scars and ranged among all sites from 25-146yrs (avg.= 53, SE= 6.5), (Table 2.1). In the Cascade stands, point sample frequency intervals ranged from 43-146yrs (avg.= 69yrs, SE= 16.2, in the Siskiyou stands ranged from 25-46yrs (avg.= 39yrs, SE= 3.2) and they ranged from 30-80yrs in the mid-Coast stands (avg.= 51yrs, SE= 7.9), (Figure 2.2).

The average point sample frequency intervals in the Shasta fir stands ranged from 28-63yrs (avg.= 46yrs, SE= 17.5), (Figure 2.2). The point sample frequency interval was 72yrs in the sugar pine stand. Because the sugar pine stand was thinned there were only a few stumps making fire history dating more difficult.

Figure 2.2 Fire intervals determined by individual trees recording multiple fires on 20, 8ha clearcut old-growth stands in southwestern Oregon Cascade, Siskiyou and mid-Coast forests. The X axis are individual trees and the Y axis are the dates that fires were detected.



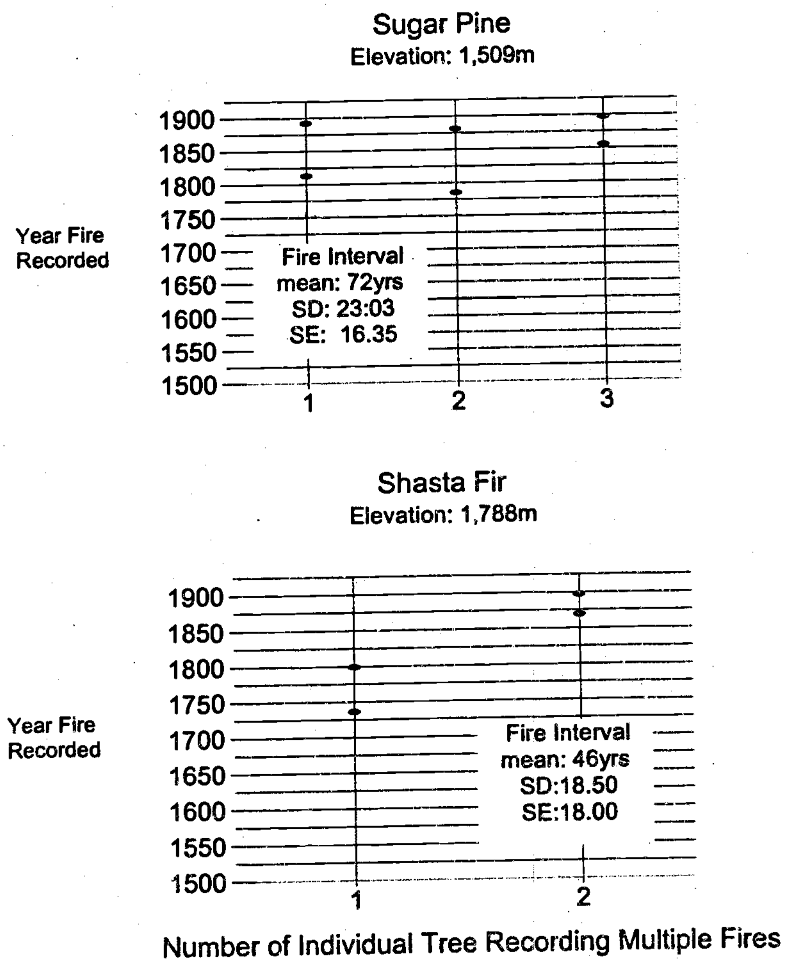
(Continued)

Figure 2.2 Fire intervals determined by individual trees recording multiple fires on twenty, 8ha clearcut old-growth stands in southwestern Oregon Cascade, Siskiyou and mid-Coast forests. The X axis are individual trees and the Y axis are the dates that fires were detected.

Cascade

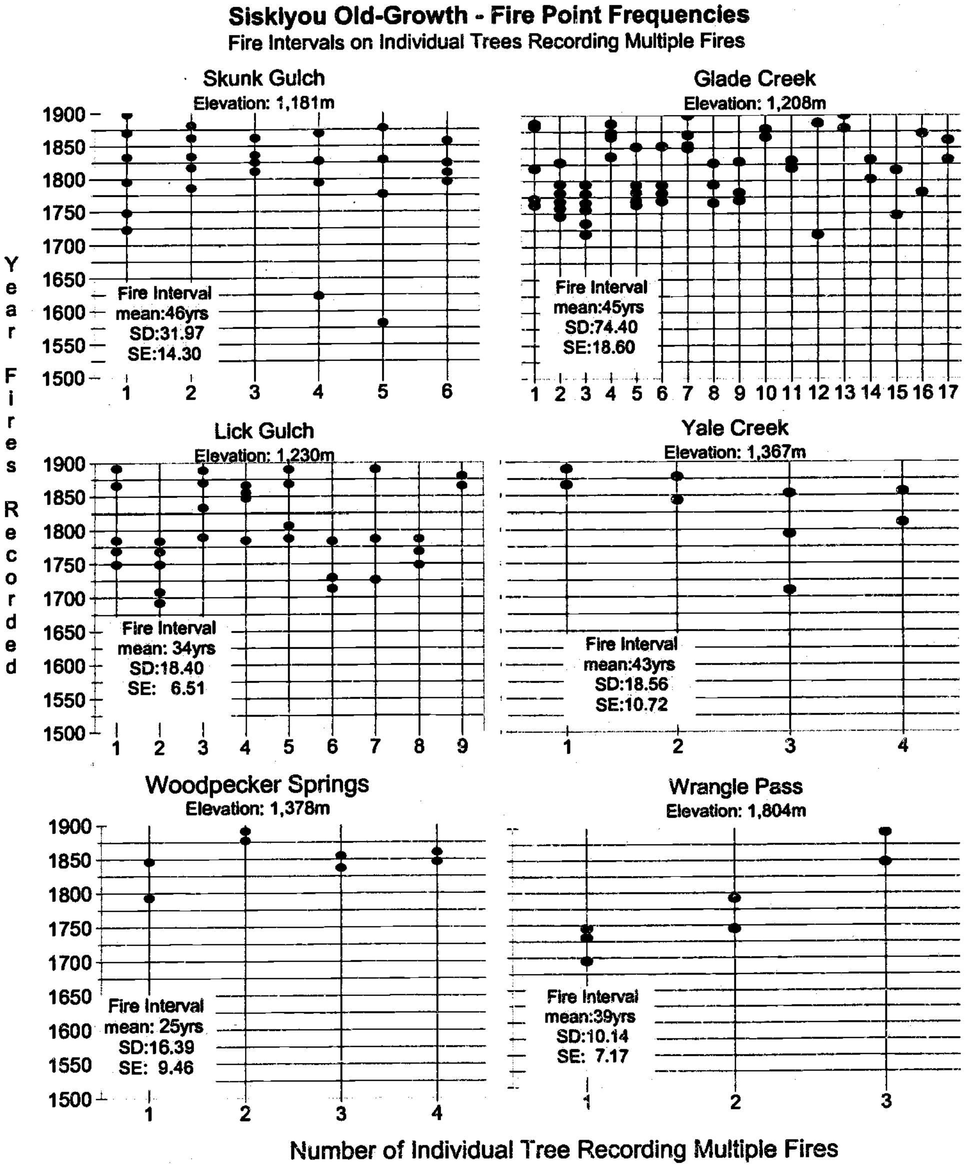
Sugar Pine and Shasta Fir Old-Growth - Fire Point Frequencies

Fire Intervals on Individual Trees Recording Multiple Fires



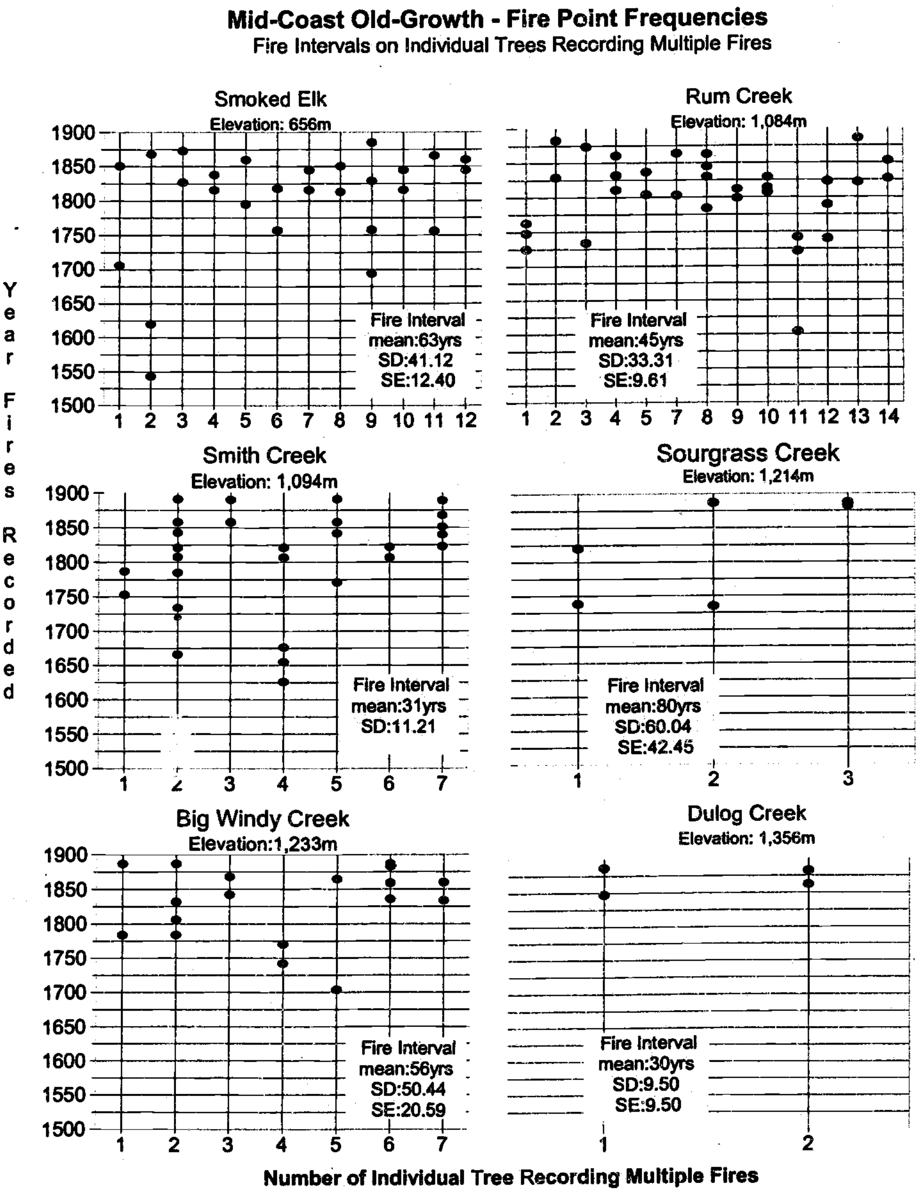
(Continued)

Figure 2.2 Fire intervals determined by individual trees recording multiple fires on 20, 8ha clearcut old-growth stands in southwestern Oregon Cascade, Siskiyou and mid-Coast forests. The X axis are individual trees and the Y axis are the dates that fires were detected.



(Continued)

Figure 2.2 Fire intervals determined by individual trees recording multiple fires on 20, 8ha clearcut old-growth stands in southwestern Oregon Cascade, Siskiyou and mid-Coast forests. The X axis are individual trees and the Y axis are the dates that fires were detected.



Only trees exhibiting external evidence of fire occurrence were cored, thus the fire detections likely under represented the actual fire occurrence.

The overall point sample frequency interval for all sites was 53yrs (SE= 6.5). However, as with composite fire frequency, an analysis of variance (ANOVA) detected no significant difference among point sample frequency intervals among forest types (p= 0.150).

Composite Fire Frequency

The estimate of fire frequencies based on all fire scars ranged from 3-17yrs, (avg.= 7yrs, SE= 0.8). In the Cascades the average fire frequency per stand ranged from 3-10yrs (avg.= 7yrs, SE= 1.1), in the Siskiyous it ranged from 3-6yrs per stand (avg.= 5yrs, SE= 0.7) and in the mid-Coast stands ranged 5-17yrs (ave. 9yrs, SE= 1.8). The Shasta fir stands had composite fire frequencies ranging from 11-25yrs (avg.= 18yrs, SE= 7.0). Because the sugar pine stand was predominately a mixed conifer community the fire frequency was within the range of other Cascade mixed-conifer sites (avg.= 9yrs, SE= 2.8), (Table 2.1). An analysis of variance (ANOVA) detected no significant difference among composite fire intervals on all sites in all forest types from 1700. (p= 0.176).

Grouped Composite Fire Frequencies

To account for the potential variation of approximately 3yrs (Weisberg 1998), fire scars were grouped (recorded as one fire event) where fires were detected within +/- 3yrs. Fire records were placed into a common group where scars were dated to within three years of one another. The intervals between group dates were averaged to derive a more probable fire frequency for each site. This method resulted in estimates of fire frequency somewhat longer (2- 4yrs) than the composite sample frequency.

More probable fire occurrence frequencies ranged from 7-13yrs in the Cascades (avg.= 11yrs, SE= 0.9), 9-14yrs in the Siskiyous (10yrs, SE= 0.8) and 9-19yrs (12yrs, SE= 1.8) in mid-Coast stands (Table 2.1). The Shasta fir stands ranged from 18-26yrs (avg.= 11yrs, SE= 1.2). The sugar pine stand had a grouped fire frequency of 14yrs (SE= 2.8). An ANOVA detected no significant differences among composite fire intervals grouped +/- 3yrs on all sites in all forest types (p= 0.933). Presumably, fires that were ignited in any forest location could, and often did, burn across and through the others. This conjecture is consistent with the fact that there were no differences between the average fire frequencies among Cascade, Siskiyou and mid-Coast forests.

Soda Meadows had the most fire scars (170) and had an average grouped interval of 7yrs (Table 2.1) however, there was considerable variation in fire frequency at this site ranging from 5-16yrs. Other sites in the Siskiyous and mid-Coast also had short fire intervals and considerable variation. For example, at Yale Creek fire frequency averaged 14yrs and ranged from 5-35yrs. Big Windy Creek had an average of 16yrs and a range of 4-38yrs

Longest Fire-Free Intervals

In stands where fires occurred frequently during stand development the lengths of the periods without fire are as important as the frequency of fire. Presumably seedling mortality was high during periods of frequent fire and during periods without fire, seedling establishment was higher. Also, during periods of less frequent fires the abundance of fire intolerant species may have increased.

From 1700 in the Cascades, the longest fire-free period ranged from 9yrs at Soda Meadows, to 30yrs at Hoxie Creek, in the Siskiyous from 12yrs at Glade Creek to 35yrs at Yale Creek, and from 11yrs at Rum Creek to 51yrs at Dulog in the mid-Coast. The Shasta fir stands had the greatest range of variability having the longest fire free periods ranged from 89yrs and 56yrs at Vulture Rock and Griffin Pass respectively. The longest fire free period in the sugar pine stand was 28yrs.

Percent of Decades Recording Fire From 1700 - 1900

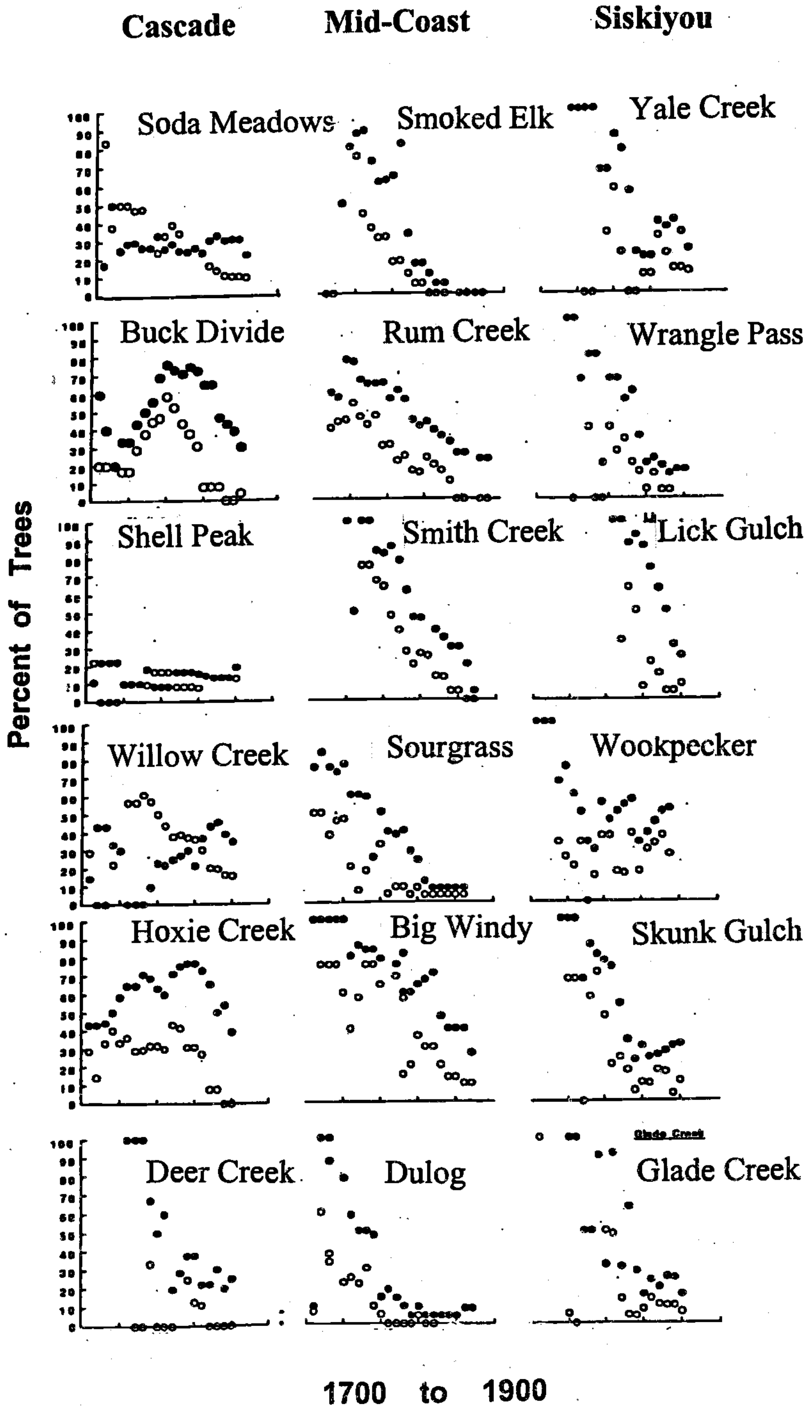
Fire occurrence viewed in terms of proportions of decades with fire suggest that fires were quite common in all forest types from 1700 -1900. Since 1700, for each forest type the average percent of decades in which fire was detected, based on the grouped fire occurrence data were 67 (SE= 8.50), 68 (SE= 7.35), 63 (SE= 4.55) in Cascade, Siskiyou and mid-Coast stands respectively.

Since 1700 fire occurrences per decade varied from a low of 35% at Willow Creek to 100% at Soda Meadows in the Cascades, 40% at Lick Gulch to 90% at Wrangle Pass in the Siskiyous and 45% at Dulog Creek to 80% at Smoked Elk in the mid-Coast. The two Shasta fir sites had 30% and 40%, decades recording fire at Vulture Rock and Griffin Pass respectively. Fire occurred 40% of the decades in the sugar pine stand. Throughout all forest types the average percent of decades recording fire was 66% (SE= 3.9).

Proportion of Small Trees <10cm and <25cm Diameter by 10yr and 50yr Periods From 1700-1900

During the period 1700-1900 fires were common yet many small trees survived, indicating that these were probably low intensity fires. In all forest types from 1700 to1900 a high percentage of the trees were <10cm or <25cm diameter and presumably susceptible to fire (Figure 2.3).

Figure 2.3 Percent of trees <10cm diameter (open circles) and <25cm diameter (closed circles) by ten year periods from1700 through 1900 at six sites each in the Cascades, mid-Coast and Siskiyou forests.



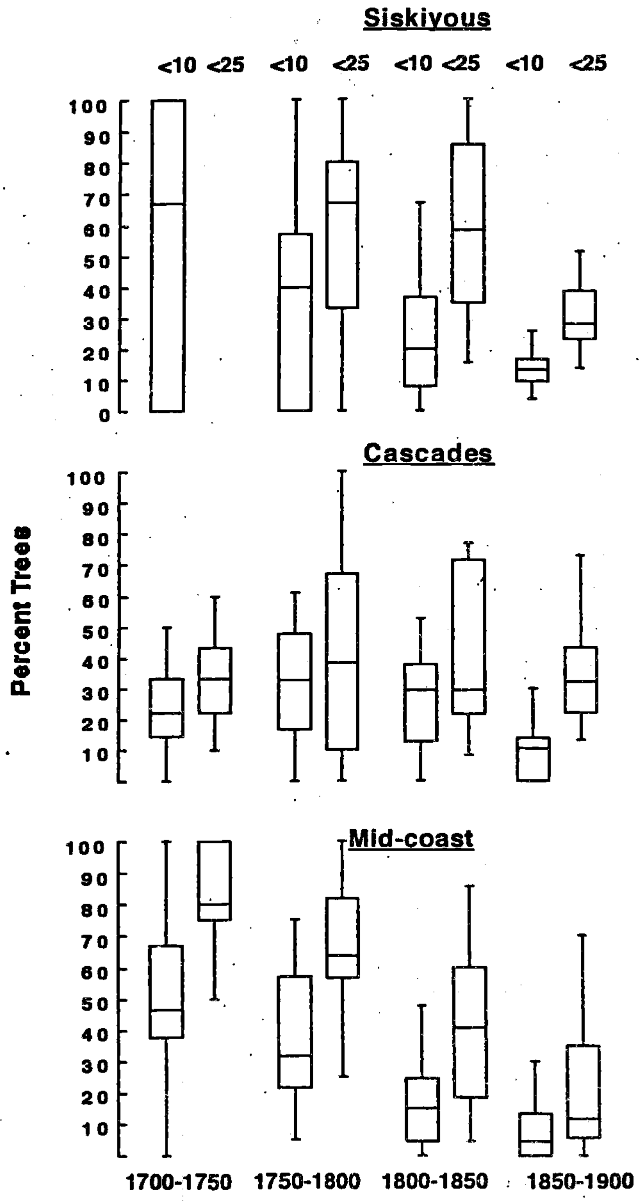
The lowest percent of small trees in the stand was at Shell Peak where less than 20% were <10cm and 12% <25cm diameter in 1700. This percentage remained relatively constant through 1900. However, all of the other sites recorded a marked decrease in the proportion of small trees for the period 1700-1900 as the trees grew and few trees were recruited (Figure 2.3). For example for the period 1700-1900 at Glade Creek and Sourgrass Creek the proportion of trees <20cm deceased from 100%-20% and 80%-8% respectively. However, considerable variability among stands for the same period was observed. Among all mid-Coast stands, for the period 1750 to1800 the proportion of the trees <10cm diameter ranged from 4%-77% and the trees <25cm diameter ranged from 25%-100% (Figure 2.4).

Among the Siskiyou stands, for the period 1750-1800 the proportions of trees <10cm and <25cm diameter both ranged from 0-100% and for the same period, the Cascade stands varied from 0-62%, <10cm and 0-100% <20cm diameter (Figure 2.4).

Size of Trees Surviving Multiple Fires at the Time of First Fire

Because smaller trees are more susceptible to fire damage and consequently mortality from fire, the diameter (measured at stump height) of the surviving trees is an indication of fire intensity at that point.

Figure 2.4 Proportion of small trees, <10cm and <25cm diameter by 50 year periods from 1700 through 1900 at six sites each in the Siskiyous, Cascades and mid-Coast forests

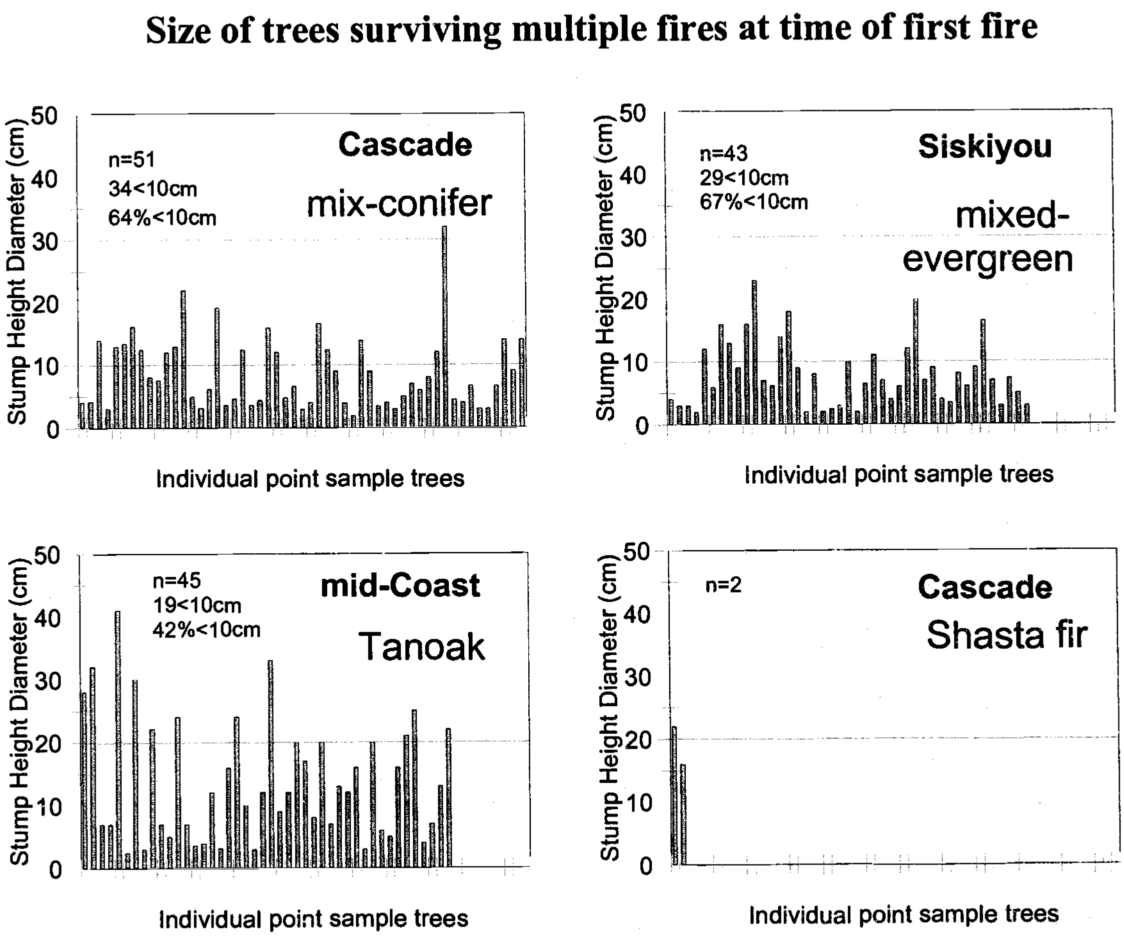


It is important to note that this data shows that a high proportion of point sample trees were small at the time their first fire scar was recorded. There may have been fires when the trees were smaller that left no scare. Also many trees, large and small may have been killed as a result of fires that are not represented in the data. The size of point sample trees when the first fire scar was recorded confirms that small trees survived fires (Figure 2.5). In the Cascades, of the 51 point sample trees surviving multiple fires, 34 (64%) were <10cm in diameter at stump height at the time of first fire. In the Siskiyous, 29 of the 43 (67%) and mid-Coast 19 of 45 (42%) point sample trees were <10cm at the time of first fire. The smallest diameter point sample trees surviving first fire were 5.8cm, 5.8cm and 7.6cm in the Cascades, Siskiyous and mid-Coast stands respectively. The diameters of the two Shasta fir trees at the time of their first fire were 22cm, 16cm respectively. One sugar pine tree recorded a fire when it was 8cm diameter.

