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Fire History and Stand Development of a Douglas-fir/Hardwood Forest in Northern California

Abstract

This paper examines the relationship between historic fires and stand structure on three sites in Douglas-fir/hardwood forests within the Klamath National Forest, California. Fire scar, tree age, and basal area distributions were used to interpret stand history. Frequent fires of variable intensity resulted in varied stand structures on our study sites. Some stands were even-aged and -sized following a relatively intense fire, while others were multi-modal following moderate or low intensity fires. Stands with dominant trees 250+ years old have old-growth characteristics. These Douglas-fir dominated stands do not resemble those of western Oregon and Washington. Douglas-fir in our stands seems to respond to fire and appropriate environmental conditions for successful establishment. Stand development may be defined by coarse and medium scale gaps. Large uniform patches created by infrequent catastrophic fire are broken up by more frequent medium scale gap processes. The pre-settlement landscape was probably exceptionally patchy containing complex mosaics of different age and size Douglas-fir dominated stands.

Introduction

Fire's role in the establishment and development of Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) forests has been comparatively well-documented for northwestern Oregon and western Washington. Both north-south and west-east gradients reflect a pattern of generally increasing fire frequency and decreasing severity (Thornburgh 1969, Hemstrom and Franklin 1982, Yamaguchi 1986, Spies and Franklin 1989, Agee 1991a).

In west-central and southwestern Oregon a pattern of relatively frequent fire has been reported. These forests experience greater fire diversity ranging from infrequent stand replacing events with mean fire intervals [MFI] of 95-149 yrs (Means 1982, Stewart 1986, Morrison and Swanson 1990) to more frequent moderate or light surface fires having MFIs of 15-50 yrs (Atzet and Wheeler 1982, Agee 1991b). The ensuing stands often have more than one cohort and are multi-sized with more than one canopy layer.

Relatively little fire ecology research has been done in northwestern California Douglas-fir forests. The fire history study closest to our study sites was conducted by Adams (1980). He examined composites of Douglas-fir stumps in clearcuts on four sites from Gasquet to Mad River, California documenting increasing fire frequency with distance from the ocean and along a north to south gradient. Mean fire return intervals ranged from 21.4 years in Gasquet (north) to 12.7 years in Mad River (south).

Our objective was to assess fire history, age structure, and stand structure in several Douglas-fir/hardwood stands. We hypothesized that dominant and co-dominant cohorts became established following either stand-replacing fire or by gap-producing moderately severe surface fire. We further hypothesized that there was a significant difference in mean fire interval across the pre-settlement (approx. 1740-1849), settlement (approx. 1849-1905), and suppression (approx. 1905-1987) time periods.

Study Area

This study was conducted within the Salmon River Ranger District of the Klamath National Forest, California. Study sites were located on Hotelling Ridge, above the South Fork of the Salmon River. Slopes averaged 56% with elevations between 900 to 980 m.

The Salmon River area has mean temperatures of 36°C in summer and 2°C in winter. Normal annual precipitation is 1120 mm, with 90% occurring between October and May (records available from the Klamath National Forest, and Six Rivers National Forest, for Orleans). Summers are long and hot, with relatively severe fire weather occurring in July, August, and September. Thunderstorms accompanied by lightning take place occasionally during the summer months. Snow may fall in early October and last until May at higher elevations.

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Study sites were located in a Douglas-fir/hardwood forest (Bingham and Sawyer 1991) dominated by open upper canopies of Douglas-fir with scattered stems of sugar pine (*Pinus lambertiana* Dougl.). A subordinate canopy layer was dominated by tanoak (*Lithocarpus densiflora* [Hook. and Arn.] Rehd), madrone (*Arbutus menziesii* Pursh.), and canyon live oak (*Quercus chrysolepis* Leibm.). Dominant shrubs include hazel (*Corylus cornuta* Marsh.) and Oregon-grape (*Berberis nervosa* [Pursh.] Nutt.).

In late August, 1987 a series of lightning strikes ignited a complex of fires on the Klamath National Forest. These fires spread quickly and extensively, having variable intensities, but often burning into the crowns of stands of all tree sizes. A total of 110,000 ha burned. One of the Klamath complex fires, the Yellow Fire, burned on Hotelling Ridge and killed the majority of trees within the study plots. Salvage logging occurred in 1988 and 1989.

Methods

Three study sites were selected. Each site was considered to be visually representative of stand conditions in the area. Stands selected were consistent in aspect, slope, elevation, and dominant canopy trees. Examination of stumps showed abundant evidence of previous fires. Study sites ranged from 5 to 8 hectares. Site 1 and Site 2 were separated by approximately 0.5 km with Site 3 being 1.0 km west of Site 2.

Fire scar and tree age class data were obtained from Douglas-fir and sugar pine stumps. Three 30m diameter circular plots were established within each site. Stem cross-sections were collected from all stumps within plot boundaries. In addition, stem cross-sections were gathered from all other fire-scarred conifer stumps within the study site. All cross-sections were cut with a chain saw at an approximate height of 30 cm. Hardwood specimens were not collected because their poor condition made accurate determination of fire scar dates and tree ages impossible.

Cross-sections were prepared with a power planer and subsequently polished with a rotary sander. Successively finer grits of sandpaper, down to 360, were used to render an easily readable surface. Following preparation, the samples were examined using both a hand lens and a binocular microscope. Annual ring counts were made on one or more radii, depending on growth and ease of interpretability. Tree diameters were measured from prepared specimens and fire scar dates recorded. Fire scars were recognized using criteria described by McBride (1983).