Fire and Old-Growth Stand Development

On all sites fire occurred in 66% (SE= 3.9), of the decades from 1700-1900 experienced fire during stand development and 56% of the decades recorded recruitment of trees into the stand during this period. Thus, all sampled trees became established during a period of frequent fire. Fires were generally more frequent than recruitment events.

Figure 2.5 Stump height diameters of all point sample trees at the time the first fire scare was detected.



In the Cascades I found cohorts numbers ranged from 6 at shell Peak to 17 at Soda Meadows and these ranges were similar at the other sites as well during the period 1700-1900 (Table 2.2).

Table 2.2 The initiation of cohort recruitment, the intervals (yrs) between cohort recruitment and the percent of decades from 1700-1900 in which recrutiment occured in eighteen old-growth stands in southwestern Oregon. In addition, the composite fire intervals and the percent of decades recording fire are displayed from Table 2.1 (p.47) for comparison.

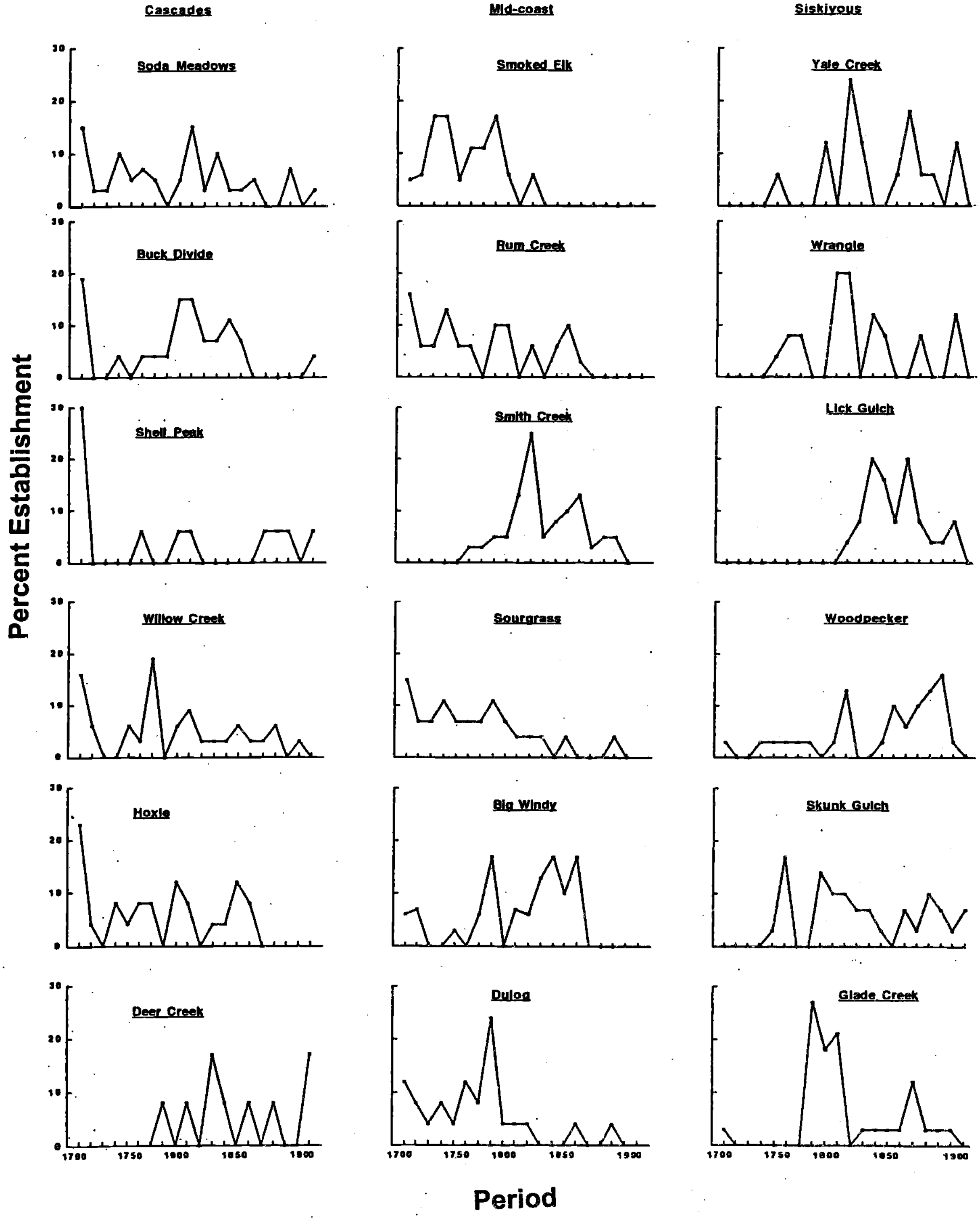
Forest Type	Total Number of Cohorts [1] From 1700 - 1900	Average and Range of Interval Between Cohorts (yrs)	Average and Range of Grouped Composite Fire Interval	Percent of Decades that Recruitment [2] Occured	Percent of Decades Recording Fire From 1700 - 1900
Cascade- mixed conifer					
Deer Creek	8	20 (10-30)	10 (6-18)	40	75
Soda Meadows	17	13 (10-30)	7 (5-16)	85	100
Hoxie Creek	12	12 (10-20)	10 (5-30)	60	65
Buck Divide	12	13 (10-40)	13 (5-24)	60	65
Shell Peak	6	24 (10-60)	13 (5-24)	30	65
Willow Creek	14	13 (10-30)	12 (5-29)	70	35
	avg. 12 SE 1.6	**avg. 16** SE 2.1	**avg. 11** SE 0.9	**avg. 57** SE 8.2	**avg. 67** SE 8.5
Siskiyou- mixed evergreen					
Glade Creek	8	12 (10-20)	9 (7-12)	40	55
Skunk Gulch	14	13 (10-30)	9 (4-25)	70	75
Woodpecker Springs	16	13 (10-30)	10 (3-22)	80	75
Lick Gulch	10	10 (10-10)	10 (4-26)	50	40
Wrangle Pass	10	18(10-30)	10 (5-27)	50	90
Yale Creek	9	20 (10-40)	14 (5-35)	45	75
	avg. 11 SE 1.3	**avg. 14** SE 1.6	**avg. 10** SE 0.8	**avg. 56** SE 6.4	**avg. 68** SE 7.3
Mid-Coast- tanoak/Douglas-fir					
Dulog Creek	13	14 (10-30)	19 (7-51)	65	45
Big Windy Creek	11	15 (10-30)	16 (4-38)	50	65
Sourgrass Creek	12	14 (10-40)	9 (4-50)	40	70
Smith Creek	13	10 (10-10)	11 (5-19)	65	65
Rum Creek	10	14 (10-40)	9 (4-21)	55	55
Smoked Elk	8	13 (10-30)	9 (5-28)	60	80
	avg. 11 SE 0.8	**avg. 13** SE 0.7	**avg. 12yrs** SE 1.8	**avg. 56** SE 4.0	**avg. 63** SE 4.9
Three Forest Types **Totals**	**avg. 11** SE 0.1	**avg. 14** SE 0.9	**avg. 11yrs** SE 0.7	**avg. 56** SE 3.5	**avg. 66yrs** SE 3.9

1 Recruitment is defined as the date at which a tree grew to stump height.
2 A cohort is the trees recruitmented in a decade (ie. 1780 to 1790).

During this period I estimated that fires occurred in 35%-100% of these 20 decades in the Cascades and from 45%-95% of the decades in the other two forest types. The frequency of cohort recruitment was somewhat less, ranging from 30%-85% in the Cascades and 40%-80% in the Siskiyou and mid-Coast sites.

It is apparent that trees were recruited onto the plots at all sites when fire was a common occurrence. Percent recruitment was quite variable among sites and there does not appear to be a clear pattern of recruitment (Figure 2.6). For example at Shell Peak 63% of the trees were on the plots at 1700 and there was periodic recruitment from 1700-1900. At Deer Creek there were none of the surviving trees on plots until 1770 and then recruitment varied from about 10% for four decades to about 20% in three decades. A similar pattern was observed at Lick Gulch, Smith Creek and Glade Creek. At Rum Creek, Sour Grass and Dulog Creek in the mid-Coast area most recruitment occurred from 1700-1800 (83%, 87%, 89% respectively). However at Big Windy and Smith Creek a high proportion of recruitment occurred after 1800 (70%, 87% respectively), (Figure 2.6).

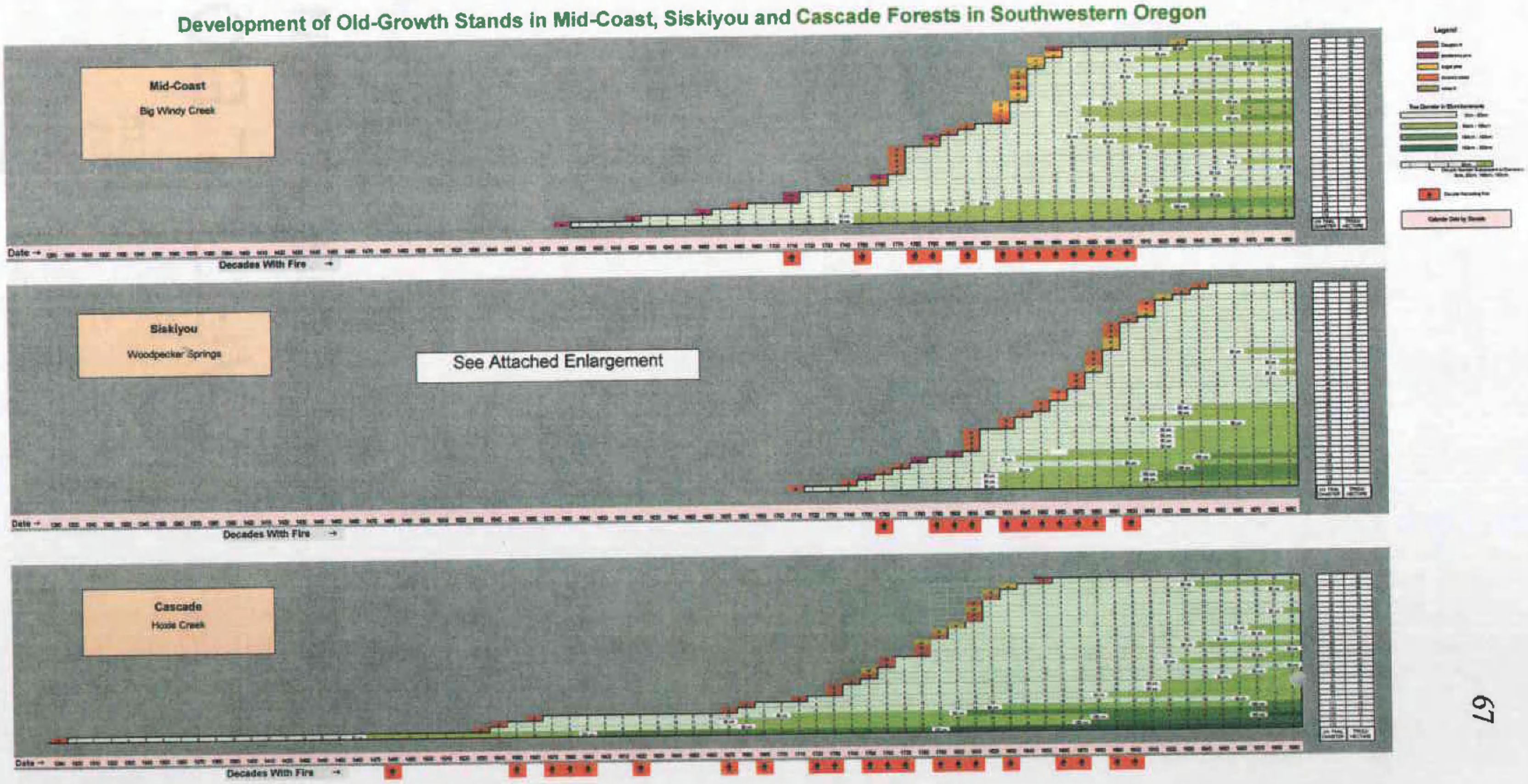
Figure 2.6 The percent of tree establishment per decade from 1700 through 1900 at six sites each in the Cascade, mid-Coast and Siskiyou forests.



As patterns of fire disturbance begin to emerge and are identified, it becomes important information, contributing to a greater understanding of the developmental dynamics of old-growth forests. A comprehensive picture of the development of old-growth stands in terms of species, rates of growth, recruitment and density was developed for the purposes of integrating fire into a dynamic portrayal of stand progression which incorporates both spatial and temporal scales. The development of old-growth stands in the context of their fire environments are illustrated for the oldest stands of this study in the Cascades (700yrs), Siskiyous (280yrs) and mid-Coast (410yrs), (Figure 2.7).

The attributes of stand development include; tree species, individual tree growth (50cm increments), dates of cohort recruitment, dates of fire events and cumulative trees/ha. When data from fire events is superimposed on stand developmental trajectories it can be utilized to understand residual stand structures and characteristics following fire. For example, in the Hoxie Creek stand more than 56 trees per hectare (denoted hereafter as trs/ha) survived the 8 most recent fires and 10 trees/ha survived all fires. In the Woodpeckers Springs stand in the Siskiyou Mountains, 23 trees/ha survived the 8 most recent fires and 10 trees/ha survived all fires. In the Big Windy Creek stand in the mid-Coast tanoak forests, 59 trees/ha survived the 8 most recent fires and 13 trees/ha survived all fires.

Figure 2.7 The X axis depicts the calendar date by decade. The horizontal bars represent trees and the number in the box above the decade represents the cumulative number of decades since reaching a milestone diameter in increments of 50cm (i.e. 50cm-100cm-150cm). The code in the first box preceding each tree represents its species (df=Douglas-fir, pp=ponderosa pine, wf=white fir, ic=incense cedar, sp=sugar pine, sf=Shasta fir). The red arrows along the base of the horizontal calendar date scale represent the date when fire events were detected. The Y axis tallies trees per hectare and the trees eventual stump height diameter in cm.



Effectiveness of Fire Suppression from 1920-1990

Since at least 1920 fire suppression efforts have been surprisingly effective through southwestern Oregon. Within the study area, 5,265 lightning ignited wildfires were extinguished by fire suppression personnel from 1920-1990. The average size reaching only 6.5ha and less than 6% attained a size greater than 250ha.

Although the data becomes less complete further back in time, particularly prior to 1970, the following maps (Figures 2.8 and 2.9) are not entirely complete however, to the extent possible they depict the 5,265 lightning caused fires during this 80 year period. Fires originating from other man caused sources, such as escaped campfires, arson and logging are not indicated on these maps. Although not depicted, on another 8,736 man caused fires were also extinguished during the same period. Of the 14,001 fires suppressed from 1920-1990 only 5.4% attained a size greater than 250ha. Although the effectiveness of fire suppression efforts is sometimes questioned, this data leaves no doubt that fire suppression efforts have been effective southwestern Oregon.

Also, during house cleaning at the Bureau of Land Management office in Medford Oregon in 1999, a folder containing fire suppression notes on 88 fires from 1941-1955 was discovered. Although few details are included in these reports, they clearly illustrate the effectiveness of suppression during that period. These records indicated that the average time until extinguished was only approximately 143 hours and the average size of these fires was only about 17 acres. A summary of these records is attached (Appendix A).

Lightning ignited fires have been extremely common and predictable throughout time in all of the study areas in southwestern Oregon. All of the fires indicated on Figure 2.8 were those suppressed by a fire suppression or logging crew. Lightning strikes that did not ignite fires are not included on the map (Figure 2.8).

The average size of the fires that were suppressed from 1970-1900 was approximately 6.5ha and 83% of all suppressed fires were contained to less than 1,000ha. This clearly illiterates the effectiveness of fire suppression efforts, even during its infancy. Figure 2.9 depicts the location and containment size of the lightning ignited wildfires from 1920-1990 throughout the study areas.

SUMMARY

Fire was common during the development of old-growth stands in all forest types. A total of 1,262 fire scars were found on all sites. There were few fire scars after 1900. There were no significant differences in the number of fire scars detected in 8ha former old-growth stands among the three forest types ($p= .610$).

Figure 2.8 Location and decade of the lightning ignited wildfires from 1920-1990 in the Cascade, Siskiyou and mid-Coast forest types in southwestern Oregon.

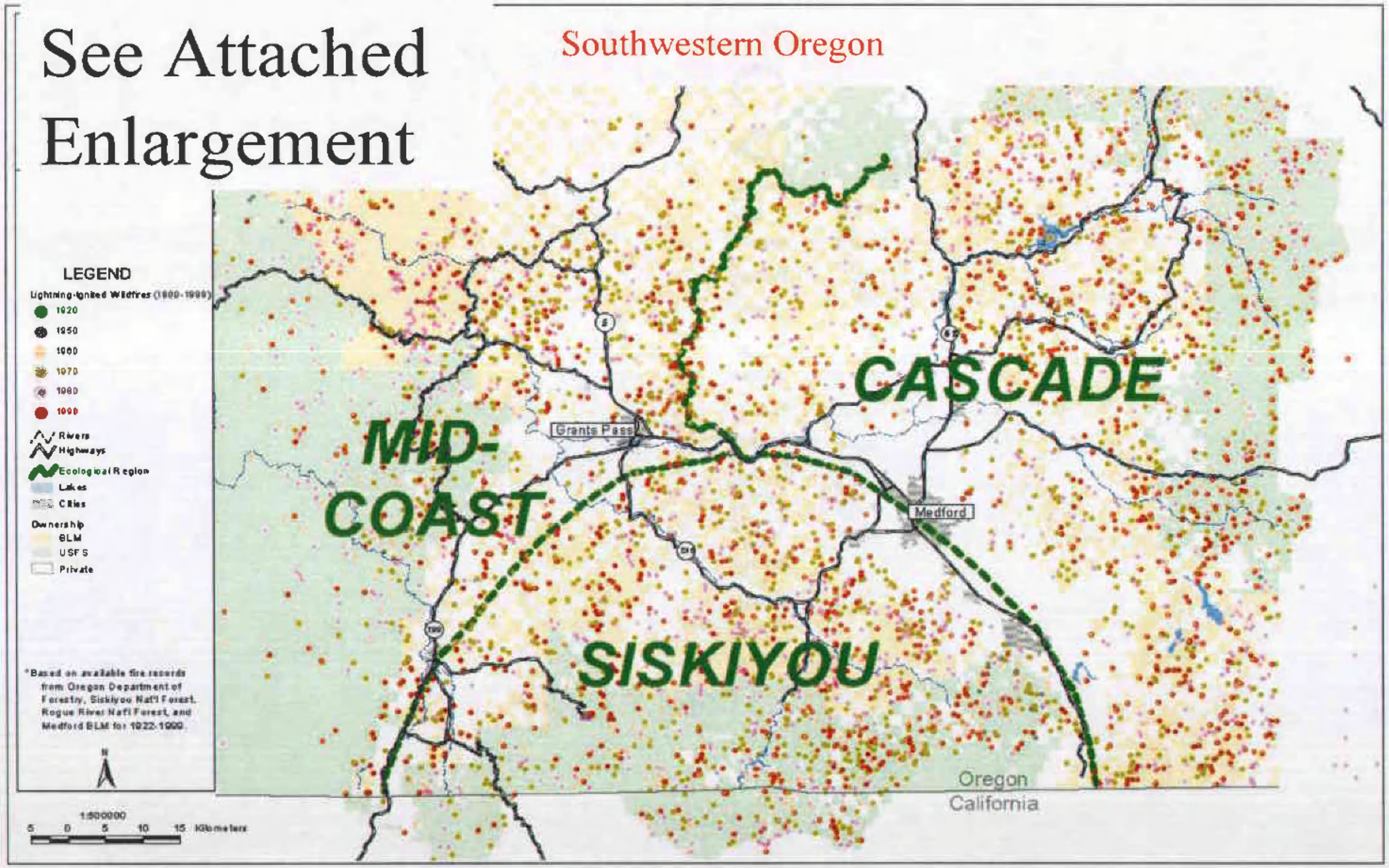
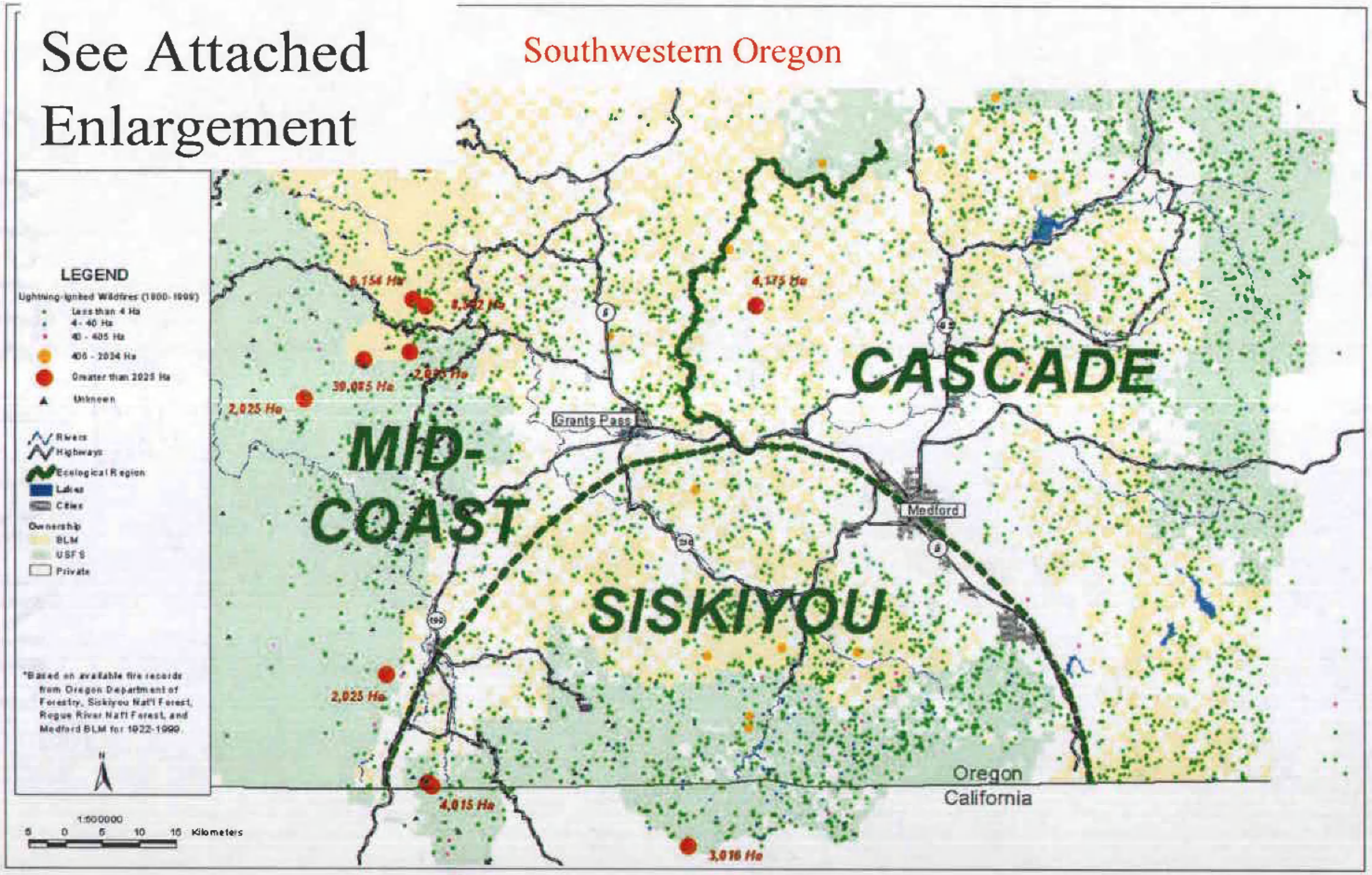


Figure 2.9 Location and containment size of the lightning ignited wildfires from 1920-1990 in the Cascade, Siskiyou and mid-Coast forest types in southwestern Oregon.



The most probable frequencies ranged from 7-13yrs in the Cascades (avg.= 11yrs, SE= 0.9), 9-14yrs in the Siskiyous (avg.= 10yrs, SE= 0.8) and 9-16yrs (avg.= 12yrs, SE= 1.2) in mid-Coast stands. For all sites 66% of the decades from 1700-1900 experienced fire during stand development (SE= 3.9) and 56% of the decades recorded recruitment into the stand during the same period, indicating that all sampled trees became established during a period of frequent fire.

The longest fire-free periods ranged from 9-30yrs, 12- 35yrs, 11-51yrs in the Cascades, Siskiyous and the mid-Coast stands respectively. Trees < 10cm often survived fires. Fire suppression efforts have been effective southwestern Oregon.

Chapter III

Comparison of Structural Development Between Old-Growth and Young Stands in Cascade, Siskiyou and Mid-Coast Forests in Southwestern Oregon

INTRODUCTION

Over the past decade forest management objectives for federally managed forests have evolved from an emphasis on timber production and reforestation to a more comprehensive approach to forest resource management (BLM 1994). This involves the need to grow and produce forests of greater complexity and biological diversity including forests possessing old-growth stand structure. Little information is available about silvicultural techniques to grow and produce complex forest structures, however trials are underway in central Oregon Coast forests (Tappeiner personal communication). Data on the historic development of old-growth forests and the determination of the potential for younger stands to develop old-growth characteristics is generally lacking.

Forest managers throughout the region have been tasked with managing forests for a broad range of values including growing and maintaining large trees and diverse structures. Currently, approximately 20% of the federally managed forest stands in southwestern Oregon are <40yrs of age and nearly 60%, <120yrs. As older forest stands are reduced in size and quantity by logging, mortality and fire, old-growth habitat related species may correspondingly diminish (FEMAT 1994). Additional reductions as a consequence of reduced habitats resulting from forest fragmentation is also likely. Thus it is important to learn more about developmental patterns of old-growth forests, in terms of the frequency of disturbance, species composition, tree growth and structural characteristics, so that silvicultural systems can be developed to manage young forests toward replacement of old-growth forest ecosystems.

Old forests generally have several large trees > 50cm per hectare in the overstory and small trees in the understory. Recent studies of old forests in the Oregon Coast Range, have found that these large trees have a considerable range in ages, often >100yrs. Also, these large trees generally grew rapidly when they were young often reaching diameters >1m in 100yrs. Old forest structures appear to result from rapid growth of large overstory trees after multiple disturbances to the understory. On the other hand, young-growth stands had narrow age ranges and unlike old-growth stands developed as a single cohort (Tappeiner *et al.* 1997).

This research was conducted in three southwestern Oregon mountain ranges, the Cascade, Siskiyou, and in the inland portion of the Coastal Mountains where forests are dominated by a tanoak understory (Atzet *et al.* 1989) referred to as the mid-Coast Mountains (Chapter I, Figure 1.1, p.14) This study investigates stand level developmental patterns, structure and growth of old-growth stands, generally >200yrs old and young-growth stands referred to as young stands generally less than <100yrs and is intended to provide silvicultural options for the management of old-growth forests and to provide base-line information and direction for monitoring and managing growth, species composition and structures of developing young stands.

HYPOTHESES

The hypotheses of these studies are that:

1. Frequent fire in old-growth stands resulted in lower densities and faster growth than current young stands that did not encounter fire. Old-growth tree diameter growth remained greater than young tree growth for possibly >200yrs or longer.

2. Old-growth trees developed structural characteristics, particularly lower tree *height:diameter* and higher tree *height:live crown* ratios, which facilitated their ability to persists on the landscape.

3. *(Null Hypothesis)*: Early (50yr) periodic annual basal area growth (PAI_{BA}, cm/yr) is not a reliable indicator of growth potential at subsequent ages through 250yrs.

RESEARCH OBJECTIVES

The overall objectives of these studies are to:

1. Document the density, ages and growth rates during the development of old-growth stands in Cascade, Siskiyou and mid-Coast stands in southwestern Oregon.

2. Compare stand development between young-growth and old-growth forest stands, in terms growth rates, basal area and density.

3. Compare old-growth tree diameters and periodic annual basal area growth (PAI_{BA}, cm/yr) at age 50yrs with subsequent ages 100yrs, 150yrs, 200yrs and 250yrs.

4. Determine how developmental patterns of old-growth and young forests influence *height:diameter* and *height:live crown* ratios, characteristics and stand structure.

5. Document the changes in density in old-growth forests since fire exclusion in Oregon in about 1900.

METHODS

In order to compare the density, ages and growth rates of trees in old-growth and young-growth forests, six former (clearcut) old-growth stands in each of the three forest types and six young-growth and uncut old-growth stands adjoining these sites were located. Three 0.1ha plots (.25 acre) were installed in each old-growth clearcut site. Bark thickness, trees species, stump height and radial growth in 10 year increments beginning from the center of the tree were measured on each stump. All stumps were cleared of debris, cleaned and wire brushed if necessary. Beginning in the center of the tree a pin was inserted into the stump to mark each tenth annual ring to facilitate counting. A hand magnifier was used where growth rings were small or difficult to delineate.

Young stands 60-100yrs having comparable slope, aspect, elevation and forest type, were located proximal to each old-growth forest stand. Sites were grouped by physiographic characteristic including elevation, aspect, and site class. Young stands were sampled using three randomly located .04ha (.10ac) plots. As in the old-growth, the young trees diameter, bark thickness, species and radial growth in 10 year increments were measured and recorded. In addition, on each young stand plot, two trees per 5cm dbh class were additionally measured inside bark at stump height and at dbh (137cm) so that stump height (~46cm) adjustment factor could be developed for each species.

Because I also had a particular interest in the growth of the largest trees on each site, data from "big trees" were also collected opportunistically from stumps of Douglas-fir and ponderosa pine encountered outside the randomly located plots. The decision to sample the stump of a big tree was always made prior to observing tree growth or age. Approximately 23 old-growth trees per site were measured for a total of 419, including 149, 136 and 134 in Cascade, Siskiyou and mid-Coast strands respectively. The same measurements were made as on the trees in the 0.1ha old-growth plots.

Uncut old-growth stands generally >250yrs and young stands generally <100yrs in each forest type having comparable slope, aspect, elevation and forest type adjoining the clear cuts were located. Fifty trees were measured along a straight line transects placed through the interior and of both young and old-growth stands. Tree species, diameter, lowest dead limb diameter, lowest live limb diameter, the presence and height of epicormic branching, crown width and length, and total tree height were measured on each tree.

DATA ANALYSIS

Breast Height to Stump Height Tree Diameter and Growth Adjustments

For all species of young trees the inside bark, *breast height:stump height* diameter ratio was calculated. All young tree growth measurements were adjusted to reflect their increase in tree diameter at stump height. To compensate for potential differences in radial measurements between old and young trees, this adjustment factor was multiplied times each diameter breast height (dbh) 10 year radial increment of all young trees. All analyses and comparisons between the growth and development of young and old trees include young tree dbh growth measurements adjusted to stump height. Comparisons between unadjusted and adjusted young tree diameters were conducted in order to determine to what extent this adjustment could influence the results. To avoid the possibility that *breast height:stump height* adjustments may not reflect the true differences in tree diameters between young trees and old-growth trees when overstory trees are averaged with understory trees, only the largest 50% of the young trees were used for this analysis, however all old-growth trees were included in this analysis.

Distribution of Old-Growth and Young Stand Tree Diameters and Ages

The age and diameters of all species of trees on three 0.1ha plots in each of the three forest types were calculated and plotted. In addition, the range, median and the standard error (SE) of the stump height diameters of trees >250yrs and the ages of trees >100cm was computed and graphed by box-and-whisker plots for comparison between forest types. The distribution of tree ages and diameters for each stand were analyzed and plotted for comparison. Box and whisker plot comparisons document the median and range distribution of both young and old stands for all thirty-two stands.

Multivariate Agglomerative Clustering of the Pattern of Radial Growth

Patterns of tree growth for each forest type were analyzed independently using multivariate agglomerative clustering analysis (McCune 1995). Decadal radial growth is the width in cm of each 10 year increment of radial growth. The first eighty years of ten year radial growth for all trees on the old-growth and young stand plots and the additional large trees located opportunistically in the old-growth stands were aligned vertically by tree age and analyzed by the decade in which the growth occurred, independent of calendar date. For example, for all trees the radial growth (cm) that occurred from ages 0-10yrs, 11-20yrs, 21-30yrs etc., through age 80 were aligned in vertical columns to form a matrix. Because the young stands in the mid-Coast sites were younger than the Cascade and Siskiyou stands only sixty years of growth data were available for analysis for young mid-Coast stands.

Together the variates, decadal increment of radial growth and the decade in which the growth occurred, establish a characteristic pattern of growth for each tree. Because tree growth is aligned and analyzed by the decade in which the growth occurred, independent of calendar date, potential variation in individual tree growth rates as a result of differing climatic and precipitation periods was eliminated.

The overall patterns of tree growth of young and old-growth trees in six Cascade mixed-conifer, and six Siskiyou mixed-evergreen and six mid-Coast tanoak stands were examined using multivariate agglomerative clustering analysis of the patterns of 10 the year radial growth increments for 80yrs in the Cascades and Siskiyous and 60yrs in the mid-Coast. For all trees in both young and old-growth stands, membership into one of two groups (clusters) were assigned when statistically significant differences in overall patters of growth of individual trees were detected through agglomerative clustering. This was accomplish by applying an algorithm which iteraivly compared the patterns of decadal growth of every tree, with the decadal growth of all other trees until the entire population of trees was obligated to one of two groups (cluster). Each cluster reflects statistically discernable differences in patterns of individual tree growth, independent of tree age and diameter.

Within a stand of trees, variation in environmental factors and stand density influence individual tree growth. In addition, the amount of radial growth is proportional to tree diameter and gradually declines as trees increase in size for an equivalent measure of wood production. Trees of the same age often vary in diameter within a stand. Thus relativization of decadal growth was preformed in order to eliminate the potential disparity among growth data from trees of differing sizes. However, agglomerative clustering was performed using both unrelativized and relativized decadal data for sensitivity analysis and comparison.

Decadal growth of all trees was relativized using the general relativization formula. For parameter (p), the Euclidean equivalent p= 2, was used because it standardizes radial increment across decades creating an equitable bases for comparing developmental patterns of tree growth among trees of different diameters. This is performed by first creating a dissimilarity matrix of N^2 (N= entities) followed by iterations of N-1 cycles where fusion of similar entities are grouped. The absolute Euclidean distance measure was used with a Ward's hierarchical clustering strategy. This fusion strategy minimizes the increase in sum of squares distance from each individual to the centroid of its group, creating minimum-variance spherical clusters. For each forest type a dendrogram depicting the cluster analysis fusion points and group memberships was created for analysis. The patterns of average 10 year (decadal) growth of each cluster and that of the actual old-growth and young trees were compared

Analyses of Basal Area and Density Development from 1800 to 1990 for Old and Young Stands

The mean, standard deviation (SD) and the standard error (SE) for stump height old stand, and dbh adjusted to stump height young stand basal areas and trees/ha were calculated for each fifty year period from 1800-1990 for Cascade Siskiyou and mid-Coast sites. The total basal area, percent of current basal area and the total trees/ha were compared between young and old stands. The differences in the final basal areas, and final trees/ha among the old-growth sites were examined by an analysis of variance (ANOVA). The differences in the final basal areas, and final trees/ha between old-growth and young stands were examined by t-tests.

Periodic Annual Basal Area Increments (PAI_{BA}, cm/yr) and Tree Diameter Growth Compared at Age 50yrs and Subsequent Ages 100yrs, 150yrs, 200yrs and 250yrs

The strength of the relationship between tree diameter at 50yrs and periodic annual basal area increments (PAI_{BA}, cm/yr), and subsequent ages 100yrs, 150yrs, 200yrs and 250yrs was examined by linear regression. Periodic basal area growth at age 50yrs (PAI_{BA}, cm^2/decade), is a better indicator of current tree growth than tree diameter at age 50yrs, because it reflects growing conditions including stand density, canopy position and tree circumference, thus the extent to which an old-growth tree's basal area growth rate (PAI_{BA}, cm^2/decade) between age 40yrs-50yrs is related to its diameter at ages 100yrs, 150yrs, 200yrs and 250yrs was also examined by linear regression.

Comparison of Tree *Height:diameter* and Tree *Heigh:live Crown* Ratios Between Young and Old Forest Stands

The distribution, median, standard error (SE), and standard deviations of both *height:diameter* ratios and percent of tree height having live crown for both young-growth and old-growth trees were calculated and analyzed using box and whisker density plot analysis for each site. Comparisons between young and old trees *height:diameter* ratios and *height:live crown* ratios were examined by t-test.

RESULTS

Breast Height to Stump Height Tree Diameter and Growth Adjustments

The average adjustment ratio varied insignificantly among forest types and averaged 1.133 (SE= 0.03). The correction factors were applied to all species of young stand trees to compensate for the potential disparity arising from measuring young trees at breast height (137cm) and old-growth trees at stump height which averaged about 46cm across all sites (Table 3.1). After application of the *breast height:stump height* ratios to all trees measured at breast height (young stand trees) their average growth rates remained far below that of old-growth rates when compared at the same age (Figure 3.1). This comparison determined whether potential disparity between old and young stand growth rates and tree diameter could be explained by differences in the *breast height vs stump height* measurements. The measuring of young trees at breast height did not account for the observed differences.

Table 3.1 The decadal growth and diameter measurements of all young stand trees adjusted by a *breast height:stump height* ratio. The adjustment factors for each species are listed.

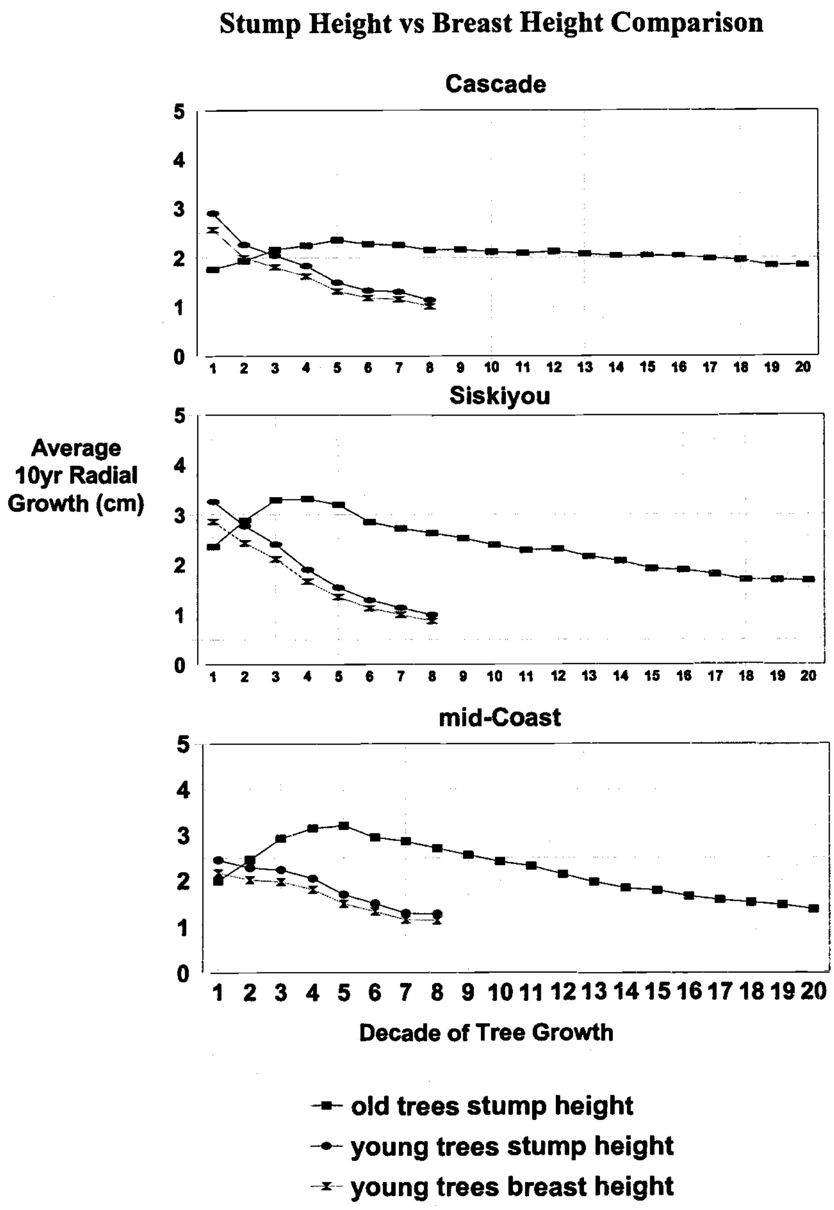
Young stand breast height diameter to stump height diameter adjustment factors

	Douglas-fir	ponderosa pine	incense-cedar	sugar pine	whit-fir	shasta fir	white pine	knobcone pine
Cascade								
Avg. ratio	1.13	1.13	1.21	NP	1.14	1.13	1.55	NP [1]
SD	0.04	0.06	0.07		0.04	0.02	0.37	
Siskiyou								
Avg. ratio	1.14	1.16	NP	NP	1.14	NP	NP	NP
SD	0.03	0.00			0.02			
Mid-Coast								
Avg. ratio	1.13	1.17	1.17	1.12	1.12	NP	NP	1.12
SD	0.04	0.03	0.08	0.04	0.05			0.02

[1] Species not present

The average 10 year growth of all old-growth trees remained statistically greater than even the largest 50% of the young trees after being adjusted to stump height diameter indicating that had the young tree diameters not been corrected from breast to stump height, the results of these studies would have remained the same (Figure 3.1). This is consistent with Tappeiner *et al.*'s (1997) observations in Oregon's Coast Range forests.

Figure 3.1 Comparison of the average 10yr radial growth of all old-growth trees measured at stump height and young overstory trees measured at dbh and young overstory trees adjusted to stump height in three forest types.

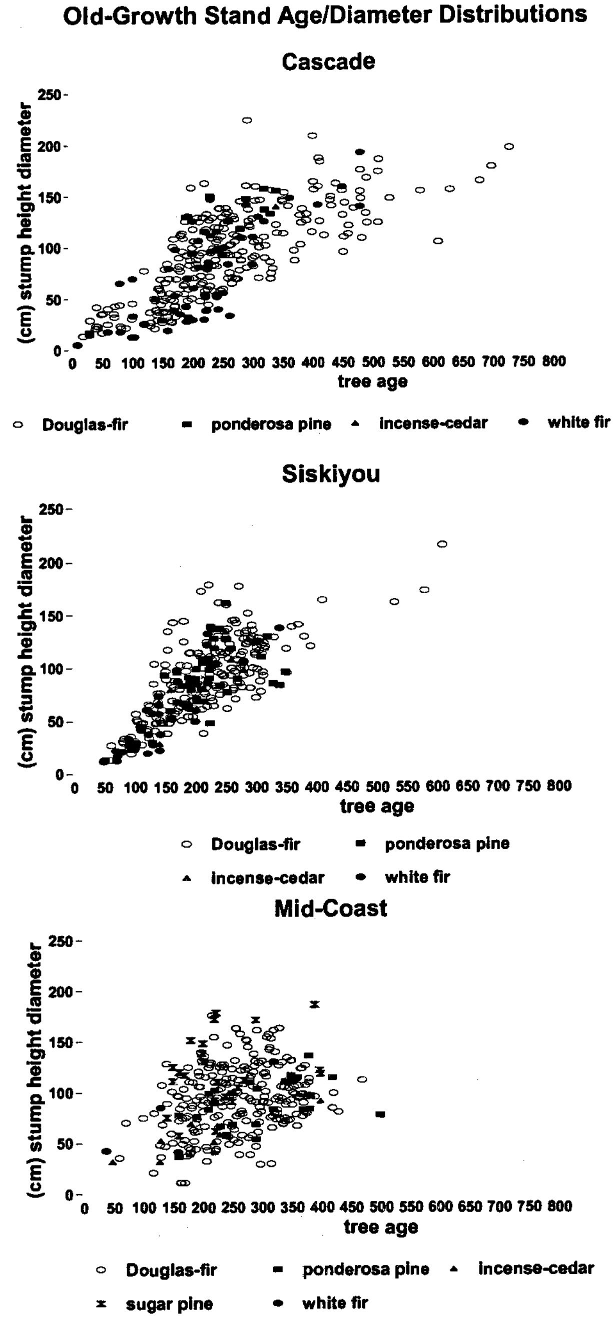


Distribution of Old-Growth and Young Stand Tree Diameters and Ages

Tree diameter distribution for trees in the old-growth stands in the three forest types ranged from 5-225cm, 12-272cm, and 11-186cm in the Cascade, Siskiyous and the mid-Coast respectively. Tree ages within the old-growth stands in the three forest types ranged from 10-730yrs 50-610yrs and 27-500yrs in Cascade, Siskiyous and the mid-Coast respectively (Figure 3.2).

Because the average diameter and age have little meaning in mixed stands where trees vary significantly in size, and because I was interested in the growth of large trees, I calculated the distribution of tree diameters of trees >250yrs and the age of trees >100cm diameter. The box and whisker plots summarize the distribution of tree ages of trees >100cm diameter and the distribution of tree diameters of trees >250yrs old (Figures 3.3a,b). The distribution of tree ages of all old-growth trees >100cm diameter ranged from 190-730yrs (avg.= 332, SE= 9.6) 130-610yrs (avg.= 254, SE= 7.3) and 130-470yrs (avg.= 250, SE= 5.7) in the Cascades (N= 137), Siskiyous (N= 59) and mid-Coast (N= 135) respectively (Figure 3.3a). The diameter of all old-growth trees in the three forest types >250yrs ranged from 33-225cm (avg.= 123, SE= 2.9) 72-272cm (avg.= 123, SE= 4.4) and 28-186cm (avg.= 103, SE= 2.5) in the Cascades (N= 137), Siskiyou (N= 59) and mid-Coast (N= 118) respectively (Figure 3.3b). For each site, the age distributions of both young and old stands are documented and compared (Figure 3.4).

Figure 3.2 Stump height diameter distribution of all trees on three,1ha plots in six clearcut old-growth stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.



Figures 3.3a,b The box and whisker plots summarizes the distribution of tree ages of trees >100cm diameter (3.3a) and the distribution of diameters of trees >250yrs (3.3b) in six old-growth stands in each of the three forest types. The boxes represent the inter quartile ranges; vertical lines represent values 1.5 times the upper or lower quartile. The notch represents the median of the range and the width of the box represents the range of the standard error of the data distribution. The dots are data points.

Figure 3.3a **Ages of trees >100cm diameter**

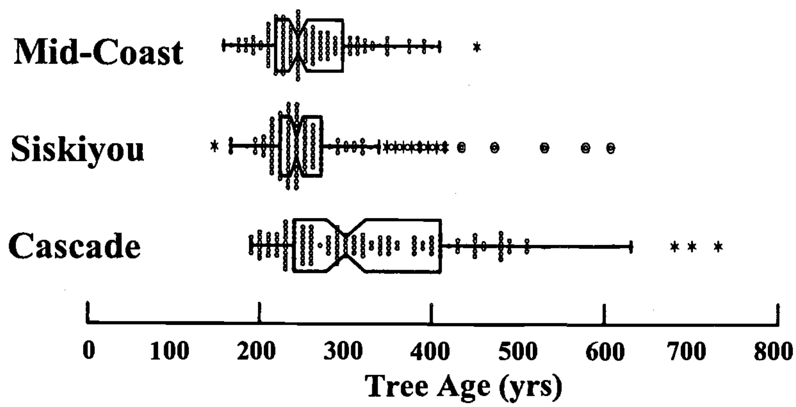


Figure 3.3b **Diameters of trees >250 years of age**

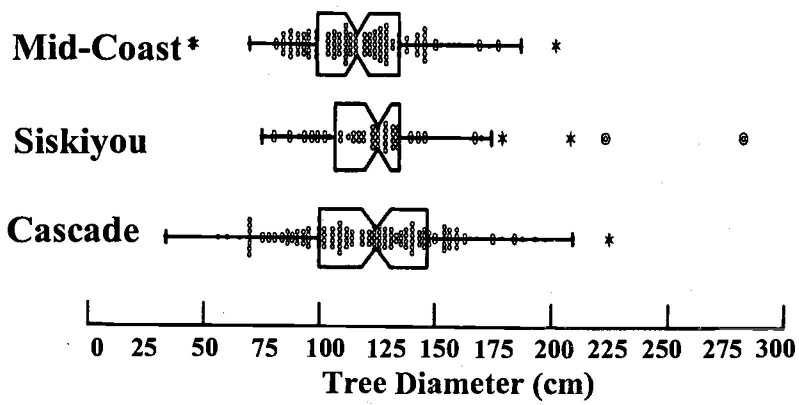
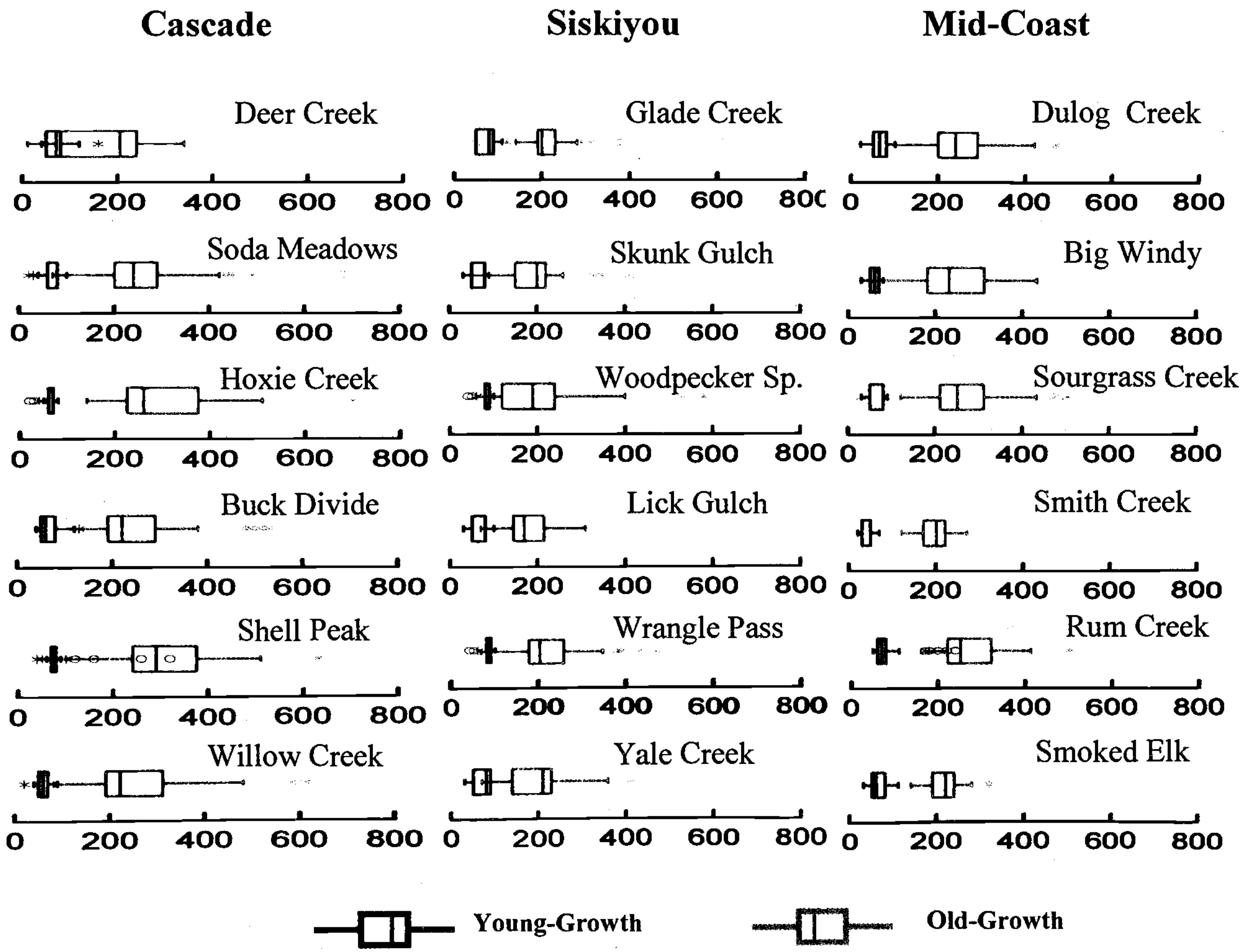


Figure 3.4 Distribution of old-growth and young-growth tree ages in Cascade, Siskiyou and mid-Coast stands in southwestern Oregon.The boxes represent the inter quartile ranges; vertical lines represent values 1.5 times the upper or lower quartile. The inner vertical line is the median and the horizontal lines show the values within 1.5 of the box, and the dots are outside values.



Multivariate Agglomerative Clustering of the Pattern of Tree Diameter

All data were normally distributed. Skewness and kurtosis were within compatible limits. Relativization of tree growth substantially improved the coefficient of variation (CV) of the sums of decadal growth (Cascade, CV= 13.37; Cascade Shasta fir, CV= 13.6; Siskiyou, CV= 4.26; mid-Coast, CV= 10.12). An agglomerative percent chaining value of 0.35 (N= 437), 1.46 (N= 268), 0.33 (N= 589), 0.56 (N= 399) Cascade, Shasta-fir, Siskiyou and mid-Coast respectively, was obtained. The patterns of average decadal growth of each cluster and that of the actual old-growth and young trees were compared for each forest type (Table 3.2).

When the developmental patterns of tree growth are summarized by two levels of group membership (clusters) and compared with those of the actual old and young tree radial growth rates, the patterns of average 10 year radial growth observed in the clusters, strongly parallels the actual patterns of both old-growth and young trees in all forest types (Figure 3.5). Agglomerative clustering clearly illustrated that the developmental patterns of the old-growth trees developed statistically dissimilar to the actual young stand trees in all forest types. An observation of particular interest is that decadal increment growth of the old-growth trees, remains well above young tree growth through eight decades in all forest types studied (Figure 3.5).

Table 3.2 Comparisons of the mean 10yr radial growth between actual old-growth and young stand trees and all trees grouped by agglomerative clustering based on similarities in their patterns of growth for eight decades in Cascade forest stands.

Cascade (Mixed-Conifer Stands)								
Decade of → Comparison	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Old-Growth Trees	**10 Year Radial Growth**							
Mean	**1.750**	**1.982**	**2.111**	**2.217**	**2.274**	**2.218**	**2.200**	**2.100**
Standard Error	0.059	0.076	0.085	0.085	0.081	0.085	0.076	0.070
Standard Deviation	0.916	1.184	1.319	1.319	1.251	1.315	1.173	1.079
Young Trees								
Mean	**2.921**	**2.253**	**2.027**	**1.807**	**1.509**	**1.288**	**1.259**	**1.132**
Standard Error	0.092	0.069	0.065	0.064	0.063	0.061	0.062	0.060
Standard Deviation	1.294	0.965	0.913	0.892	0.878	0.852	0.877	0.836
Cluster I (Compares with old-growth tree patterns of growth)								
Mean	**1.646**	**1.732**	**2.007**	**2.206**	**2.274**	**2.286**	**2.323**	**2.225**
Standard Error	0.045	0.057	0.073	0.079	0.078	0.084	0.075	0.068
Standard Deviation	0.694	0.875	1.113	1.201	1.187	1.292	1.145	1.042
Cluster II (Compares with young tree patterns of growth)								
Mean	**3.007**	**2.426**	**2.149**	**1.832**	**1.531**	**1.237**	**1.144**	**1.017**
Standard Error	0.094	0.086	0.084	0.073	0.070	0.059	0.054	0.051
Standard Deviation	1.341	1.220	1.197	1.033	0.995	0.834	0.766	0.720

N=437

(Continued)
Table 3.2 Comparisons of the mean 10yr radial growth between actual old-growth and young stand trees and all trees grouped by agglomerative clustering based on similarities in their patterns of growth for eight decades in Cascade forest stands.

Cascade
(Shasta fir)

Decade of Comparison →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Old-Growth Trees			**10 Year Radial Growth**					
Mean	**1.630**	**1.936**	**2.646**	**3.114**	**3.292**	**3.226**	**3.202**	**2.659**
Standard Error	0.086	0.156	0.236	0.292	0.269	0.258	0.233	0.206
Standard Deviation	0.791	1.438	2.172	2.692	2.483	2.379	2.149	1.900
Young Trees								
Mean	**2.286**	**2.305**	**2.591**	**2.062**	**1.962**	**1.876**	**1.687**	**1.095**
Standard Error	0.074	0.063	0.254	0.077	0.075	0.071	0.072	.087
Standard Deviation	0.994	0.849	3.432	1.040	1.017	0.955	0.971	1.172
Cluster I (Compares with old-growth tree patterns of growth)								
Mean	**2.107**	**2.109**	**2.502**	**2.781**	**2.851**	**2.709**	**2.701**	**2.567**
Standard Error	0.090	0.086	0.122	0.160	0.159	0.148	0.138	0.117
Standard Deviation	1.126	1.078	1.520	1.995	1.986	1.851	1.721	1.450
Cluster II (Compares with young tree patterns of growth)								
Mean	**2.038**	**2.299**	**2.755**	**1.859**	**1.733**	**1.741**	**1.580**	**0.815**
Standard Error	0.070	0.103	0.419	0.126	0.097	0.112	0.101	0.091
Standard Deviation	0.739	1.085	4.430	1.335	1.022	1.182	1.014	0.558

N=268

(Continued)

Table 3.2 Comparisons of the mean 10yr radial growth between actual old-growth and young stand trees and all trees grouped by agglomerative clustering based on similarities in their patterns of growth for eight decades in Siskiyou forest stands.

	Siskiyou (Mixed-Evergreen)							
Decade of Comparison →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Old-Growth Trees	**10 Year Radial Growth**							
Mean	**2.297**	**2.864**	**3.311**	**3.327**	**3.266**	**2.883**	**2.772**	**2.652**
Standard Error	0.058	0.080	0.096	0.094	0.089	0.082	0.084	0.080
Standard Deviation	0.853	1.166	1.407	1.379	1.292	1.198	1.225	1.163
Young Trees								
Mean	**2.984**	**2.462**	**2.131**	**1.695**	**1.399**	**1.176**	**1.064**	**0.937**
Standard Error	0.077	0.071	0.063	0.052	0.039	0.035	0.030	0.030
Standard Deviation	1.501	1.377	1.222	0.999	0.758	0.677	0.575	0.580
Cluster I (Compares with old-growth tree patterns of growth)								
Mean	**2.666**	**3.378**	**3.876**	**3.902**	**3.808**	**3.371**	**3.180**	**3.016**
Standard Error	0.112	0.111	0.110	0.095	0.084	0.078	0.088	0.086
Standard Deviation	1.421	1.413	1.399	1.210	1.068	0.990	1.123	1.096
Cluster II (Compares with young tree patterns of growth)								
Mean	**2.762**	**2.315**	**2.058**	**1.671**	**1.416**	**1.194**	**1.113**	**1.004**
Standard Error	0.064	0.056	0.051	0.042	0.032	0.029	0.027	0.028
Standard Deviation	1.316	1.153	1.045	0.865	0.665	0.609	0.560	0.580

N=589

(Continued)

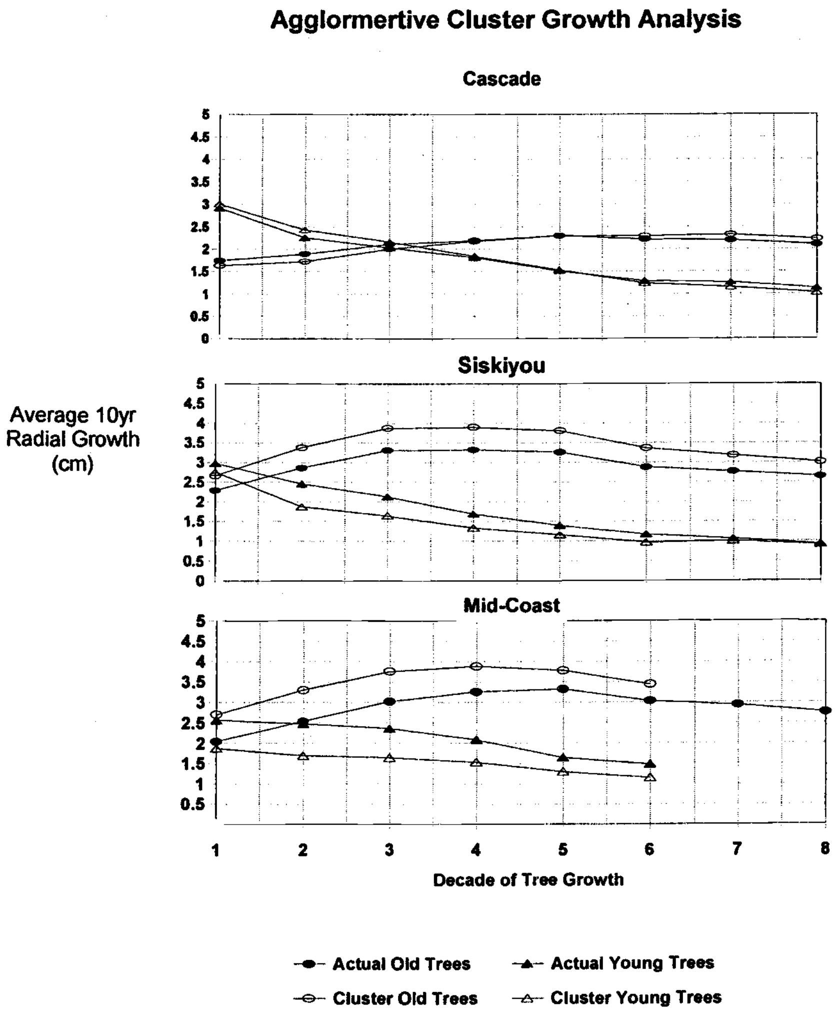
Table 3.2 Comparisons of the mean 10yr radial growth between actual old-growth and young stand trees and all trees grouped by agglomerative clustering based on similarities in their patterns of growth for six decades in mid-Coast forest stands.

Mid-Coast
(Tanoak Understory)

Decade of → Comparison	**1**	**2**	**3**	**4**	**5**	**6**
Old-Growth Trees	**10 Year Radial Growth**					
Mean	**2.107**	**2.580**	**3.052**	**3.299**	**3.344**	**3.030**
Standard Error	0.067	0.094	0.118	0.119	0.117	0.106
Standard Deviation	0.999	1.412	1.768	1.789	1.758	1.597
Young Trees						
Mean	**2.568**	**2.479**	**2.365**	**2.089**	**1.651**	**1.491**
Standard Error	0.089	0.095	0.091	0.089	0.082	0.085
Standard Deviation	1.189	1.265	1.208	1.183	1.092	1.128
Cluster I (Compares with old-growth tree patterns of growth)						
Mean	**2.705**	**3.302**	**3.762**	**3.890**	**3.783**	**3.444**
Standard Error	0.076	0.091	0.102	0.102	1.104	0.098
Standard Deviation	1.102	1.316	1.481	1.484	1.513	1.414
Cluster II (Compares with young tree patterns of growth)						
Mean	**1.878**	**1.696**	**1.645**	**1.537**	**1.303**	**1.158**
Standard Error	0.068	0.055	0.051	0.050	0.050	0.049
Standard Deviation	0.945	0.755	0.707	0.700	0.692	0.678

N=399

Figure 3.5 The average 10yr radial growth of old-growth and young stand trees, and trees assigned membership into one of two groups by agglomerative clustering of all trees based on similarities in their pattern of growth in three forest types in southwestern Oregon.



In all forest types young trees that exhibit slow early growth, trended to remain relatively slow growing. Although average growth in both the young stand clusters and actual young stand trees declines at about 25yrs and continue to do so, trees with the greatest early growth remain growing at a greater rate than the initially slow growing trees.

Thus, is it possible to predict the possibility of any tree to become large in diameter by its growth rate or diameter at a young age? This question became the fundamental bases for examining the relationships between periodic annual basal area increments (PAI_{BA}, cm/yr) and tree diameter growth at a the relatively young age (50yrs) and its eventual diameter at older ages 100yrs, 150yrs, 200yrs and 250yrs.

Analyses of Basal Area (PAI_{BA}, m^2/ha) and Stand Density Development From 1800 to 1990 Among and Between Three Forest Stand Types

The mean, standard deviation (SD) and the standard error (SE) for stump height old stand, and dbh adjusted to stump height, young stand basal areas and trees/ha are tabulated for each fifty year period from 1800-1990 for Cascade Siskiyou and mid-Coast sites (Table 3.3).

Table 3.3 Summary of stand density (basal area and trees per hectare) development by 50yr periods from 1800 -1990 for eight old-growth and eight young stands in Cascade, Siskiyou and mid-Coast forests in southwest Oregon.

Analysis of Stand Density Development by Period

Year →	1800	1850	1900	1950	1990
Cascade					
Old-growth Stands					
Average Basal Area in m²/ha	9.32	15.12	23.97	36.51	46.58
SE of average m²/ha	2.28	2.57	3.81	6.64	6.89
SD of average m²/ha	5.59	6.30	9.33	16.26	16.88
% of final BA grown by period	20.02	12.43	19.00	26.92	21.63
Average trees/hectare	57.00	76.00	85.00	94.00	98.00
SE of average trees/ha	10.18	13.63	13.68	11.27	11.25
SD of average trees/ha	24.94	33.42	33.50	27.60	27.55
Young Stands					
Average Basal Area in m²/ha			1.42	9.73	43.05
SE of average m²/ha			0.97	2.08	3.87
SD of average m²/ha			1.68	5.10	9.47
% of final BA grown by period			0.97	20.95	77.40
Average trees/hectare			38.00	579.00	782.00
SE of average trees/ha			14.68	80.06	94.30
SD of average trees/ha			25.42	196.10	230.98
Siskiyou					
Old-growth Stands					
Average Basal Area in m²/ha	1.46	7.80	19.47	34.18	43.69
SE of average m²/ha	0.22	0.73	2.42	5.00	6.94
SD of average m²/ha	0.54	1.79	5.92	12.23	17.00
% of final BA grown by period	3.70	15.99	29.46	37.13	13.72
Average trees/hectare	55.00	64.00	89.00	99.00	101.00
SE of average trees/ha	21.93	7.95	7.67	7.29	8.31
SD of average trees/ha	53.70	19.48	18.78	17.87	20.37
Young Stands					
Average Basal Area in m²/ha			0.00	14.33	47.83
SE of average m²/ha			0.01	1.75	6.44
SD of average m²/ha			0.01	4.28	15.77
% of final BA grown by period			0.05	29.90	70.05
Average trees/hectare			57.00	590.00	895.00
SE of average trees/ha			24.50	77.47	133.11
SD of average trees/ha			34.65	189.77	326.05
Mid-Coast					
Old-growth Stands					
Average Basal Area in m²/ha	7.73	19.20	34.84	49.95	59.12
SE of average m²/ha	1.50	2.64	4.17	6.28	7.87
SD of average m²/ha	3.67	6.46	10.21	15.38	19.29
% of final BA grown by period	13.07	19.42	26.44	25.55	15.52
Average trees/hectare	79.00	96.00	98.00	98.00	98.00
SE of average trees/ha	4.26	8.02	9.58	9.58	9.583
SD of average trees/ha	10.44	19.65	23.47	23.47	23.47
Young Stands					
Average Basal Area in m²/ha			0.12	5.80	38.19
SE of average m²/ha			0.01	2.15	6.04
SD of average m²/ha			0.01	5.26	14.80
% of final BA grown by period			0.01	14.01	85.98
Average trees/hectare			97.83	402.00	740.00
SE of average trees/ha			9.58	103.54	107.93
SD of average trees/ha			23.47	253.62	264.3

ANOVA reveled no significant difference in stand total basal area among old-growth sites (N= 18, R^2= .146, p= .306), nor trees/ha (R^2= .005, p= .966). As with old growth, young stand total basal area (N= 18, R^2= .051, p= .678) and trees/ha (N= 18, R^2= .063, p= .614) did not significantly vary among sites.

The total basal area (PAI_{BA}, m^2/ha) by 50 year periods from 1800 to1990 for the Cascade, Siskiyou and mid-Coast sites (Figure 3.6), percent of current basal area (Figure 3.7) and the total trees/ha (Figure 3.8) are compared between young and old stands.

Although t-tests did not detect significant differences between young stand and old-growth stand basal areas (Cascade p= .519, Siskiyou p= .671, mid-Coast p= .143), significant differences in stand density existed between all young and old-growth stands (Cascade p= .001, Siskiyou p= .002, mid-Coast p= .002).

Figure 3.6 Total basal area by period for old and young stands in three forest types in southwestern Oregon. Boxes represent the inter quartile ranges; vertical lines represent values 1.5 times the upper or lower quartile. The horizontal line is the median.

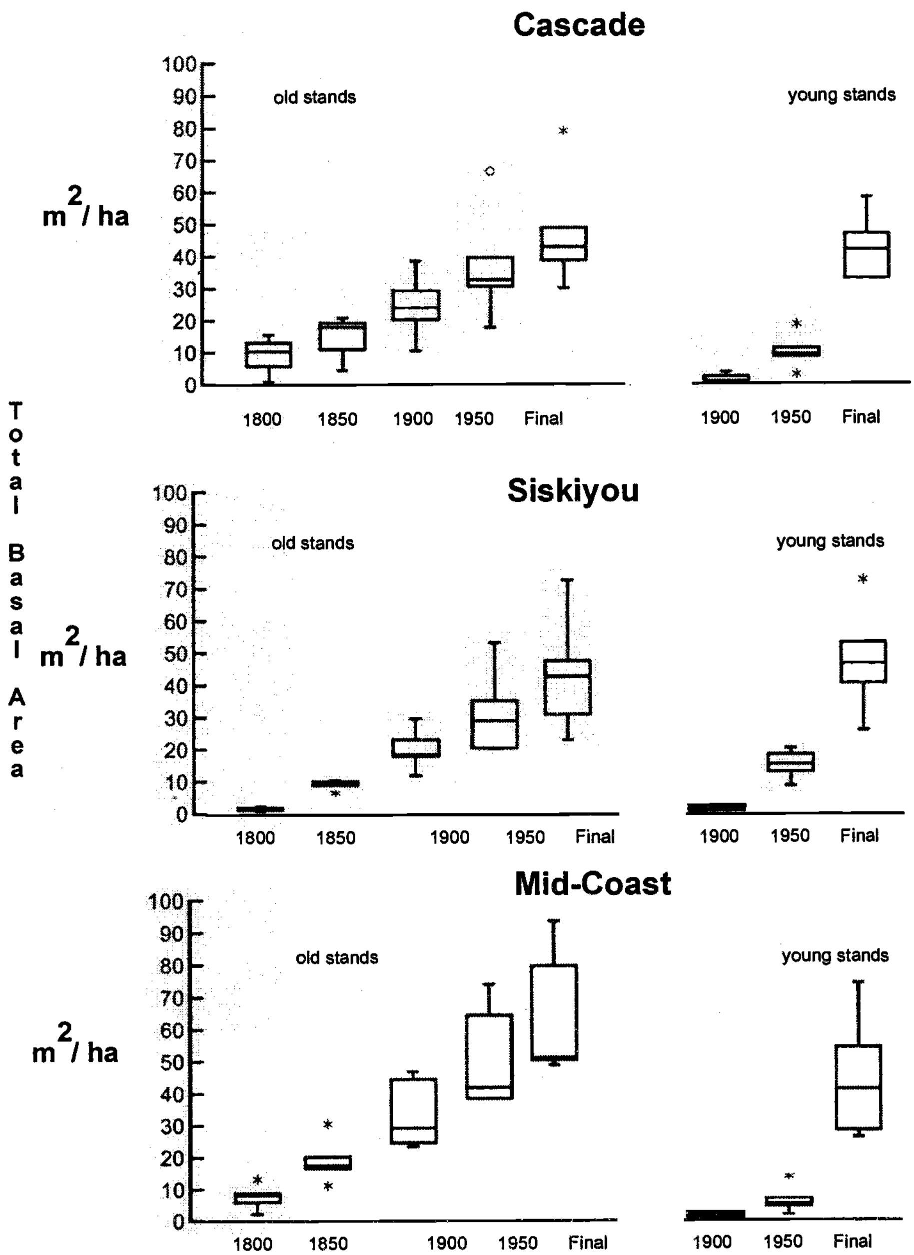


Figure 3.7 Percent of current basal area by period for old and young stands in three forest types in southwestern Oregon. Boxes represent the inter quartile ranges; vertical lines represent values 1.5 times the upper or lower quartile. The horizontal line is the median.

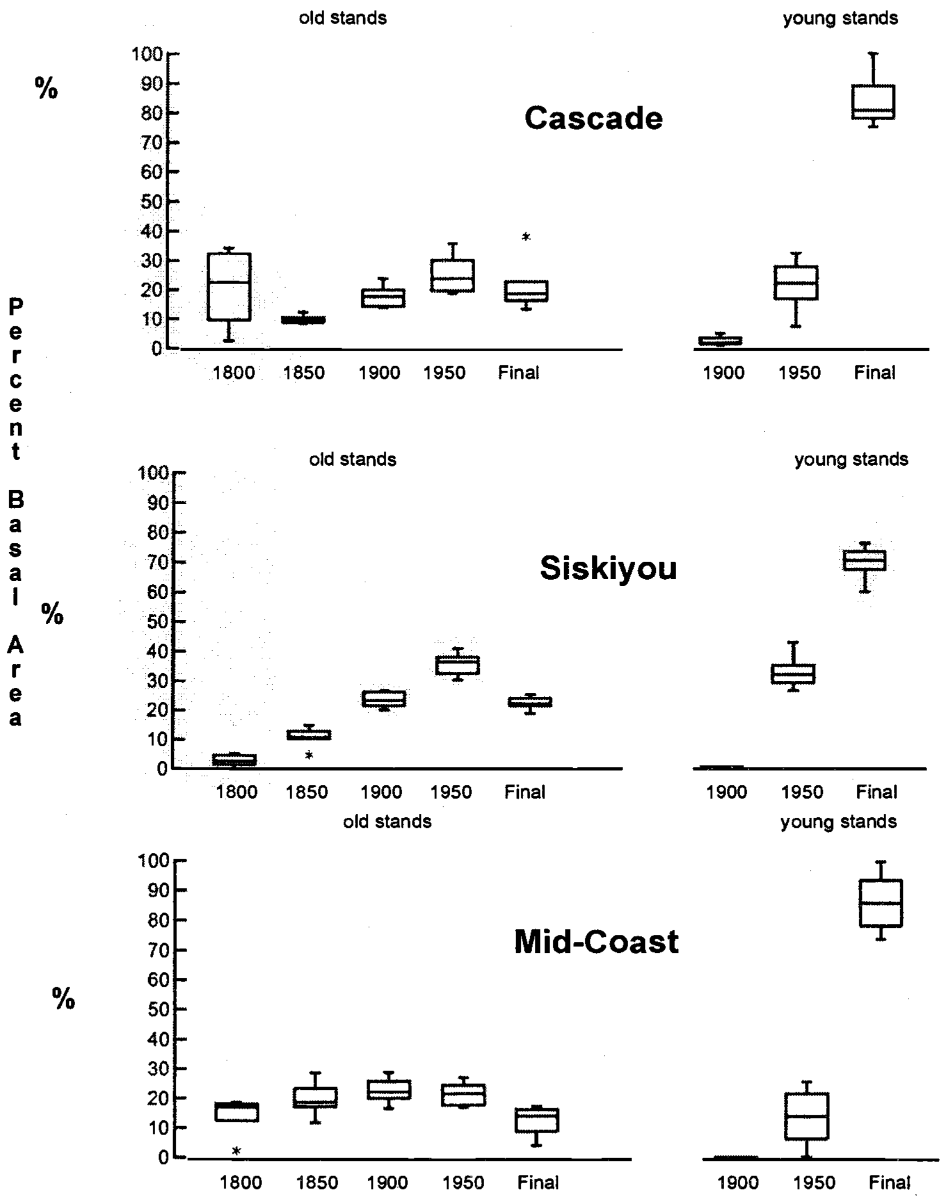
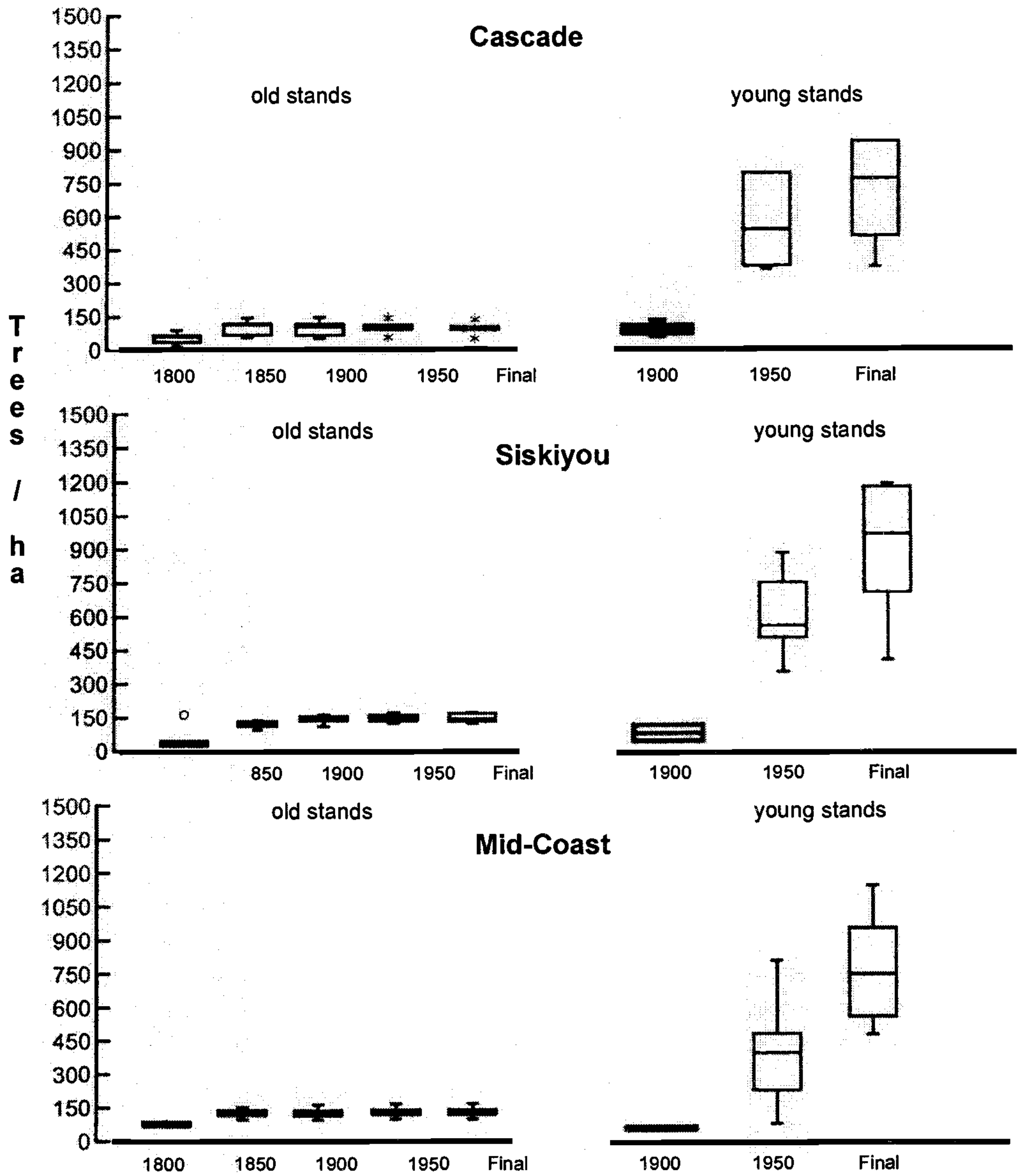


Figure 3.8 Total trees per hectare by period for old and young stands in three forest types in southwestern Oregon. Boxes represent the inter quartile ranges; vertical lines represent values 1.5 times the upper or lower quartile. The horizontal line is the median.



Periodic Annual Basal Area Increments (PAI_{BA}, cm/yr) and Tree Diameter Growth Compared at Age 50yrs and Subsequent Ages 100yrs, 150yrs, 200yrs and 250yrs.

In all stands and for all species, tree diameter at ages 100-250yrs was positively and linearly related to its diameter at age 50yrs (Table 3.4). At age 250 the relationship between tree diameter to its diameter at age 50yrs was still highly significant for all sites (p= <.0001) for all tree species (Cascade R^2 = 0.43, Siskiyou R^2= 0.29, mid-Coast R^2 =.057), (Figure 3.9).

As with tree diameter growth at 50yrs, basal area growth rate (PAI_{BA}, cm^2/decade) between age 40-50yrs was significantly and linearly related (p= <.0001) for all sites, (p= <.0001), (Cascade R^2 = 0.48, Siskiyou R^2= 0.27, mid-Coast R^2=0.54) (Table 3.5).

Table 3.4 Linear regression statistics for the relationships between tree diameters at age 50yrs vs their diameters at ages 100yrs, 150yrs, 200yrs, 250yrs for all species and Douglas-fir alone in three forest types.

Linear Regression Statistics for Tree Diameter at Age 50yrs

VS

	Age 100yrs			Age 150yrs			Age 200yrs			Age 250yrs		
	r^2	SE	N	r^2	SE	N	r^2	SE	N	r^2	SE	N
Cascade												
All species	0.79	8.63	321	0.65	14.27	269	0.53	19.24	249	0.43	23.68	208
Douglas-fir	0.77	8.01	247	0.59	13.86	209	0.44	19.48	191	0.33	23.63	158
Siskiyou												
All species	0.76	8.96	316	0.55	16.70	280	0.37	19.98	192	0.29	22.13	125
Douglas-fir	0.74	8.88	216	0.55	16.70	195	0.40	19.96	136	0.32	20.86	88
mid-Coast												
All species	0.84	9.53	313	0.72	15.65	311	0.64	19.06	292	0.57	19.59	196
Douglas-fir	0.83	9.65	242	0.72	15.48	240	0.66	18.24	225	0.60	19.34	153

r^2 = Squared multiple of pair, SE= Standard Error, N = Number of cases

Table 3.5 Linear regression statistics for the relationships between tree basal area growth at age 50yrs vs their basal area growth at ages 100yrs, 150yrs, 200yrs, 250yrs for all species and Douglas-fir alone in three forest types.

Linear Regression Statistics for Diameter Growth at age 50yrs

VS

	Age 100yrs			Age 150yrs			Age 200yrs			Age 250yrs		
	r^2	SE	N	r^2	SE	N	r^2	SE	N	r^2	SE	N
Cascade												
All species	0.81	8.07	321	0.73	12.52	269	0.60	17.72	249	0.48	22.48	208
Douglas-fir	0.81	7.38	247	0.67	12.38	209	0.53	17.69	191	0.42	21.79	158
Siskiyou												
All species	0.68	10.2	316	0.57	16.38	280	0.42	19.23	192	0.27	22.33	125
Douglas-fir	0.65	10.3	216	0.55	16.78	195	0.40	19.93	136	0.27	21.59	88
mid-Coast												
All species	0.77	11.5	313	0.68	16.74	311	0.60	20.20	292	0.54	20.15	196
Douglas-fir	0.76	11.6	242	0.66	16.62	240	0.62	19.39	225	0.56	20.05	100

r^2 = Squared multiple of pair, SE= Standard Error, N= Number of cases

Figure 3.9 Liner regressions of diameters (cm) of Douglas-fir trees at age 50yrs and their diameters at ages 100yrs, 150yrs, 200yrs and 250yrs for three forest types in southwestern Oregon.

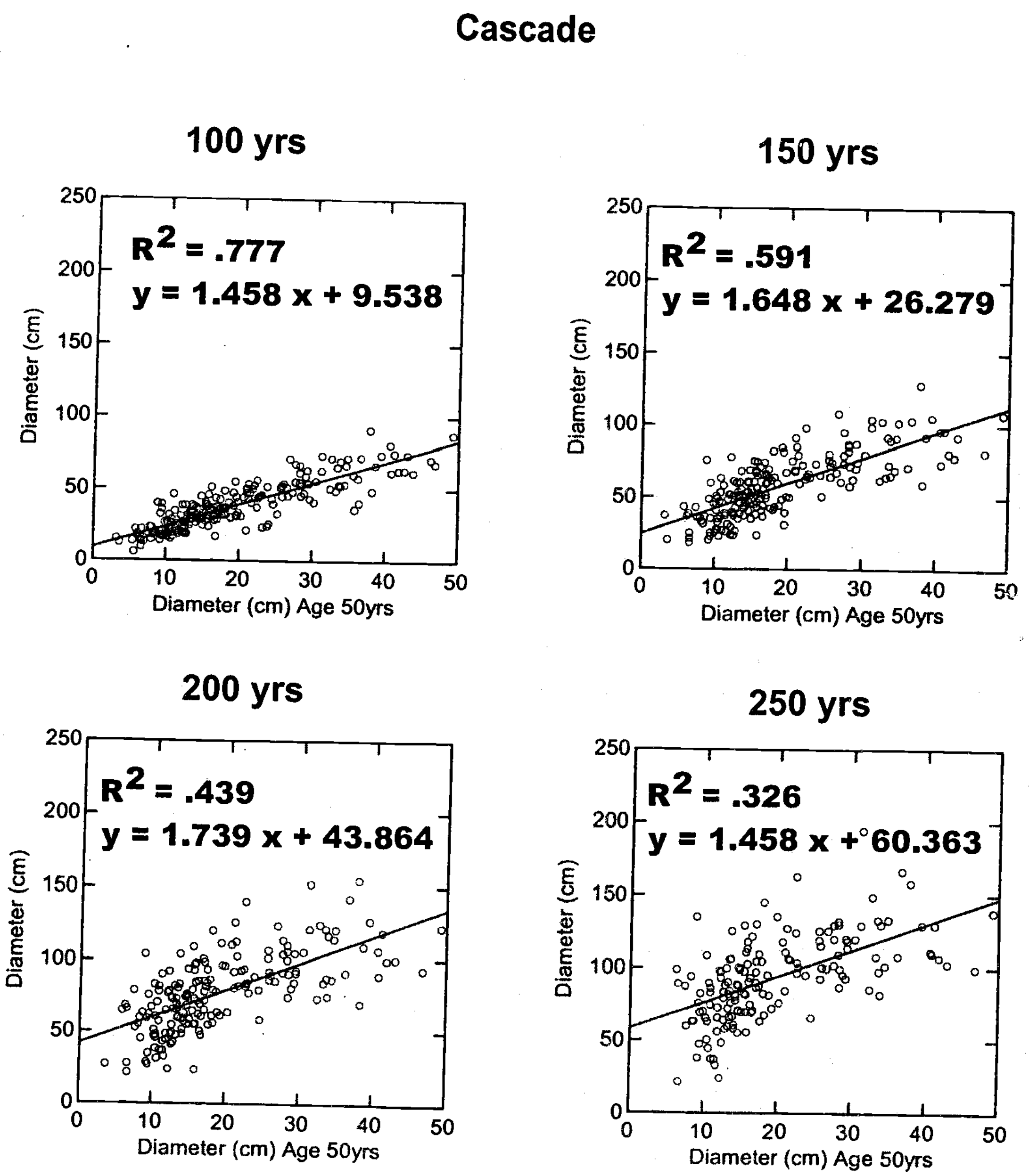


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Figure 3.9 Liner regressions of diameters (cm) of Douglas-fir trees at age 50yrs and their diameters at ages 100yrs, 150yrs, 200yrs and 250yrs for three forest types in southwestern Oregon.

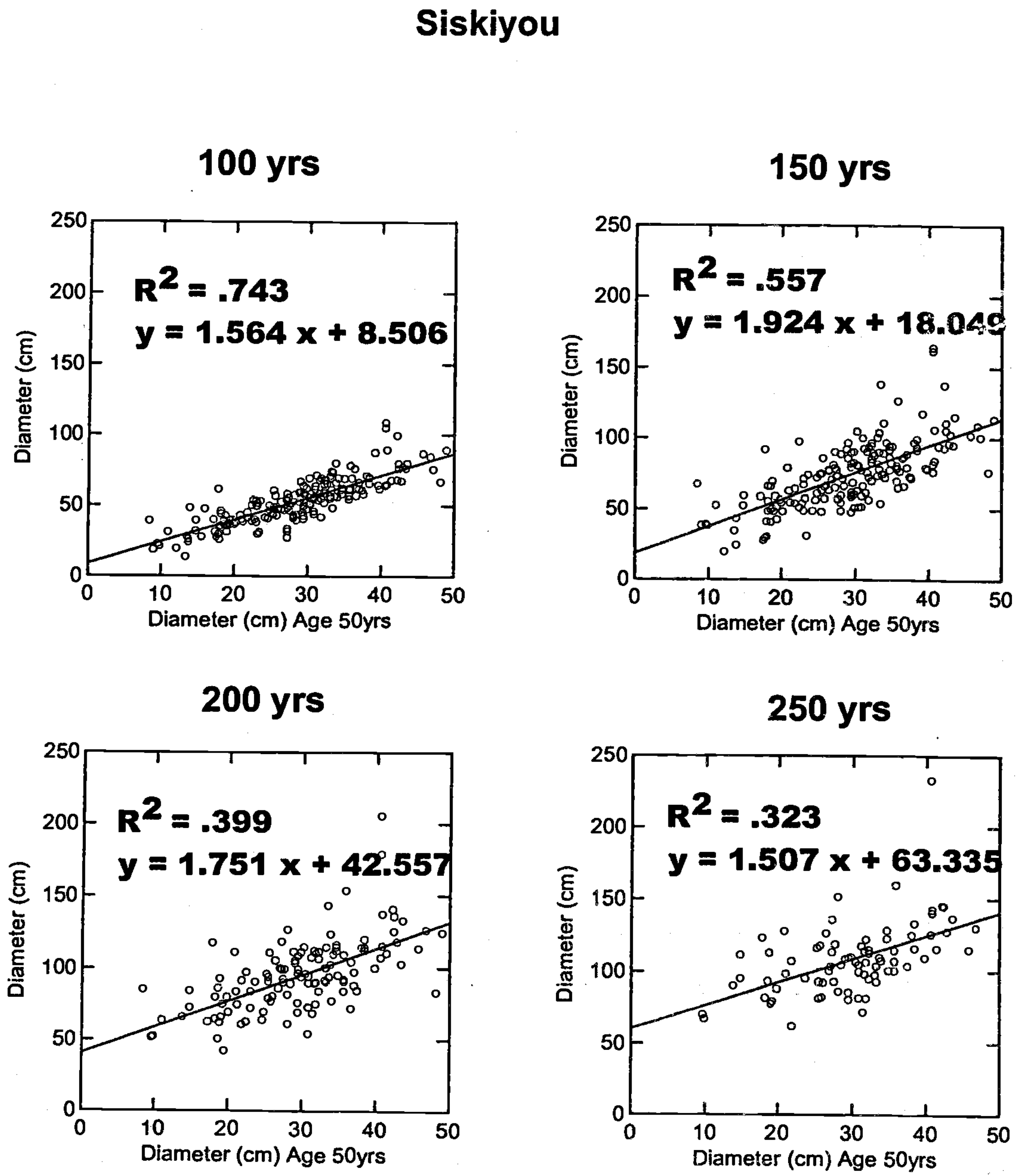

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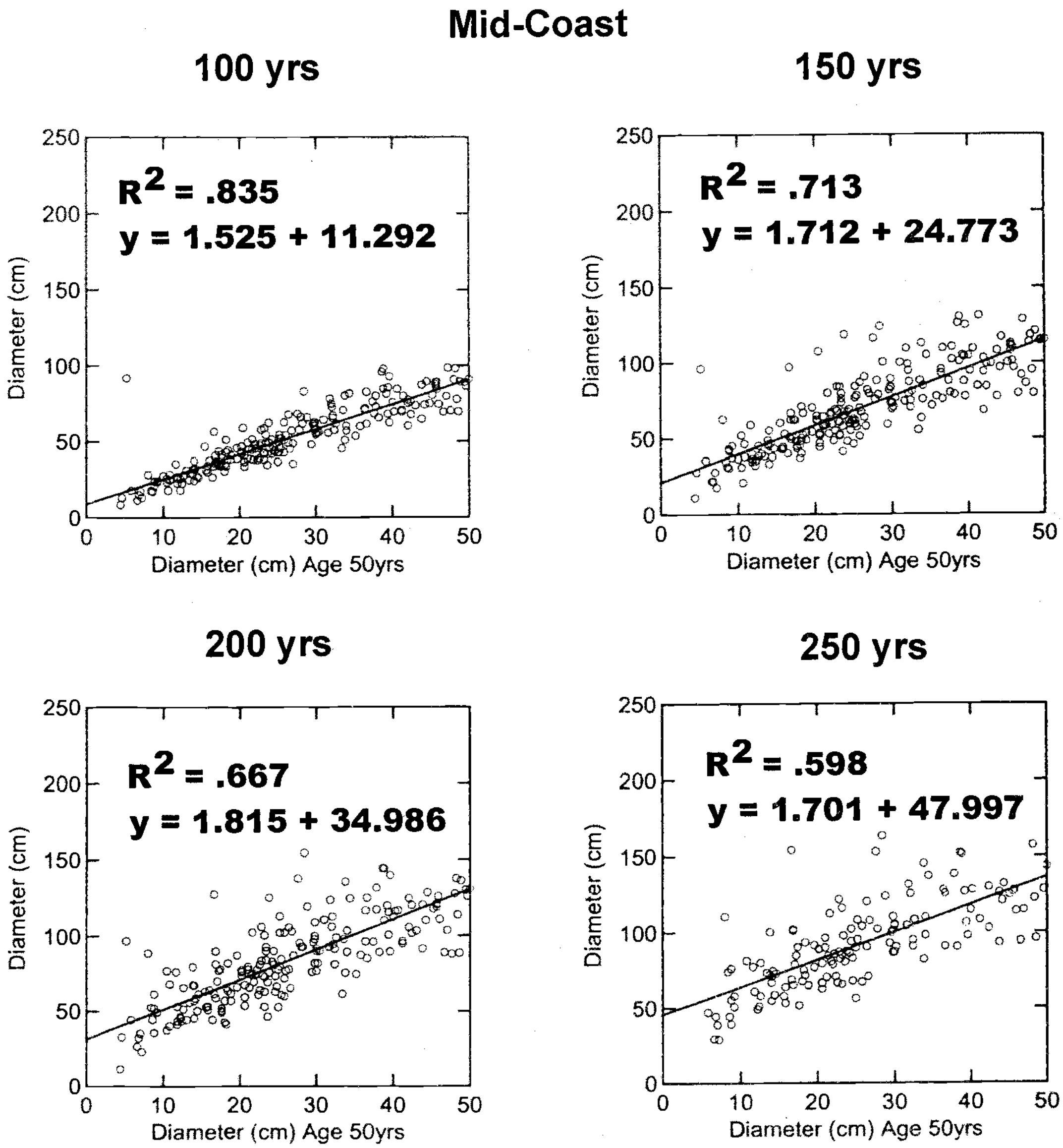
Figure 3.9 Linear regressions of Douglas-fir tree diameters at age 50yrs and their diameters at ages 100yrs,150yrs, 200yrs and 250yrs for three forest types in southwestern Oregon.



Comparison of Tree *Height:Diameter* Ratios and Tree *Heigh:Live Crown* Ratios Between Young and Old Forest Stands

The distribution, median, standard error (SE), and standard deviations of both *height:diameter* ratios and percent of tree height having live crown for both young-growth and old-growth trees was calculated and analyzed using box and whisker density plot analyses for each site. Tree *height:diameter* ratios averaged 50.7:1 (SD= 12.89), 55.6:1 (SD= 12.3) and 54.7.1 (SD= 15.0) for all trees in old-growth stands whereas young stand *height:diameter* ratio averaged 71.4:1 (SD= 22.187), 75.9:1 (SD= 25.3) and 79.0:1 (SD= 23.1) in Cascade, Siskiyou and mid-Coast stands respectively (Figure 3.10).

Further, the tree *heigh:live crown* ratio averaged 59.1:1 (SD= 18.9), 56.1:1 (SD= 18.7) and 61.1:1 (SD= 17.2) for all trees in old-growth stands whereas young stand *height:diameter* ratio averaged 48.4:1 (23.2), 47.6:1 (SD= 19.7) and 46.8:1 (SD= 19.6) in Cascade, Siskiyou and mid-Coast stands respectively (Figure 3.11). This information is observational and presented to document the current tree crown attributes. Because it is theoretically possible for the percent live crown to increase as trees grow in height, and for *height:diameter* ratios to decrease as trees age, direct statistical comparisons between young and old trees are not particularly meaningful. However, these differences indicates that rather dramatic reductions in stand densities in the young stands are necessary for significant improvements in crown attributes to occur.

Figure 3.10 The ratio of tree height to diameter for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

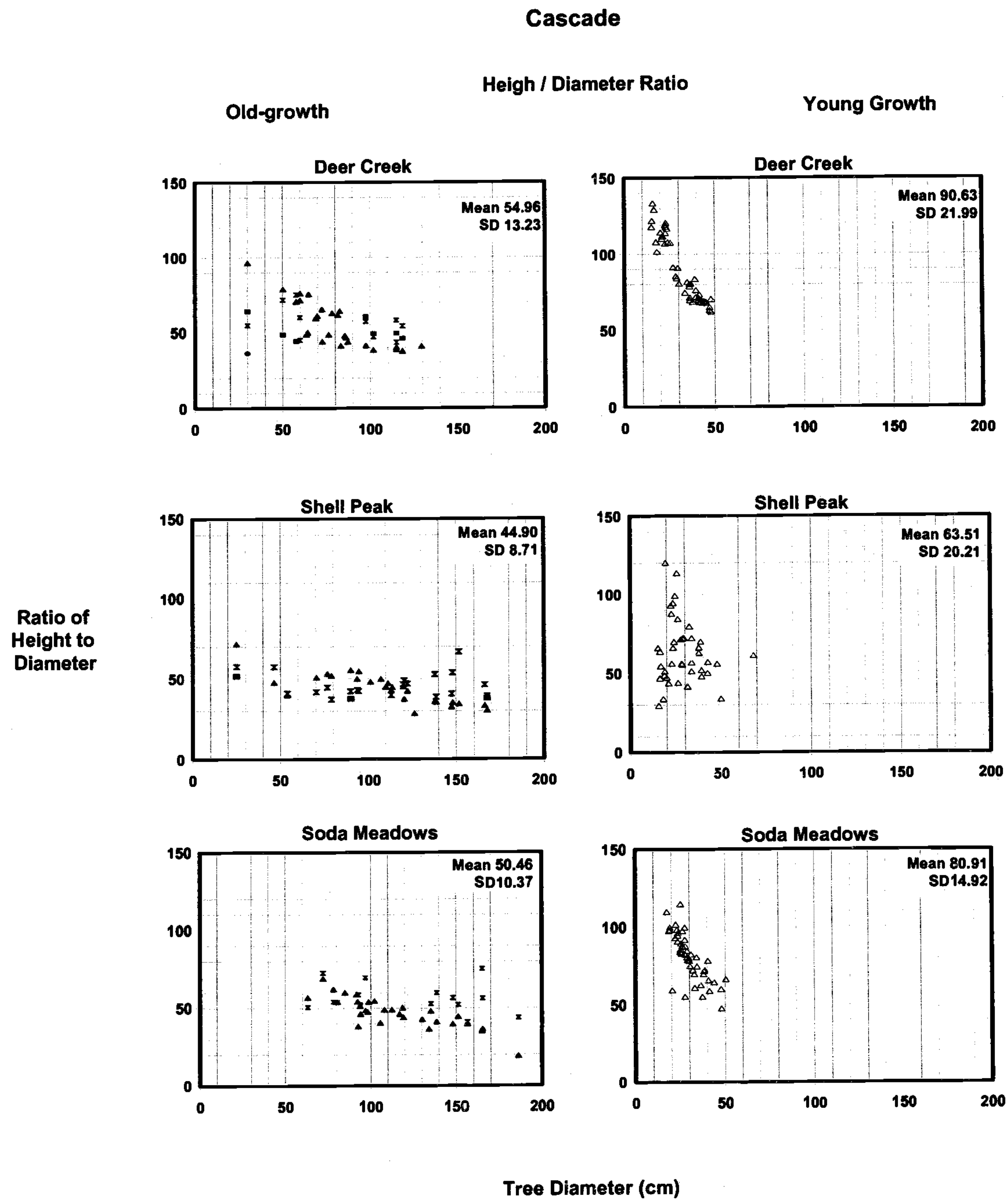


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Figure 3.10 The ratio of tree height to diameter for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

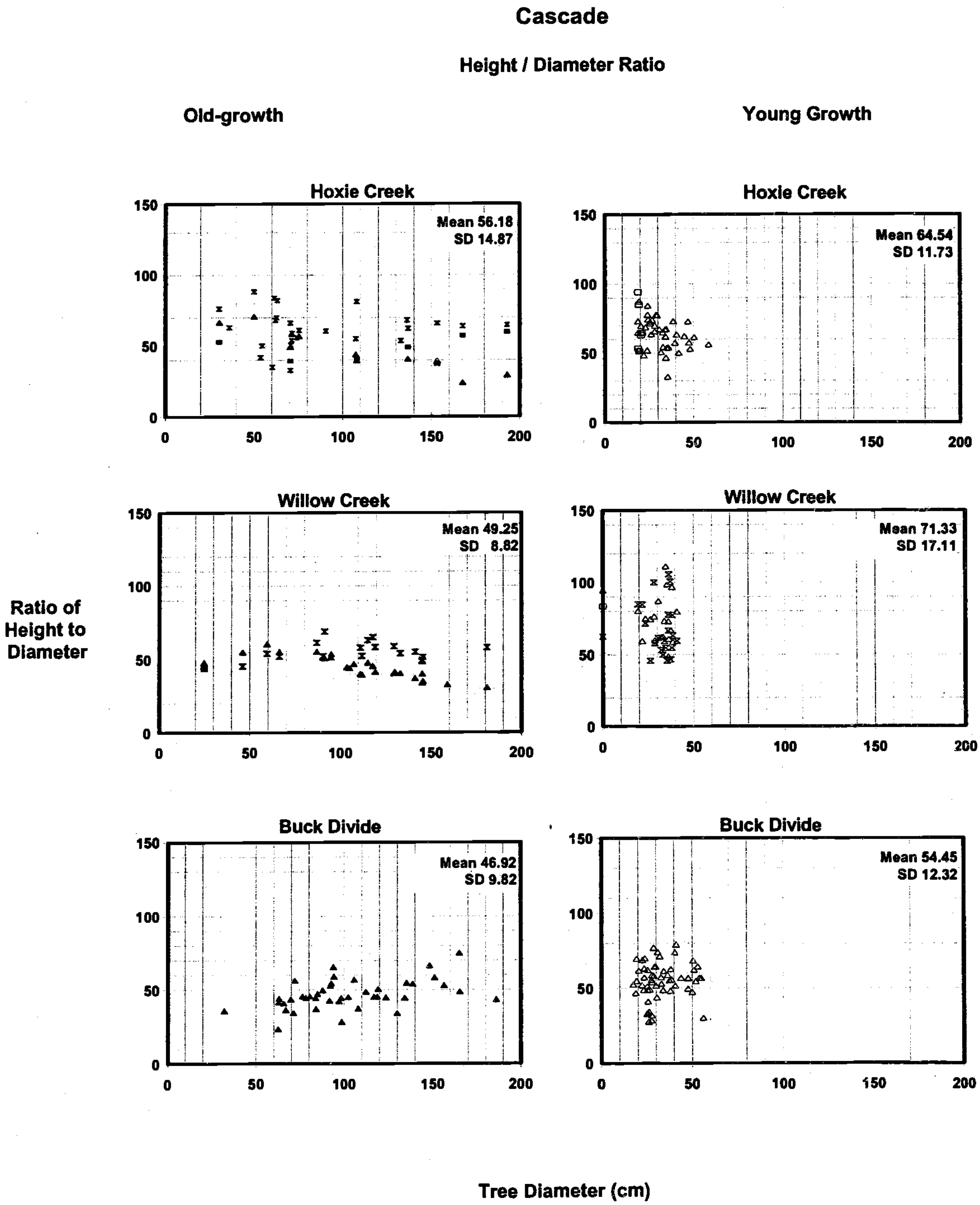

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Figure 3.10 The ratio of tree height to diameter for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

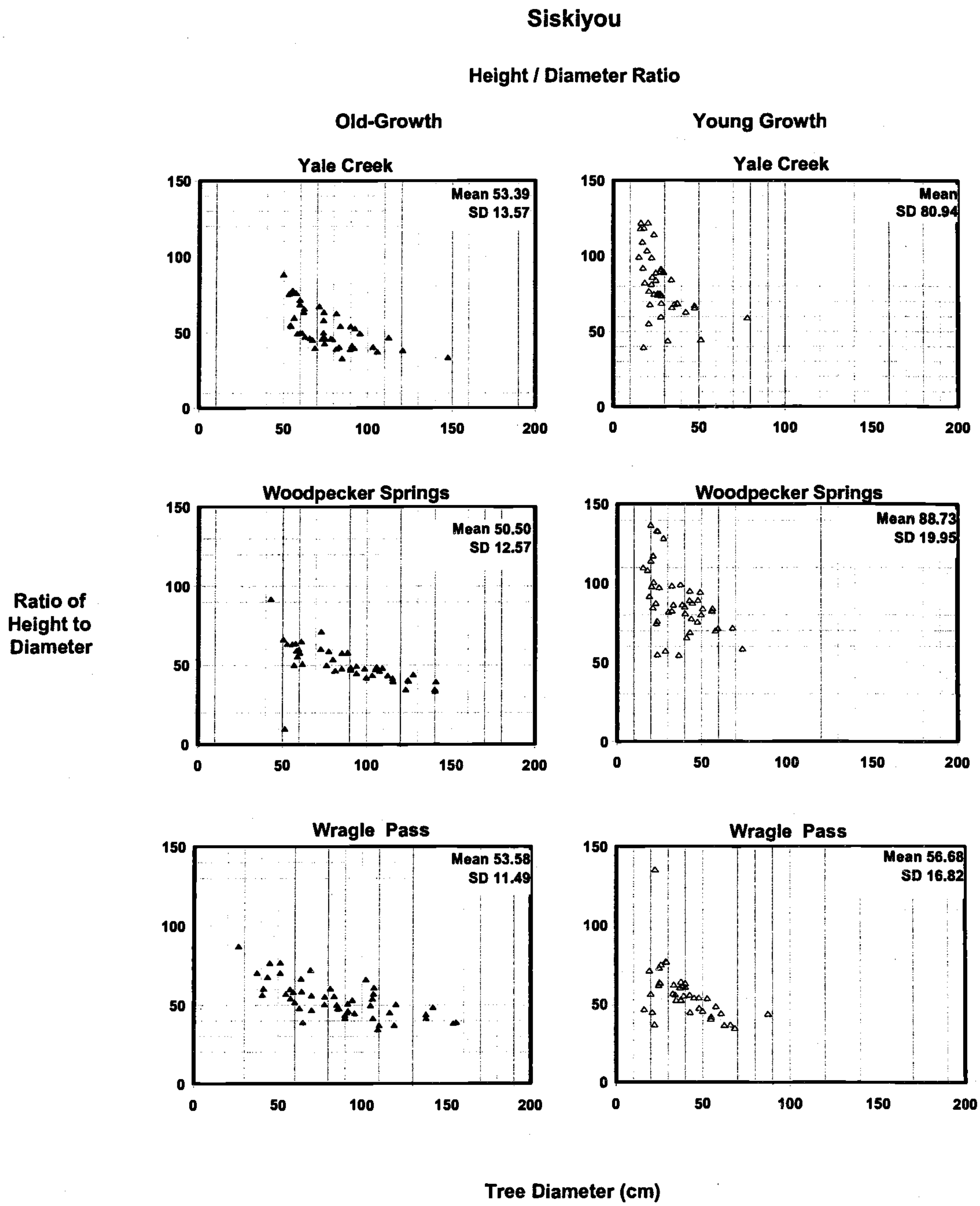

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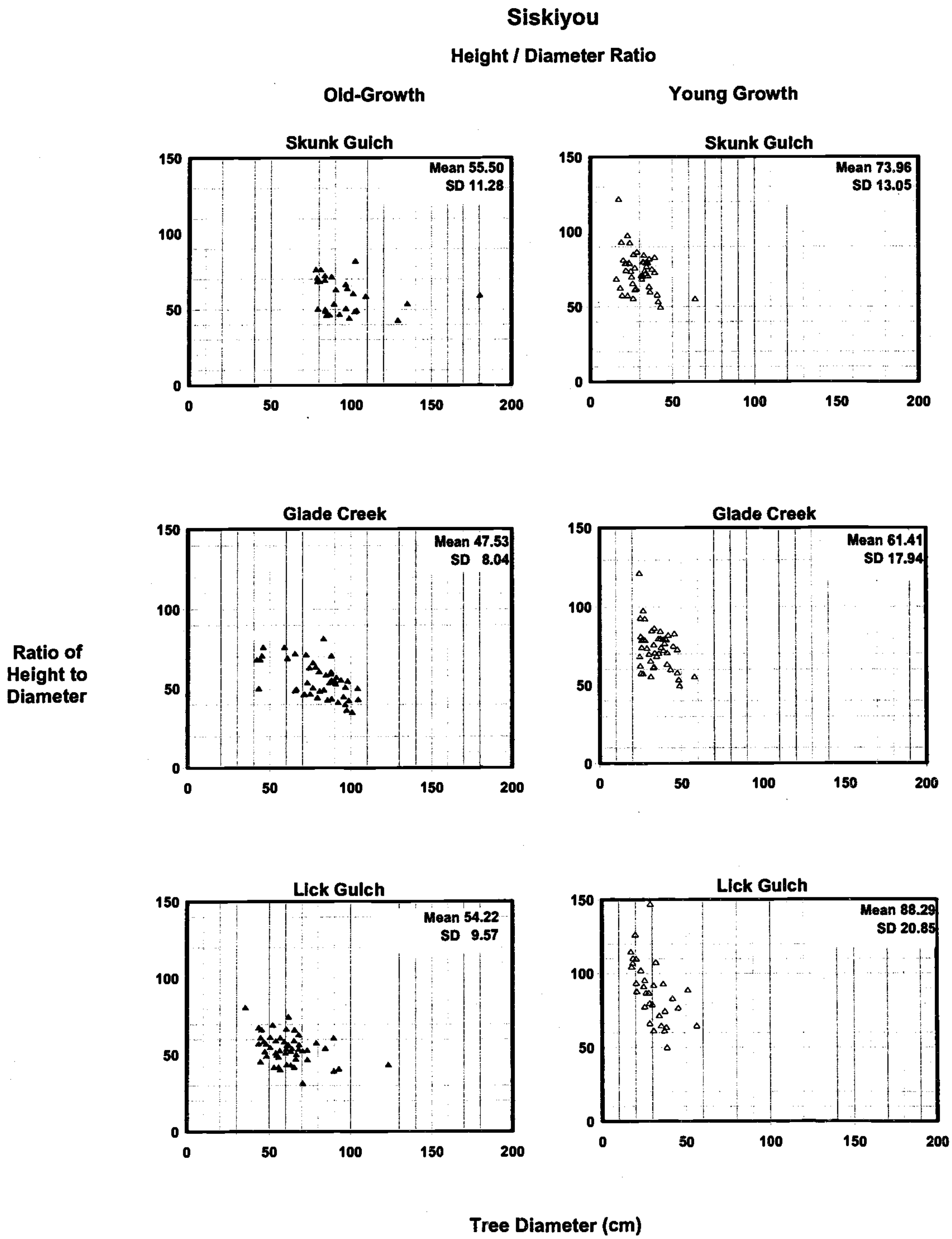
Figure 3.10 The ratio of tree height to diameter for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.



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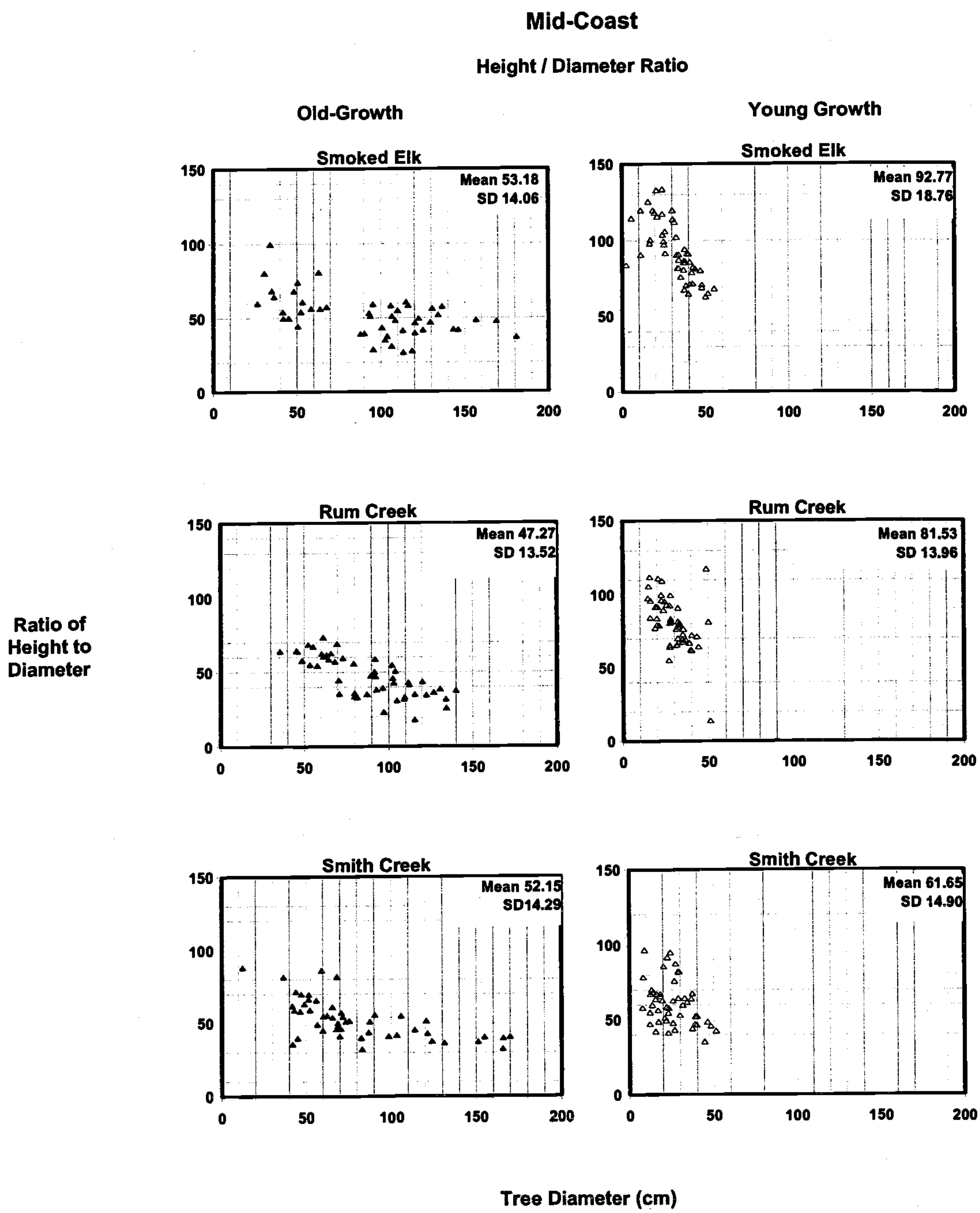

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Figure 3.10 The ratio of tree height to diameter for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

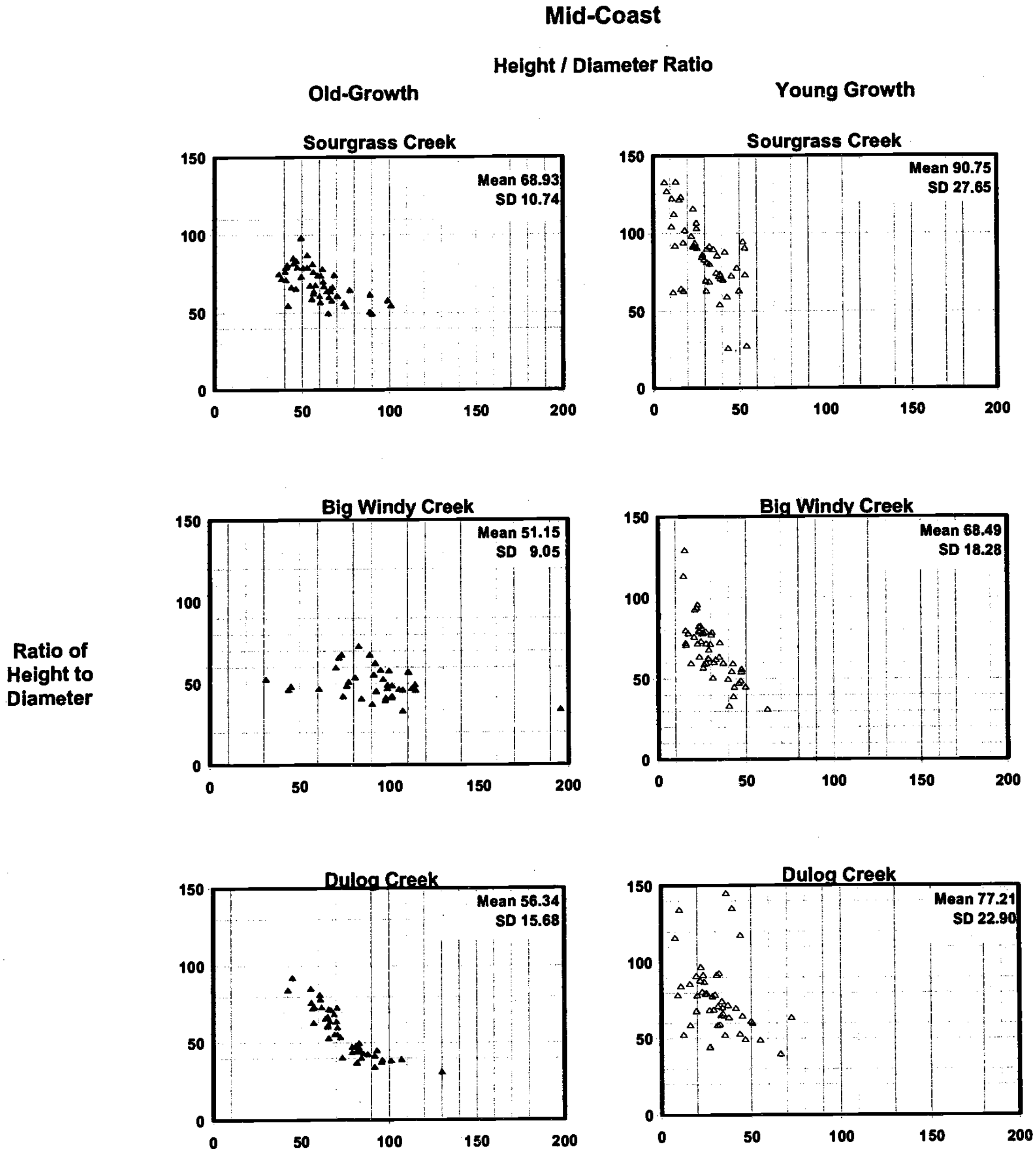

Figure 3.11 The ratio of tree height to live crown for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

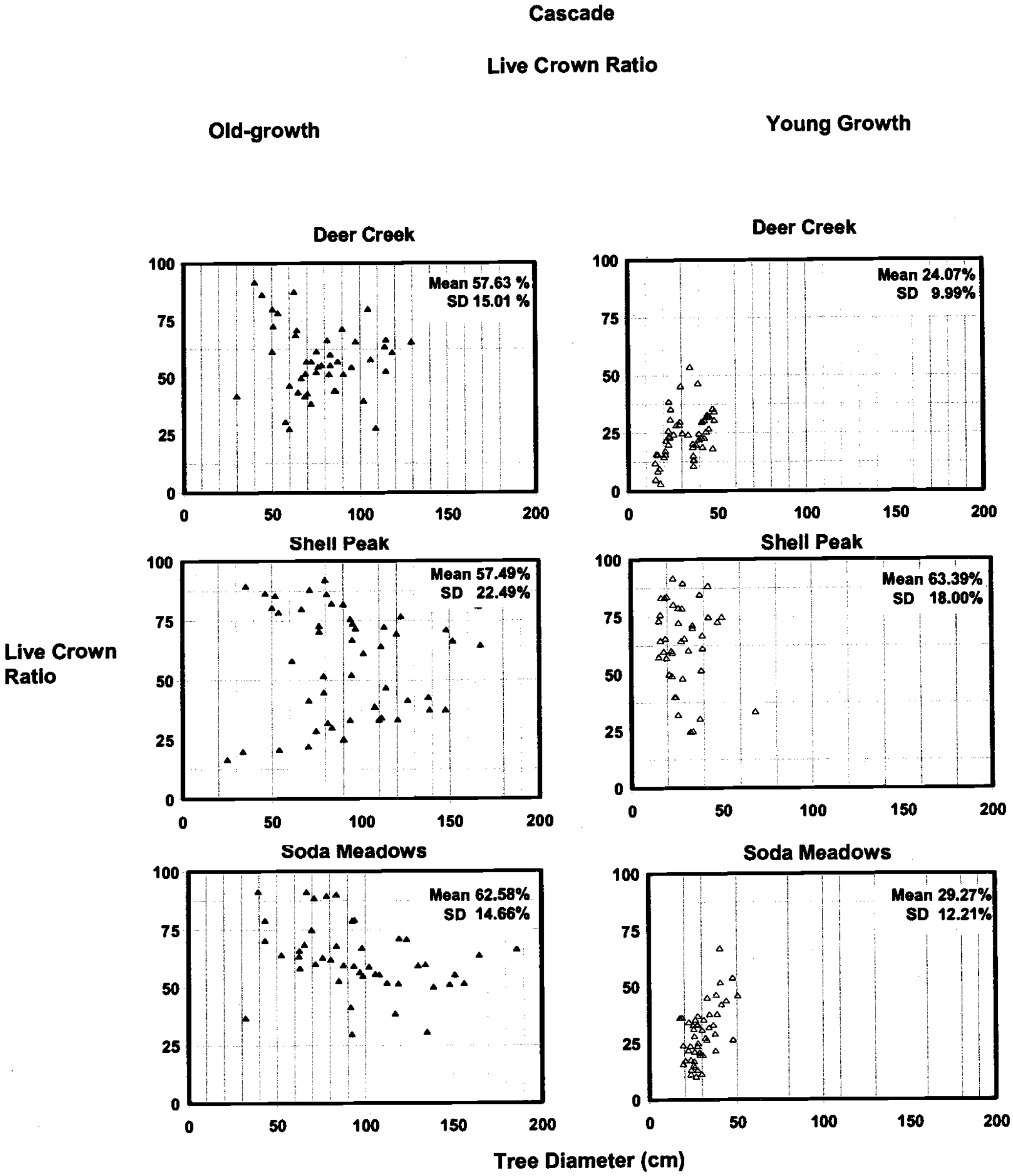

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Figure 3.11 The ratio of tree height to live crown for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

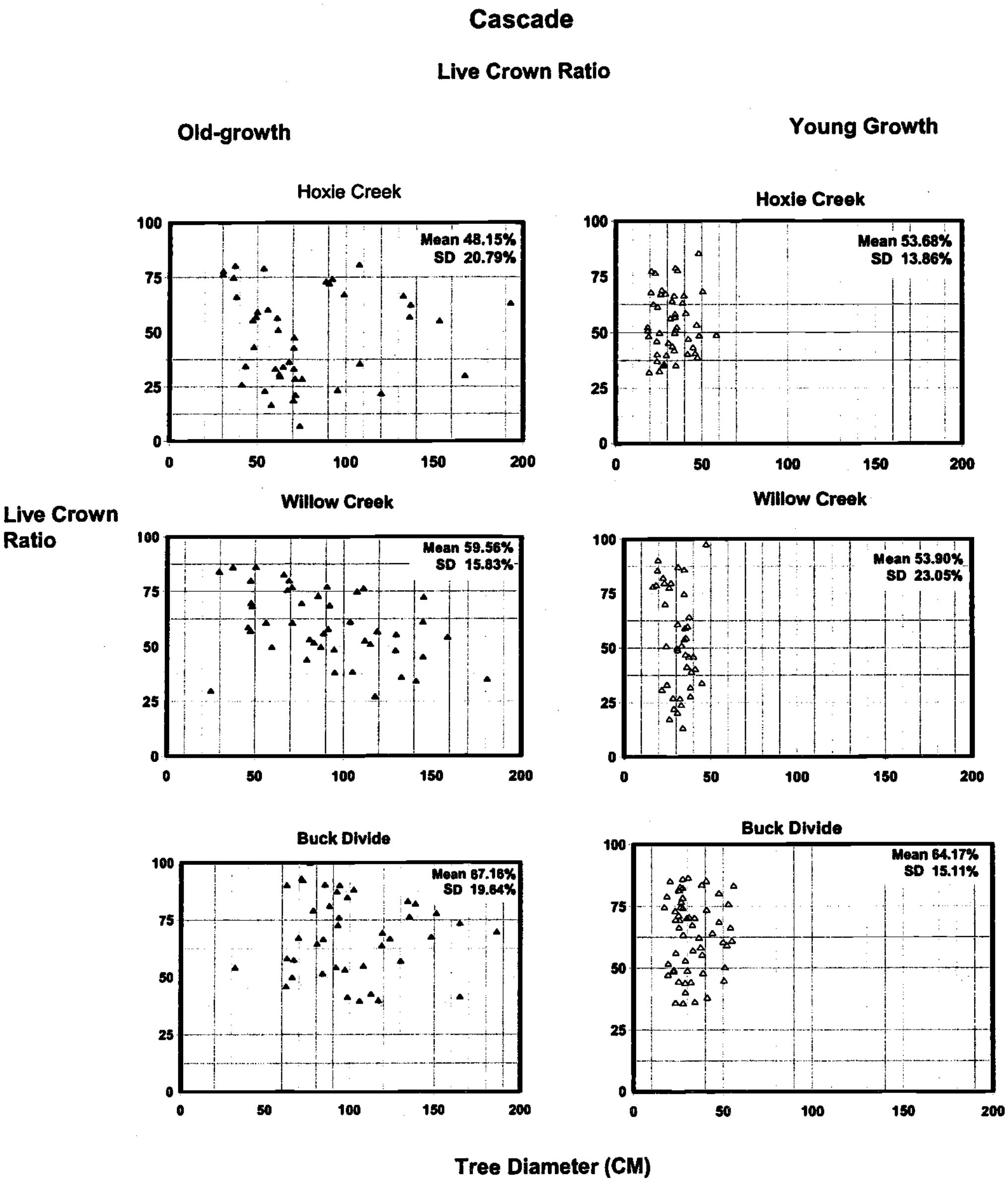

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Figure 3.11 The percent of tree height supporting live crown for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

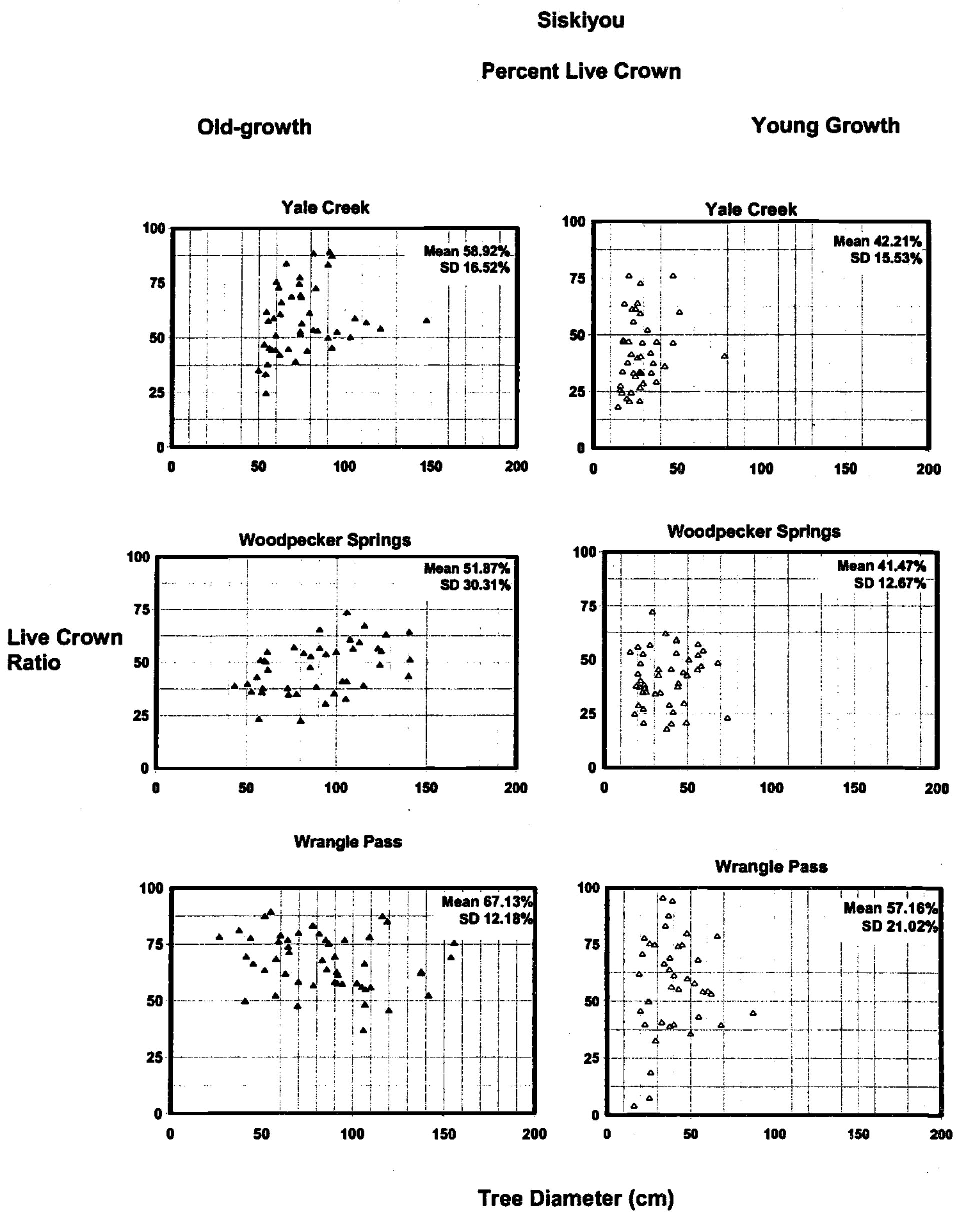

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Figure 3.11 The percent of tree height supporting live crown for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

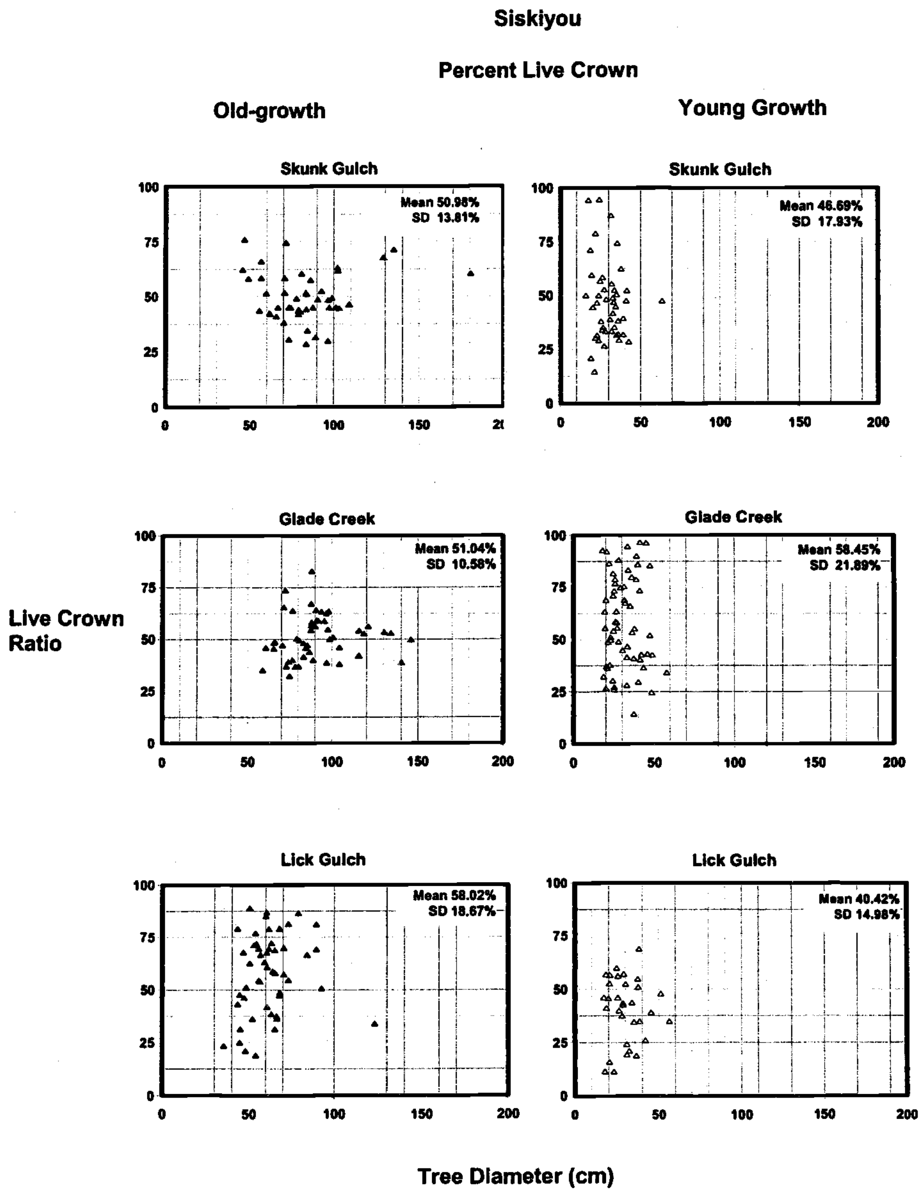

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Figure 3.11 The percent of tree height supporting live for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.

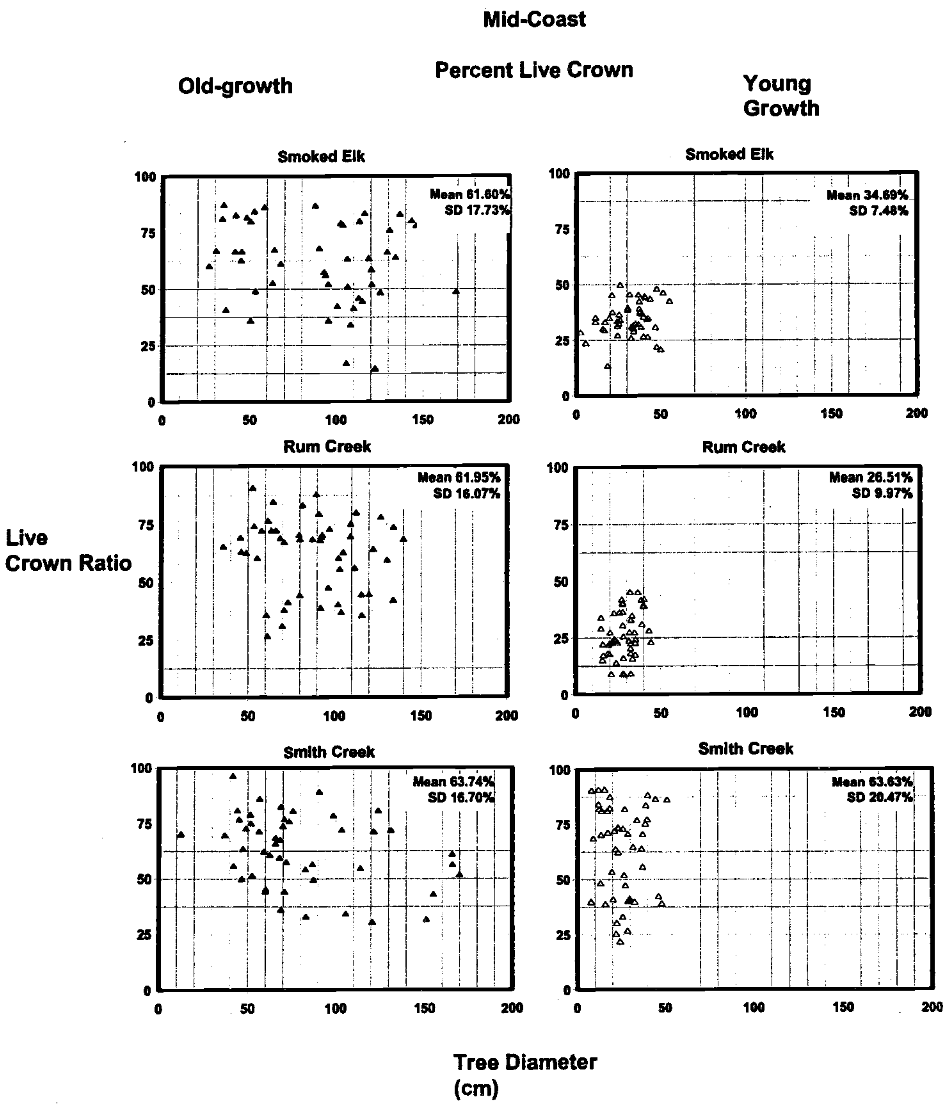

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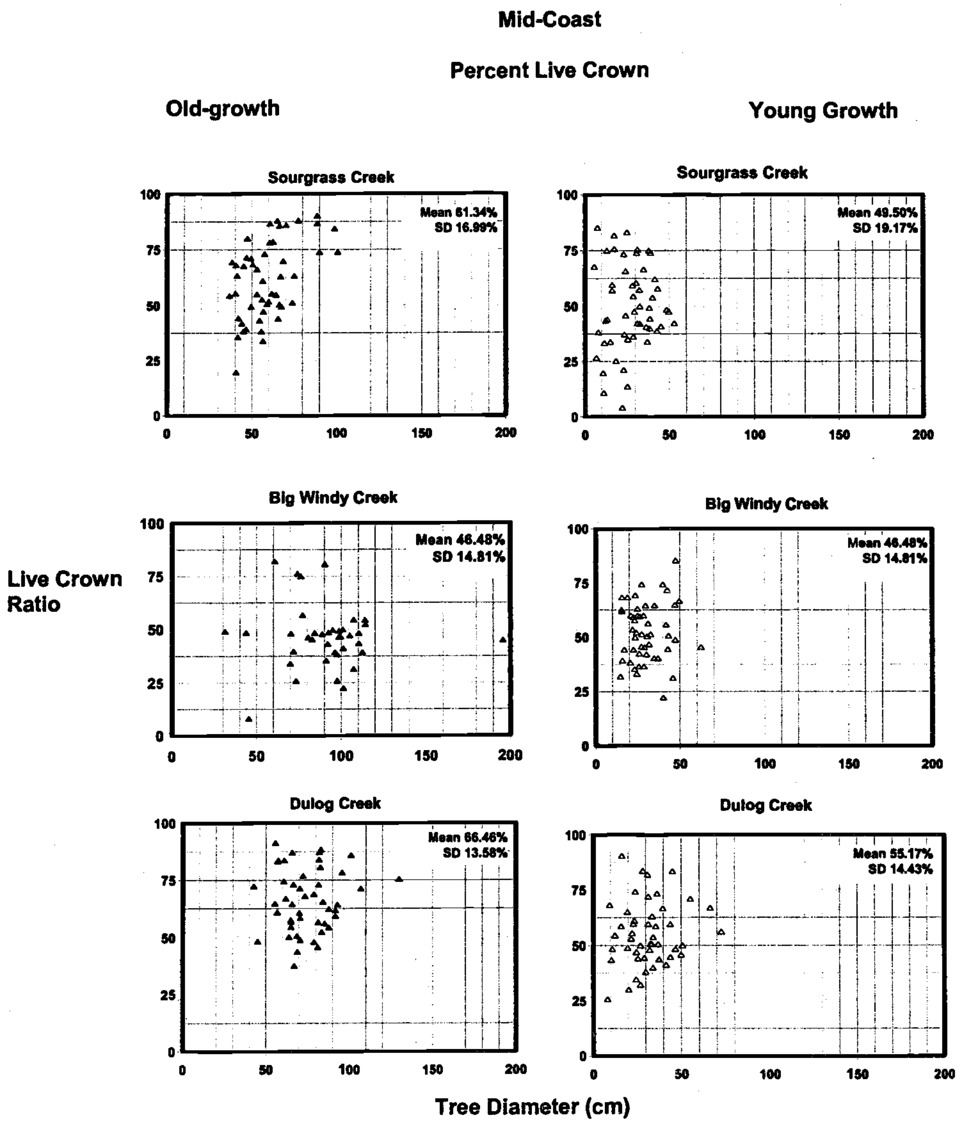
Figure 3.11 The percent of tree height supporting live crown for six old-growth and young stands in Cascade, Siskiyou and mid-Coast forests in southwestern Oregon.



SUMMARY

In southwestern Oregon, significant differences in the developmental patterns of young and old-growth stands existed. These differences were so great that tree growth and size comparisons, biased by measuring young trees at breast height rather than stump height, yielded no significant differences in results (Figure 3.1).

Agglomerative clustering clearly illustrated that the developmental patterns of the old-growth was statistically dissimilar to the young stand trees in all forest types. ANOVA revealed no significant difference in stand total basal area among old-growth sites (N= 18, R^2= .146, p= .306), nor trees/ha (R^2= .005, p= .966).

As in old growth, young stand total basal areas (N= 18, R^2 = .051, p= .678) and trees/ha (N= 18, R^2= .063, p= .614) did not significantly vary among sites, however significant differences in trees/ha existed between all young and old-growth stands (Cascade p= .001, Siskiyou p= .002, mid-Coast p= .002).

In old-growth stands, tree diameter and periodic annual basal area increment (PAI_{BA}, cm/yr) at age 50yrs was a reliable indicator of the tree's future potential size through, 200yrs and possibly longer. Thus, to a great extent a tree's likelihood of growing large and persisting to old-growth has been determined by age 50 (Cascade R^2= .439, Siskiyou R^2 = .399, mid-Coast R^2 = .667).

Tree *height:diameter* ratios averaged 51:1 (SD= 12.89), 56:1 (SD= 12.3) and 55:1 (SD= 15.0) for all trees in old-growth stands whereas young stand *height:diameter* ratios averaged 71:1 (SD= 22.187), 76:1 (SD= 25.3) and 79:1 (SD= 23.1) in Cascade, Siskiyou and mid-Coast stands respectively. Further, tree *height:live crown* ratios averaged 59:1 (SD= 18.9), 56:1 (SD= 18.7) and 61:1 (SD= 17.2) for all trees in old-growth stands and young stand tree *height:live crown* ratios averaged 48:1 (SE= 23.2), 48:1 (SD= 19.7) and 48:1 (SD= 19.6) in the Cascade, Siskiyou and mid-Coast stands respectively. These differences indicate that rather dramatic reductions in young stand densities are necessary for significant crown expansion to occur.

CHAPTER IV

CONCLUSION AND MANAGEMENT IMPLICATIONS

DISCUSSION

Comparison of Fire Dating Methods

As expected, point sample fire occurrence consistently yielded lower fire frequencies than composite sampling when conducted at the stand level. Point sample frequency analysis indicated approximately 8 times fewer fires than detected by composite sampling at the 8 hectare scale. For all sites, the mean composite fire frequency was 7yrs yet 53yrs for point fire frequencies, 87% greater fire frequency from the composite sampling than from the point sample.

At the 8ha scale, point sample fire frequencies clearly underestimate stand level fire occurrence, and composite intervals, without cross dating, presumptively overestimate occurrence. Therefore, in the absence of cross-dating each fire scar, a more likely estimate of fire occurrence can be obtained by grouping composite samples where scars cluster (+/- 3yrs) around a probable event (mid-point of a cluster of fires dated to approximately the same date). For all sites the probable estimate of fire occurrences averaged 11yrs but ranged from 3-50yrs. This is 4yrs greater than composite sample frequency and 42yrs less than the point frequency data.

Point samples established with certainty the minimum fire occurrence intervals. Not all fires burned with enough severity to cause scars on point samples trees or perhaps every fire did not burn throughout the 8ha stand. Also, where trees were damaged but survived fire while small (generally <20cm), they appeared to be more likely to record subsequent fires, presumably because the scar tissue covering the previous fire wound is thinner or less resistant to fire than the bark of undamaged trees.

Native American Burning and Fire Occurrence

Not only did natural disturbances play a role in shaping southwestern Oregon's forests, but the Native Americans of this area interacted with the ecosystem, shaping the landscape to promote the resource important to them. The use of fire by Native Americans to enhance the production of plants and animals is well documented (Pullen 1995, Lewis 1973).

Although this study did not attempt to distinguish between aboriginal burning and lightning ignited fires, it is interesting to note that the Cascade Soda Meadows and Deer Creek sites which recorded the highest fire occurrence of all areas is within a locality of documented Native American occupancy as evidenced by the discovery of Indian encampments and artifacts recovered during recent excavations conducted by Bureau of Land Management archeologist Dr. Kate Windthrope (personal communication). She identified these areas as having the richest concentration of known Native American cultural sites in the southwestern Oregon Cascades. This observation is consistent with the hypothesis that Native Americans frequently ignited fires (Hebda and Mathews 1984, Boyd 1986, Pullen 1995. In the Rocky Mountains of Colorado (Barrett and Arno, 1982), in Montana (Barrett 1980) and in California (Lewis 1973) speculated that Indian burning had a profound effect on the ecology of the area. The extent Native Americans intentionally ignited and controlled fire in southwestern Oregon is not known. However, in 1899 while surveying southwestern Oregon for the U.S. Geological Survey, Leiberg estimated that 95% of the fires in the Siskiyous were ignited by lightning and 5% by aboriginal settlers (Leiberg 1899).

Fire Suppression

Fire suppression efforts have been clearly effective in southwestern Oregon (Figure 4.2). Since 1920 over 5,265 lightning ignited wildfires were extinguished by fire suppression personnel within the study area. The average size reached only 6.5ha and less than 6% attained a size >400ha. It is presumed that, had these fires not been suppressed, many if not most would have continued to burn across the landscape, perhaps throughout the entire dry season (June-October) until extinguished by fall precipitation. Even during summer thunderstorms, it is likely that parts of the landscape would escape precipitation allowing for continued burning, perhaps extending across a large region. Prior to fire suppression and in the absence of artificial barriers, such as roads, farmland and European settlement these results suggest that fires burned perpetually across the landscape from the Cascades, Siskiyous and mid-Coast forests of southwestern Oregon. This conjecture is consistent with the fact that there were no differences between the average fire frequencies among Cascade, Siskiyou and mid-Coast forests.

Modification of Stand Structure by Fire

Fires likely meandered throughout the forests year after year, modifying the forest vegetation and structure with every pass. In time, only ecological process and species able to persist in the presence of frequent fire reproduced, creating forest ecosystems that are not only adapted to frequent fire but dependant upon it. However, as a result of fire suppression, forests that once burned regularly began to develop differently, and the ecological processes that sustained their productivity and resiliency are being dismantled rendering them vulnerable to both insects infestations, disease and catastrophic fire.

Historically, the low intensity fires served as a thinning mechanism, thereby regulating the density of the forests. In the absence of frequent fire, forest densities have been increasing at an unchecked rate. More slow growing trees are produced rather than fewer, faster growing trees resulting in differences in stand structure and composition. Trees growing at lower densities tend to be more resilient to insects and disease and exhibit more vigorous growth, eventually becoming large and tall, enhancing vertical and structural diversity of the forest. Also, increased inter-tree competition for resources reduces tree vigor, increasing their susceptibility to insect epidemics and harmful forest pathogens. Increasingly, organisms that thrived in the more biologically diverse forests provided by large trees with broad and lengthy crowns are becoming listed by federal biologist as potentially at risk of becoming threatened (FEMAT 1994).

In the absence of frequent fire, ponderosa pine trees that thrive in fire pron environments can become out competed by more shade tolerant species primarily Douglas-fir. As a result, ponderosa and sugar pine, which are ecological important for their contribution to the regions biological diversity and habitats, are rapidly declining in abundance throughout southwestern Oregon. Noteworthy, in the three year period 1993-1996, over 50 million board feet of dead overstory trees, predominately ponderosa pine, were salvaged harvested across the study area using helicopters.

Historically, ground fuel was routinely removed by frequent fires. In the absence of frequent fire, organic material has been accumulating to unprecedented levels, creating the potential for fires of greater intensity. High intensity fires are more likely to reduce seed bank propagules, diminish soil structure and cause tree mortality (Heinsehman 1981, Borchers and Perry 1990). Both young and old forests throughout southwestern Oregon are becoming increasingly at risk of encountering fires of greater intensity. In many old stands, fire suppression has facilitated an increase in understory vegetation creating ladder fuel, thereby increasing the potential for canopy damage and stand mortality in the event of a fire.

Stand Development and Structure

The old-growth forests analyzed here were the result of rather continuous tree establishment form 1700 until 1900, under conditions of chronic disturbance by fire. This is a quite different pattern of development than one where fire, or other disturbance, eliminates an entire stand and regeneration occurs promptly thereafter resulting in a relatively uniform age/size distribution of trees (Oliver and Larson 1990). A similar pattern of development was reported by Deal (1999) for a hemlock and spruce forest in southeast Alaska where wind caused frequent disturbances. Wind removes large trees from the overstory and provides favorable micro-sites for the growth of advanced regeneration or establishment and growth of new seedlings.

Because all of the old-growth forest ecosystems in the Cascades, Siskiyous and mid-Coast forests recorded similar fire occurrences, other factors must be responsible for the species compositional difference observed. The differences among these forest types is likely the result of variations in climate, insects and pathogens disturbance regimes. Wintertime climatic differences among areas may also influence species composition. In mid-Coast forests, climates maintained above freezing are known to facilitate tanoak regeneration (Jimmerson *et al.* 1996).

In Cascade stands, tree pathogens such as laminated root rot [*Phellinus weirii* (Murr.)Gilbon)], Armillaria root disease, [*Armillaria ostoyae* (Romagon. Herink)] annosus root rot (*Heterobasidion annosum* (Fr.) Bref.) and fir dwarf mistletoes (*Arceuthobium abietinum* Engelm.) and (*Arceuthobium douglasii* Engelm.) are common and selectively cause mortality modifying the species diversity of the stands. In all areas bark beetles are ubiquitous and often selectively kill trees during drought. For example, many of the overstory ponderosa pine trees growing in dense stands in the Siskiyous were killed by western pine beetles [Dendroctonus brevicomis Le Conte (*barberi* Hopkins] during a period of drought from 1987-1993. During the same period, mortality rates of understory white-fir were high in the Cascades from fir engraving beetles, *(Scolytus ventralis* LeConte.).

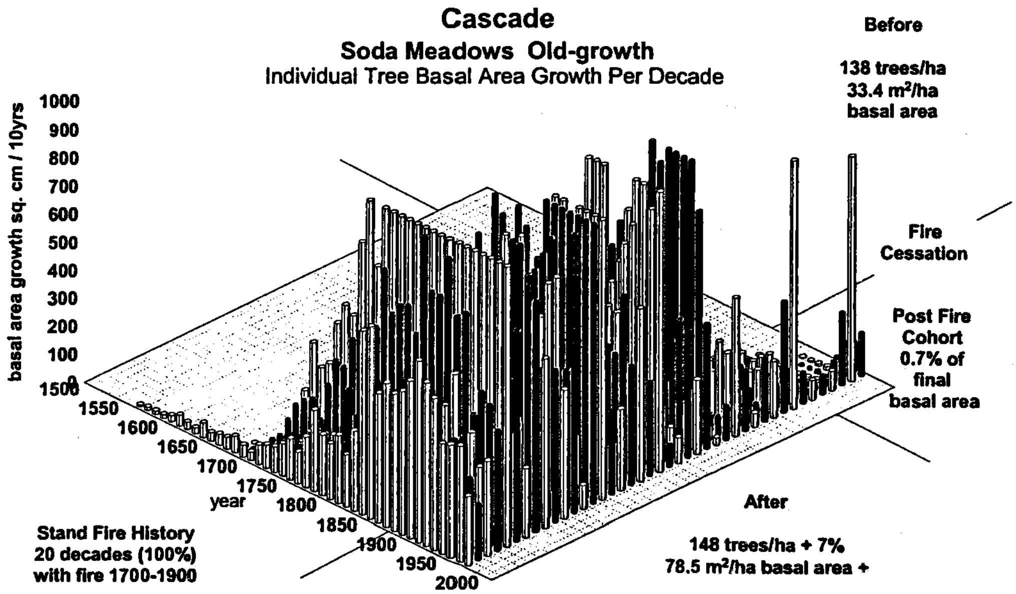
Cold soil temperatures and the prolonged winter snow pack is more conducive to Shasta fir regeneration. Although indications of fires were less prevalent in Shasta fir stands, evidence of low intensity fire during stand development was present, indicating that fire was a component of old-growth development even in high elevation forests. Because Shasta fir trees are susceptible to fire, fewer surviving trees would therefore be available to subsequently sample. The lack of point sample trees in the Shasta fir stands is probably a result of high intensity fires where fewer trees survived and persisted. The Cascade, Willow Creek and Buck Divide stands recorded comparatively fewer fires than other sites. These two sites are primarily comprised of white-fir which is characteristic of a less frequent fire regime more typical of higher elevations. Dulog Creek recorded notably fewer fire scars and fires than all other sites in the mid-Coast. Although the highest elevation of mid-Coast sites, Dulog Creek is dominated by dense tanoak indicative of a high intensity fire regime (Atzet 1989). These higher intensity fires would likely cause greater tree mortality, reducing the availability of extant samples to detect.

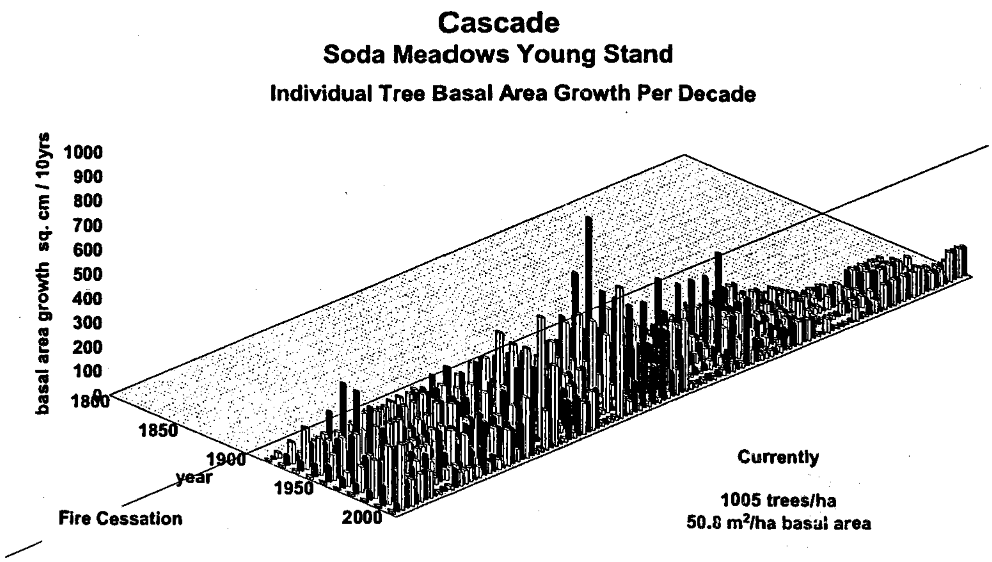
Because the old-growth stands in these studies developed in an active fire environment their habitats were not static, varying substantially. It seems likely that the greatest effects were on understory trees, shrubs and herbs since these frequent fires likely burned with low intensity. Historically, the low intensity fires served as a thinning mechanism, thereby regulating the density of the forests. In the absence of frequent fire, forest densities have been increasing at an unchecked rate. More slow growing trees are produced rather than fewer, faster growing trees resulting in differences in stand development, structure and composition. Thus, where management objectives are to promote late-successional habitats, early stand intervention and manipulation to alter developmental trajectories to more closely pattern old-growth structural development becomes important.

The young stands examined in this study are not on a trajectory that will likely lead to old-growth. At this time they improbably posses the vertical stability (*height:diameter* ratio) that will enable their persistence on the landscape for the hundreds of years necessary to become old-growth. Also, most are becoming homogeneous stands of overly dense, fire prone Douglas-fir, which curtails the development of species and habitat diversity. If young stands are to develop old-growth stand structures, silvicultural treatments appear to be imperative. Management designed to restore tree growth, large conifers and reduce the increasing risk of potentially damaging wild fire are warranted.

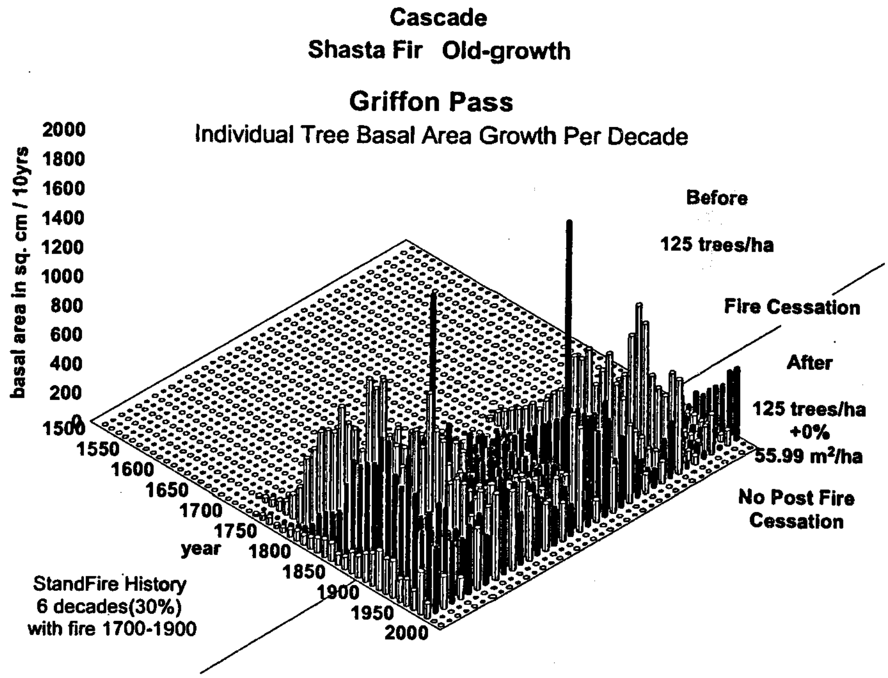
Figures 4.1 Compares young and old-growth stands that developed during an active fire environment and young stands that development in th absents of fire in Cascade, Siskiyou and mid-Coast sites prior to and after fire suppression.

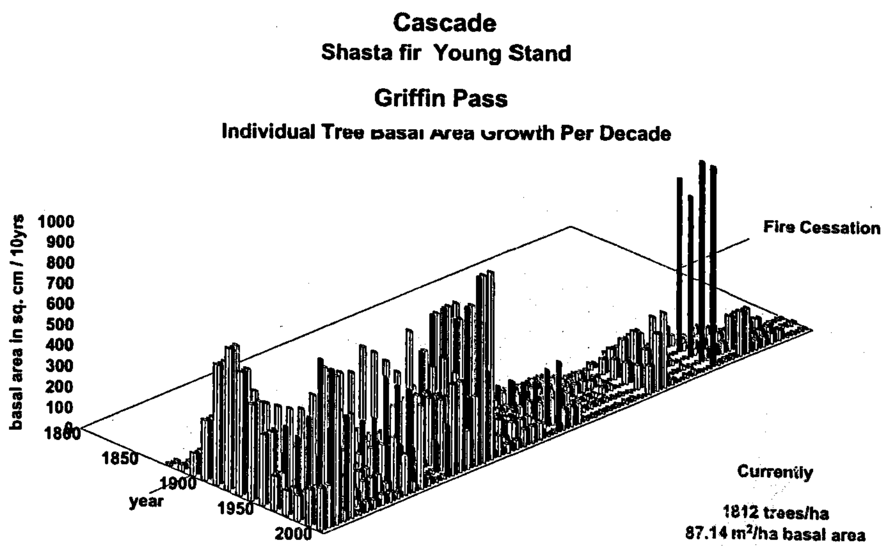
Figure 4.1 Stand development of an old-growth and young stand prior to, and after fire suppression in Cascade, Siskiyou and mid-Coast forests.



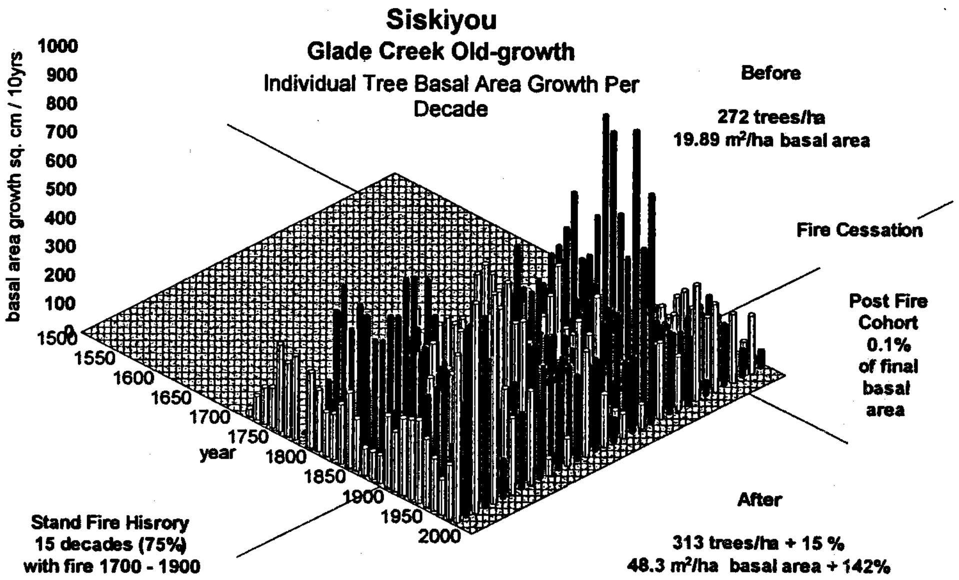


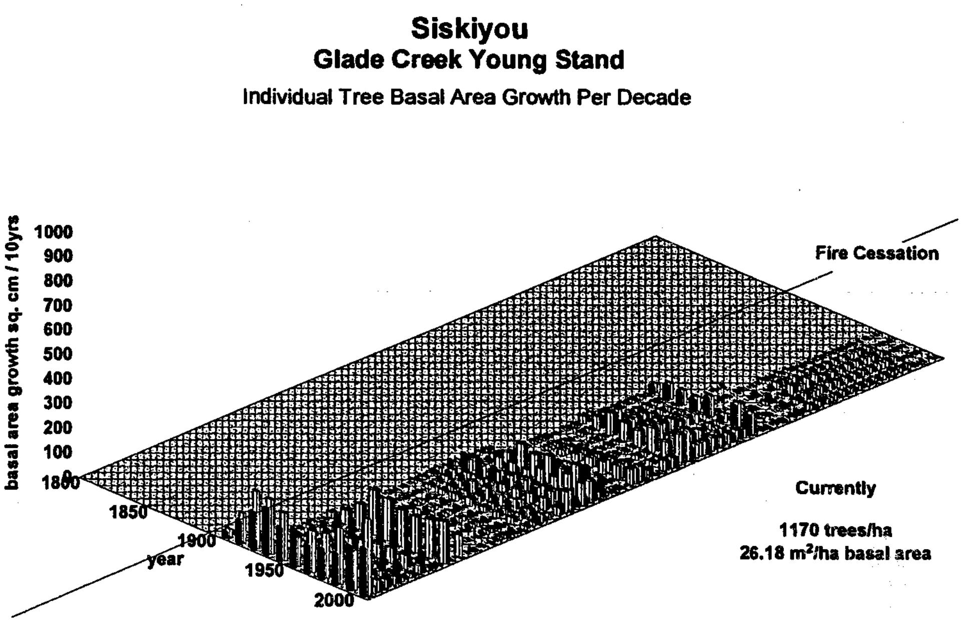
(Continued)
Figure 4.1 Stand development of an old-growth and young stand prior to, and after fire suppression in Cascade, Siskiyou and mid-Coast forests.



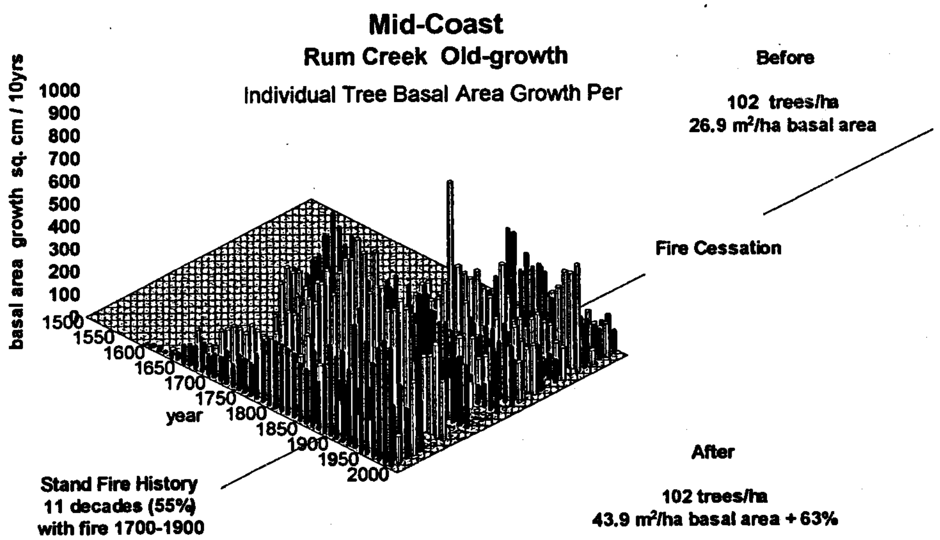


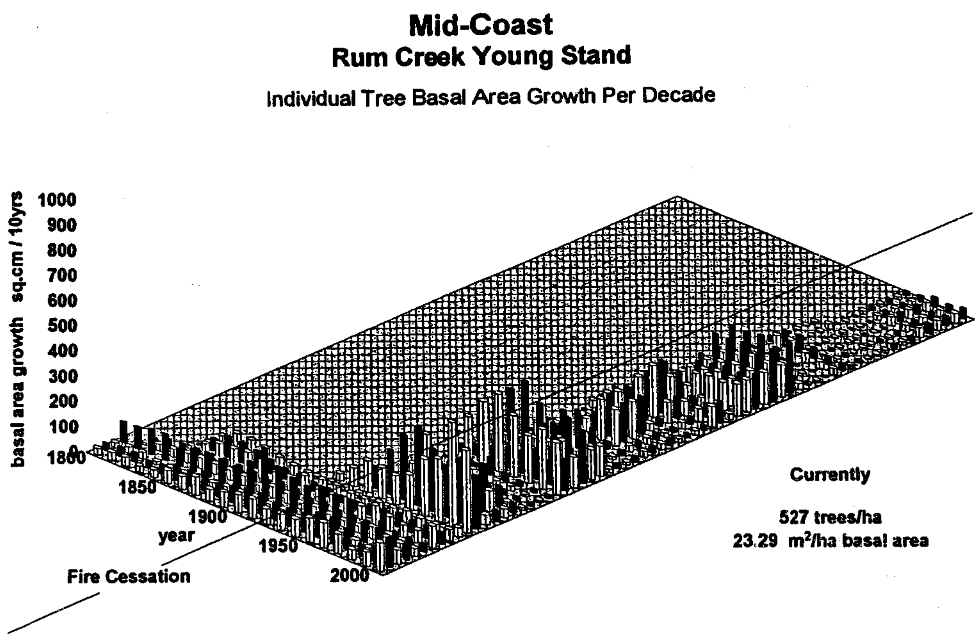
(Continued)
Figure 4.1 Stand development of an old-growth and young stand prior to, and after fire suppression in Cascade, Siskiyou and mid-Coast forests.





(Continued)
Figure 4.1 Stand development of an old-growth and young stand prior to, and after fire suppression in Cascade, Siskiyou and mid-Coast forests.





Fire and Oak Woodlands

Although not the focus of this study I believe it is worth mentioning that prior to fire suppression the oak woodlands typically mixed among the forests throughout southwestern Oregon, were variably subjected to frequent low intensity fires like the neighboring coniferous forests studied here. As a result of the clearing of land for development and agriculture, the abundance of oak woodlands communities has been greatly reduced throughout southwestern Oregon. Oak woodlands are known to be biologically diverse and have been identified as an important ecological component of the landscape (Riegel *et al.* 1992). Consequently, like coniferous stands, the ecology of oak woodlands is also being impacted by the lack of fire. It has been observed that hardwoods are being crowded out by the unabated advance of conifers and brush species that were once regulated by frequent fire. Additional research needs to focus on oak woodland ecology relative to its historic fire environment throughout southwestern Oregon.

The Life of a Southwestern Oregon Ponderosa Pine Tree

Recently, naturalist and good friend Dr. Pepper trail of Ashland, Oregon prepared a journal publication titled "Fire Scars: The Story of a Ponderosa Pine" a theoretical chronology of the development of a pine tree in southwestern Oregon. The dates and fire intensities are presumed, based on the Siskiyou fire history data recorded in during this research effort. Dr. Trail's imagination has made for some interesting and imaginable reading on the life story, as seen by a ponderosa pine tree in southwestern (Appendix B)

CONCLUSION

All of the old-growth stands studied developed under a regime of frequent fire until about 1900 after which there were few fires recorded (Figure 2.1). Throughout the 8ha old-growth study areas the fire frequencies ranged from 7-19yrs and averaged 11yrs, and about 66% of the decades recorded fire during stand development from 1700 to 1900. This is consistent with Agee's (1991) observation in the Applegate Valley near the Siskiyou sites where he recorded a fire frequence ranging from 12-59yrs (avg.= 17yrs) on 2ha.

These fire frequencies suggests that during the period 1700-1900 fires were of low intensity. During this period a large proportion of the seedlings were <25cm in diameter (Figure 2.3) and grew to diameters >30cm. About 57% of the trees with multiple fire scars recorded their first fire when they were <10cm diameter and nearly all trees recorded their first fire when they were <25cm diameter. Thus, the fires on these sites did not result in stand replacement. The fact that fires were so frequent, (Figure 2.1) suggested fuels were probably kept at low level, thus reducing the likelihood of intense fire.

As a result of frequent fire, recruitment and probably loss of trees were likely continuous (Table 2.1). Fire undoubtedly killed seedlings and some larger trees as well, however I found little evidence of snags or large trees that died prior to cutting the stands about 1980-1990 so I could not document mortality of trees on these sites. The dead stems of these trees may have been consumed by fires, especially during the period of frequent fire from 1850 to1900. Also, there may have been few trees on the plots in 1700 and the data documents the establishment of a new stand by a gradual accretion of trees under a sparse overstory.

It is not surprising that I could not find a clear correlation between tree establishment and fire occurrence. I could not evaluate the severity of fire on the 8ha plots. In the Cascades, cohorts were being recruited into the stands, on average, every 16yrs while fires were occurring about every 11yrs (Table 2.2). Also, fire can both hinder and facilitate establishment. Fire likely killed some seedlings and small trees and thus they were not present when the stands were cut in about 1980-1990. However, fires that remove all, or reduced thick litter layers on the forest floor and cover of shrubs or herbs, undoubtedly provide micro-sites conducive for seedling establishment and growth. A coincidence of fire and a good seed crop soon afterward, might account for periods of high recruitment. Periods where there was no fire would also favor survival and growth of established seedlings. The apparent lack of recruitment may be the result of fires killing a large number of seedlings or saplings in other years. Because I counted recruitment at the time when seedlings reach stump height there is no prior information on seedling establishment or morality. Depending on the characteristics of the micro-site which effect seedling height growth, such as local shading, moisture availability and the interference from competing vegetation, it could take 5-15+ years for seedlings to reach stump height.

There was a wide range of diameters and ages in the old growth stands (Figure 3.3a,b) indicating that seedling recruitment into these stands was ongoing and that these stands did not originate as a single cohorts. For example, in the Cascades the diameters of old-growth trees >250yrs ranged from 33-225cm. Similarly, in the Siskiyous they ranged from 72-272cm. Their range of ages were also quite broad. In the mid-Coast old-growth trees >100cm diameter ranged from 130-470yrs. However, the age range of the young stand trees was quite narrow, typically ranging 40-80yrs indicating that they originated rather abruptly leading to cohorts of similar trees (Figure 3.4). Because these stands were fully stocked, meaning that they entirely occupy their available growing space, additional recruitment is not likely without disturbance or intervention that crates new canopy gaps for seedlings to become established.

The diameter growth rates of young trees were significantly less than those of old-growth trees by age 30- 40yrs (Figure 3.5). Because tree growth is directly related to stand density (Reukema and Pienaar 1973), it appears that the old-growth stands were considerably less dense than the young stands even at early ages. Consequently, tree growth in the old-growth stands remained relatively higher than the young-stand trees through age 200yrs (Figure 3.1). Tappeiner *et al.* (1997), observed in the Oregon Coast Range a similar trend whereby old-growth trees developed at stand densities lower than those typical for young-growth stands at present.

Lower densities within the old-growth stands during early development apparently facilitated rapid growth of some trees which tended to be the largest trees in the stand at subsequent older ages (Figure 3.9). In these old-growth stands the largest tees at age 50yrs generally remained the largest trees in the stand through age 250yrs (Table 3.5). Because slower growing trees have a reduced potential to become relatively large at subsequent ages (100-250yrs), young stands comprised of relatively slow growing trees, will not achieve the size (diameters) as the once faster growing old-growth trees through 250yrs. A similar observation was described by Poage (2000) in central Oregon's Cost Range where 86 of 281 trees for which the diameters at age 50yrs were measured attained a diameter of >100cm by age 200yrs, and >50% of the old-growth trees at 200yrs had diameters at age 50yrs >50cm, whereas the small diameter old-growth trees generally remained relatively slow growing at age 200yrs. In addition, he observed that 95% of the old-growth trees with diameters <100cm at age 200yrs were <50cm at age 50yrs.

The patterns of development in the young stands diverged from that of the old-growth stands and by about age 20-30yrs, their long-term growth trajectories departed significantly (Figure 3.5). In addition, basal area growth in the old stands, which development during an active fire environment, had ongoing establishment and thinning leading to slow net basal area increases until about 1950 (Figure3.6), while in the young stands the basal areas increased rapidly, achieving the same basal areas observed in the old stands by 1950-1990 (Table 3.3). For example, the total basal area of the Siskiyous old-growth stands increased from 7.80-19.47m^2 from 1850-1900, and then from 34.18- 43.69m^2 from 1950-1990 while the young stands went from having no measurable basal area in 1900 to 47.83m^2 by 1990, which is greater than that of the old stands in 1990. In addition, the trees/ha in the old stands stayed relatively constant through time increasing only slightly over the past 100yrs, while all of the young stands showed abrupt increases in the numbers of trees from 1950-1990. In the mid-Coast for example, from 1800 to 1990 the old stands increased from an average 79-98 trees/ha while during an even shorter period from 1900-1990, the young stands increased on average from 97-740 trees/ha. As a result, the young stands in this study are developing significantly different stem and crown characteristics than those of the old-growth stands. Although the young and old stands had similar basal areas, the number of trees/ha in the young stands was significantly higher, leading to reduced tree *height:live crown* ratios and presumably higher tree *height:diameter* ratios. High levels of inter-tree competition as exhibited by these young stands, have been associated with diminished tree vigor, insect infestations and competition mortality (Carlson *et al.* 1982). It is likely that the currently abundant young forest stands will develop much different stand structures than those of old-growth stands studied.

Overall, the ratio of tree height to diameter, which is a measure of a tree's vertical stability and consequently its potential to persist on the landscape, averaged about 1:54 for the old-growth trees compared to1:75 for the young-growth trees. This is a strong indication that given their current form, few young-stand trees poses the necessary structural capability to withstand infrequent but inevitable violent wind events. Likewise, the percent of tree height supporting live crown of the young trees <100yrs has, on average, diminished below that of the old-growth trees. In the mid-Coast, the percent of tree height supporting live crown in the old trees was 61.%, whereas the young trees currently average only about 47%.

As a tree grows, the crown is added primarily to its top, and because the young-stand trees are approaching their maximum height, it remains uncertain if they will have the capability to recover sufficient live crowns to produce stand structures similar to those observed in the old-growth stand.

With the exception of the highest elevation stands dominated by Shasta fir where only 30-40% of the decades prior to 1900 encountered fire, no significant differences in overall fire occurrence were observed among Cascade, Siskiyou and mid-Coast old-growth stands. In southwestern Oregon, even mid-Coast forests dominated by tanoak, experience the same prolonged dry season as the inland Siskiyou and Cascade forests. Presumably fires that were ignited in any of the forest locations could meandered through and into adjacent forests, extending from the Cascades through the Siskiyous to the mid-Coast or vice versa providing a continues source of ignition to areas where fuel accumulations were dry and of sufficient quantity to sustain a fire. The fire interval may therefore be more of a function of fuel reaccumulations rather than a fire ignition.

In southwestern Oregon the lack of fire has replaced frequent fire as a significant ecological factor influencing stand development, altering historic forest structures, processes and functions. As a result, young stands are developing on a significantly different developmental pathway than old-growth stands. Therefore, the currently abundant young forest stands will likely develop profoundly different stand structures and species compositions than that of old-growth. Further, both the young and old forest stands studied are accreting in density, placing them at an increasing risk of accelerated density related mortality and increased fire severity.

Forest ecosystems have been evolving for thousands of years, thus their composition, structure, and ecological processes are essentially a product of their ongoing physical environment. Fire modifies stand characteristics and biological processes with each event by affecting; the distribution and density of surviving trees and shrubs, stand composition and growth, and stand structure and habitats for a variety of species (Agee 1991). Therefore, the wildlife and other organisms that old-growth forests sustain throughout southwestern Oregon are a consequence of the historic fire environment and during stand development.

The basic principle of forest ecosystem restoration is to identify the natural processes that sustained forest productivity, then manage the existing resources utilizing an understanding of the these principles. Therefore, silvicultural techniques, including harvesting, thinning and prescribed burning, can potentially be utilized in both old and young stands to achieve long-term developmental pathways that create, restore or partially mimic these historic processes that fires once imposed.

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APPENDICES

Appendix A

Historic Bureau of Land Management Fire suppression records

Year of Fire	Month of Fire	Hours From Discovery to Controlled	Acres of Burned Timber	Cause 1= lightning 2= logging 3= human	Board Feet of Timber Killed (mmbf)	Suppression Cost Total $
1952	July-August	159	38.4	3	100	2028
1952	Oct.-Nov.	540	34.8	2	0	53.5
1952	Oct-Nov.	650	52	2	15	90
1952	Sept.-Oct.	245	1.25	3	0	0
1952	Nov.	152	27	2	40	2000
1952	Nov.	223	9.5	2	0	2000
1952	Nov.	253	7	2	0	200
1952	Nov.	190	57.5	2	0	0
1952	July-Aug.	40	0.1	1	0	0
1952	June	68	0.2	1	0	0
1952	June	41	0.2	1	0	0
1952	July	23	0.12	1	0	0
1952	Aug.	5	0.25	1	0	0
1952	Sept.	33	0.25	1	0	0
1952	Aug.	142	0.25	1	0	0
1952	Aug.	73	0.5	1	0	92
1952	Aug.	63	0.5	1	0	64
1952	Aug.	116	6	1	0	108
1952	June	72	0.01	1	0	0
1952	Aug.	69	0.25	1	0	434.2
1951	June	340	4	2	6900	583.8
1952	Aug.	70	8	1	0	280
1952	Sept.	193	2.5	1	0	19.62
1952	Sept.	93	0.5	1	0	37.6
1952	April	105	80	1	0	0
1952	July	5	0.01	1	0	0

Appendix A (Continued)

Historic Bureau of Land Management Fire suppression records

Year of Fire	Month of Fire	Hours From Discovery to Controlled	Acres of Burned Timber	Cause 1= lightning 2= logging 3= human	Board Feet of Timber Killed (mmbf)	Suppression Cost Total $
1952	Sept.	23	0.1	1	0	0
1952	Aug.	68	0.1	1	25	174.58
1952	Aug.	13	0.24	1	0	33
1952	Aug.	48	0.01	1	0	0
1952	Aug.	101	0.01	1	0	17
1952	Sept.	41	0.01	1	0	0
1952	Aug.	36	0.01	1	0	0
1952	Aug.	67	0.12	1	0	150.1
1952	Sept.	17	0.01	1	0	0
1952	Sept.	40	0.03	1	0	0
1952	Sept.	53	0.1	1	0	0
1952	Aug.	48	0.1	1	0	0
1952	Sept.	19	0	1	0	25
1952	Aug.	27	0	1	0	45
1952	Aug.	16	0.75	1	1	252
1952	Aug.	14	0	1	0	35
1952	Aug.	23	0.1	3	0	0
1952	Oct.	70	0.5	3	0	0
1952	July	4.3	0.01	3	0	0
1952	dec	4	0.1	3	0	0
1952	June	27	0.01	3	0	0
1952	Oct.-Nov.	333	8	3	0	0
1952	Aug.-Sept.	254	218	3	0	346.58
1952	July	47	0.5	2	0	0
1952	July	15	0.1	2	0	0
1952	July-Aug.	845	102	2	0	265
1952	Aug.	60	0	1	0	0
1952	Aug.	16	0.75	1	1	0
1951	April	129	58	3	0	65

Appendix A (Continued)

Historic Bureau of Land Management Fire suppression records

Year of Fire	Month of Fire	Hours From Discovery to Controlled	Acres of Burned Timber	Cause 1= lightning 2= logging 3= human	Board Feet of Timber Killed (mmbf)	Suppression Cost Total $
1951	April	251	28	3	0	118.95
1951	April	204	215	2	0	65
1951	Sept.	78	1	2	0	0
1951	July-Aug.	343	2	2	0	275
1951	Sept.	313	199	2	9	6000.15
1951	Sept.	101	2	3	0	0
1951	Aug.	62	20	1	0	0
1951	Aug.	87	0.2	1	0	0
1951	Oct.	100	0..5	3	0	0
1951	Oct.	100	0.1	3	0	0
1951	Oct.	23	0.1	3	0	0
1951	July	93	2.5	3	0	402
1951	April	24	0.2	3	0	0
1951	July	43	0.001	1	0	0
1951	Oct.	52	0.1	3	0	0
1951	Oct.	52	0.1	3	0	0
1951	Oct.	80	3.5	3	0	0
1951	Sept.	14.25	0.1	3	0	0
1951	Sept.	21	0.75	3	0	0
1951	Aug.	201	0.4	2	0	318
1951	Aug.	52	0.01	1	0	0
1951	Aug.	0.5	0.1	3	0	0
1951	Aug.	78	0.4	2	0	0
1951	July	30	0.01	2	0	0
1951	April	61	0.01	3	0	0
1951	April	204	35	3	0	65.5
1951	June-Oct.	2884	4	2	6900	3747
1950	Oct.	18	0	3	0	0
1949	Sept.	124	0.02	1	0	0

Appendix A (Continued)

Historic Bureau of Land Management Fire suppression records

Year of Fire	Month of Fire	Hours From Discovery to Controlled	Acres of Burned Timber	Cause 1= lightning 2= logging 3= human	Board Feet of Timber Killed (mmbf)	Suppression Cost Total $
1948	July	29	10	3	0	0
1944	July	336	203	2	203	1590.96
1946	July	13	0	1	0	0
1946	June	18	0	1	0	0

Appendix B

FIRE SCARS by Pepper Trail Ph.D.

The author thanks Tom Sensenig of the Bureau of Land Management for sharing his path-breaking research on the fire history of southwestern Oregon, and David Steinfeld of the Forest Service for information on ponderosa pine biology. The trees of our region write their own histories year by year, recording the wet and the dry winters, the heat and the cold, and the fires, especially the fires, in their living bodies. The study of tree rings and fire scars has revealed a wealth of information about our forests, and has confirmed that frequent fire was almost universal throughout the Klamath-Siskiyou until the beginning of the twentieth century. The following is the life story of one ponderosa pine and its experiences with fire.

This Journal publication tilted **"Fire Scars: The Story of a Ponderosa Pine"** by Dr. Pepper Trail is a theoretical chronology of the development and life story of a pine tree in southwestern Oregon. Although not exact, the dates and fire intensities are presumed, based on the Siskiyou fire history data recorded in this research effort (Chapter II). I wish to thank Dr. Trail, for his imagination has transformed the sometimes perplexing research data into an intriguing and imaginable life story, as seen by an old-growth tree, in a land before time.

1723

Birth. On a wet day in the middle of April, the needles of an infant ponderosa pine pierced the sodden duff, and a tree was born. Eight months earlier, the seed had been whirled out its cone by a hot August wind and had flown spinning to a fortunate landing. Under the shade of an ancient and half-dead black oak, the seed had been quickly covered by ash from the fire that had worked its way across the valley just weeks before four hundred feet below, a creek rushed noisily north toward the Applegate River. One hundred feet above, a trail worn by the feet of deer, wolves, and Takelma people angled upward toward the ridgeline and over a low saddle into the next drainage. From the germinating tree, it was 30 feet to the black oak, 70 feet to a white pine, 82 feet to a young Douglas-fir, and 134 feet to an old ponderosa pine, its parent. No other large trees were near in the park-like forest of Pine Creek.

1732

Nine years old. The pine had grown well. It now stood over 10 feet tall, and was 4 inches across at its base. The oak above it was dead now, and the slow process of decay was sending a steady trickle of nutrients into the pine's roots. In September, a line of flames blew up over the ridge and swept down the slope. It was not a large fire, but it kindled more strongly in the pile of fallen bark heaped under the oak, and the side of the pine nearest the flames was scorched. In the following weeks, the strong young tree repaired itself with tough new bark. Hidden beneath that bark, the pine recorded its first fire scar.

1737

Fourteen years old. In the depths of winter, a starving porcupine waddled across the open expanse of snow to the young pine and laboriously began to climb. Reaching the topmost rosette of branches, it settled into place and began to gnaw. Within a few hours, the uppermost trunk of the pine was stripped of bark, and its growing tip was dead.

1747

Twenty-four years old. The pine had recovered well from its encounter with the porcupine. It now had two growing tips, curving upward gracefully like a wishbone, and in this year, it produced its first cones. In September, a slow-moving fire entered the little valley from below, one of the many started by the Takelma people at this time of year. It left a small scar on the pine as it passed.

1754

Thirty-one years old. An August lightning storm spread fires throughout the mountains. One of them moved through the valley and left its scar on the pine. Despite the hot, dry weather, it found little fuel to feed it, and was soon gone.

1755

Thirty-two years old. In the nutrient-rich ashes left by the fires of the previous summer, a white-fir had sprouted eight feet from the pine. In less than a year, it would grow to more than three feet tall.

1769

Forty-s ix years old. After three dry years in a row, fires burned hot across the mountains. One swept into the valley, driven by strong winds from the south. The pine received a thick fire scar when the nearby white-fir, unprotected by its thin bark, exploded into flames.

1770

Forty-seven years old. The pine lay down a broad growth ring, thanks to a wet winter and the death of the white-fir, which had become a deadly competitor for water and nutrients. It was a good year.

1784

Sixty-one years old. Another fire scar.

1794

Seventy-one years old. Another fire scar.

1800

Seventy-seven years old. Another fire scar.

1813

Ninety years old. Another fire scar.

1816

Ninety-three years old. A four-year old grizzly bear, recently driven into independence by its mother with bellows and slaps, entered the valley over the low saddle. Prickling with aggression, it reared to its hind legs and scraped deep vertical gashes in the pine's trunk with its four-inch claws.

1829

One hundred and six years old. Another fire scar.

1833

One hundred and ten years old. Another fire scar.

1841

One hundred and eighteen years old. Another fire scar.

1851

One hundred and twenty-eight years old. A different sort of people entered the valley for the first time. They carried pans and picks, and made strange metallic sounds

that kept the chickadees that nested high in the pine in a constant state of noisy outrage,

until she was shot. The men did not find what they were looking for, and by the end of the summer they were gone.

1862

One hundred and thirty-nine years old. Another fire scar. One hundred and forty-four years old. A new creature passed beneath the shadow of the pine. A flock of nearly 100 sheep was driven by on the trail toward the high meadows. In that autumn and many afterward, the creek ran brown and its deep pools filled with gravel washed down from high above.

1870

One hundred and forty-seven years old. Another fire scar.

1871

One hundred and forty-eight years old. At night, on silent feet, three women and eight children passed up the trail toward the mountains. They were the last Takelma people to ever walk the path along Pine Creek.

1883

One hundred and sixty years old. Another fire scar.

1889

One hundred and sixty-six years old. A group of loggers entered Pine Creek, and for weeks the valley rang with the sounds of axes and saws. When the men and their teams of horses departed, all that remained of the giant white pines were stumps. Most of the big ponderosa pines were also dragged away, but the double-headed pine was spared, its trunks too crooked for good timber.

1896

One hundred and seventy-three years old. Smoke lay thick across the mountains all summer and fall, as fires spread from the over-grazed high meadows and down into the lowest valleys. The flames flared higher as they passed through the valley of Pine Creek, feeding on the piles of limbs still left from the logging seven years before. The pine was badly scorched and some of its lower limbs were killed, but its crown, now over one hundred feet tall, remained high above the fire.

1897

One hundred and seventy-four years old. In the spring following the big fires, the slopes of the valley were dotted with the sprouts of white-fir, Douglas-fir, and ponderosa pine. Moving to an ancient rhythm, new life sprang from the ashes and began its race against the next return of fire in five or ten or twenty years. This time, unknown to all, fire would not return. But the plants continued the race all the same.

1954

Two hundred and thirty-one years old. In half a century without fire, the forest had changed more than in the previous thousand years. A grizzly bear would have had a hard time pushing through the dense young firs that covered the slopes; but of course the grizzlies had long ago disappeared. The pine's double head now rose above a tossing sea of branches, like a swimmer fighting for breath. Three white-firs and a Douglas-fir were crowded together within thirty feet of the old pine. In early September, smoke wreathed the pine's long needles for the first time in over fifty years. A great fire was burning on the other side of the mountains. For days, the valley echoed with the throbbing of propellers as planes lumbered south to deliver smoke jumpers and water to the fire. Finally, silence returned, and the smoke melted away. The fire had been defeated.

1972

Two hundred and forty-nine years old. In June, bulldozers entered the valley, blading a road along Pine Creek. After that, a gang of men appeared every morning, bringing laughter, curses, and the unimaginable noise of chainsaws and heavy machinery. They spent the summer executing a government timber sale. It was a selection cut, unusual for those years when clearcuts were the fashion. Almost all the large Douglas-fir were felled and yarded. Some white-fir were also cut, but most were left lying where they fell. The two-topped pine was spared for a second time, saved by its shape.

1973

Two hundred and fifty years old. Responding to the soil disturbance and the bright sunlight on the forest floor, seeds sprouted everywhere in the spring. A new round in the one-sided race began, and the pine fell farther behind.

1986

Two hundred and sixty-three years old. The pine' southern top was dying. Exposed to the sun, its needles lost water at a high rate, and the water could not be replaced. This was a drought year, like-the one before and the one before that. The densely-packed 93doghair94 firs sucked the water from the soil before it reached the pine, which was not alone in its trouble. Towering red spires were scattered across the mountains that year, the bodies of dead ponderosas. In August, a fast-moving thunderstorm burst over the valley, and a bolt of lightning forked down to ignite the tinder-dry needles of one of these corpses. The tree flared instantly, and a column of smoke rose into the sky. In less than two hours, a helicopter appeared from the east and dumped chemicals on the smoldering snag and the nearby brush. The fire was suppressed.

2001

Two hundred and seventy-eight years old. Death. Another drought year. In September, the hot exhaust pipe of a truck high in the mountains ignited a grass fire. Driven by a hot late-summer wind, the fire raced through the thick alien grasses lining the logging road with incredible speed. Within hours, it had grown to hundreds of acres in size. The dense dead branches of the crowded firs provided perfect ladders for the flames to climb into the forest canopy. By the time the fire swept over the saddle and into the valley, it was an inferno, leaping from crown to crown at a runner's pace. This year, the helicopters and the planes were already in battle elsewhere. There was little to stop this fire, and none of it would have been enough. Fire had never been gone from this landscape for so long. It returned, as it must. Long denied, it devoured. The twin tops of the pine flared incandescent, the arching wishbone outlined in flame. The pine died, as did all its seeds, and all its offspring. When everything had burned, the fire died too.

Among the ashes, a thin spine of blackened wood was alone left standing. It was the pine's fire-hardened heart, its final fire scar.