Cross-dating of tree rings (Stokes and Smiley 1968) wasn't possible with most specimens, presumably because competition influenced radial growth more than climate. Scarring dates were affixed for fire scars on stumps with indeterminable 'bark' dates by matching fire scar intervals with those on stumps of known age. Established fire scar dates of all trees within a site were collated into a master fire chronology. Less reliable fire scar dates were adjusted using the techniques described by Arno and Sneck (1977). No scar date was adjusted more than ± 3 years. Only confirmed fire scar dates were used to calculate mean fire intervals.

Statistical Analysis

Descriptive statistics were used to report age structure, size structure, and fire history. We used inferential statistics to detect differences in mean fire interval across study sites and across time periods. We used multiple Kruskall-Wallis non-parametric tests on our data in lieu of analysis of variance because of untransformable heteroscedasticity.

Results

Fire histories varied among the three sites (Table 1). Four fires occurred on both sites 2 and 3; 1987, 1870, 1795, 1776. The 1987 fire was the only one to have occurred on all the sites. Site 1 also shares the 1849 fire with site 3. Table 2 lists mean fire intervals for the pre-settlement, settlement, suppression periods. There was no significant difference in mean fire interval between sites ($p = 0.388$), but there was a significant difference between periods ($p = 0.033$). The suppression period had significantly longer MFIs than the settlement and pre-settlement periods combined ($p = 0.010$), but there was no significant difference between the settlement and pre-settlement periods ($p = 0.686$).

The age of Douglas-fir stumps ranged from 47 to approximately 520 years, while sugar pine ages ranged from 60 to 251 years. The first twenty years of radial growth varied from 0.32 mm/yr, among highly suppressed trees on site 2, to 2.20 mm/yr among individuals established following a stand replacing fire in the late 1800's on site 1.

TABLE 1. Master fire chronology for study sites. Number of fire-scarred trees are listed by plot for each date.

	Site 1	Site 2	Site 3						
Date	Plot A	Plot B	Plot C	Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
1987									
1944	1	1							
1942					2				
1919				3					
1916								1	
1913								2	
1901					2				
1894		1	5						
1890				1	6	2			
1888									1
1882					2				
1870				1	10			1	
1868	1								
1862				1	6				
1860	1								
1855				2	4				
1854								2	
1849	1	1						2	
1842				1	1				
1839				2	3				
1835							1	1	
1834				1	1				
1828					4				
1820	2								
1818				1	4				
1811					1				
1810								2	
1806				1	2	1			
1797	1		1						
1795					4			5	
1785					1	1			
1783								1	
1776					4				1
1760					4				
1759							1		
1756			2						
1752								3	
1750	1	1							
1745	1	1							
1742				1	1				

Site 1 had two well-defined even-aged cohorts (Figure 1) in plots B and C. Two of the oldest individuals in Plot A germinated within 12 years of each other and may represent the remnants of an older cohort. Of the remaining 3 individuals, two trees have ages correlated with the two well-defined regeneration cohorts of plots B and C. Trees in plot B were mostly associated with the cohort which became established in about 1722. Individuals sampled in plot C were established over a 40 year period between 1892-1932.

Each of the plots in site 2 had well defined regeneration cohorts (Figure 2). The majority of older trees in plot A originated following an apparently high intensity, stand replacing fire around 1802. Only two trees, established in 1582 and approximately 1473 survived this fire. Four surviving trees were established, at even intervals, between 1837 and 1887. A second regeneration cohort began in about 1895. Plot B had a bi-modal age distribution, with the oldest trees germinating between 1717-1722. Establishment lasted approximately 50 years. Only one surviving tree was established between 1770 and 1910. Understory trees germinated after 1910 with regeneration continuing for 40 years. Plot C also had a bi-modal

TABLE 2. Means and ranges of fire intervals for each site. Data are reported for the pre-settlement, settlement, and suppression periods as well as for the complete chronology. Data are in years.

Site	Interval	Mean	Range
Site 1 (N = 11)			
Complete chronology	1745-1987	22.0	5-50
Pre-settlement	1745-1849	17.3	5-41
Settlement	1849-1894	15.0	8-26
Suppression	1894-1987	46.5	43-50
Site 2 (N = 19)			
Complete chronology	1742-1987	12.9	5-45
Pre-settlement	1742-1855	10.3	5-18
Settlement	1855-1901	9.2	7-12
Suppression	1901-1987	28.7	18-45
Site 2 (N = 13)			
Complete chronology	1752-1987	18.1	3-71
Pre-settlement	1752-1849	13.9	7-25
Settlement	1849-1913	16.0	5-25
Suppression	1913-1987	37.0	3-71

age distribution, but with only one third the tree density of plot B.

The age structure of combined plots in site 3 exhibited a bi-modal distribution (Figure 3). Plots A and C had single regeneration cohorts apparently initiated by a stand replacing fire in the late 1800's. Surviving seedlings in plot C became established over a 35 year period, while the regeneration period in plot A lasted 50 years. Dominant trees in plot B survived the late 1800 event which replaced stands in plots A and C. Plot B's age distribution may be best described as having occasional seedling establishment since 1800 with a well-defined cohort spanning 40 years centered in 1757.

Site 1 had an average of 54.6m²/ha of basal area with site 2 having 72.9m²/ha and site 3 having 38.4m²/ha. Each plot in site 1 had only one dominant cohort (Figure 1). The greatest basal area was concentrated in the dominant age cohort of plot B, centered around 1735.

Plot B of site 2 had more basal area then either plot A or plot C (Figure 2). Even though plot B has a bi-modal age distribution, it was overwhelmingly dominated by the cohort established in the mid-1770s. Plots A and C had relatively small basal areas spread across several cohorts.

A bi-modal distribution of basal area was found in site 3. Two groups can be distinguished among plots A and B and plots A and C. Basal area values were low, particularly for plots A and C.

Discussion

Mean fire return intervals resulting from this study further substantiate the trend for shorter MFIs in

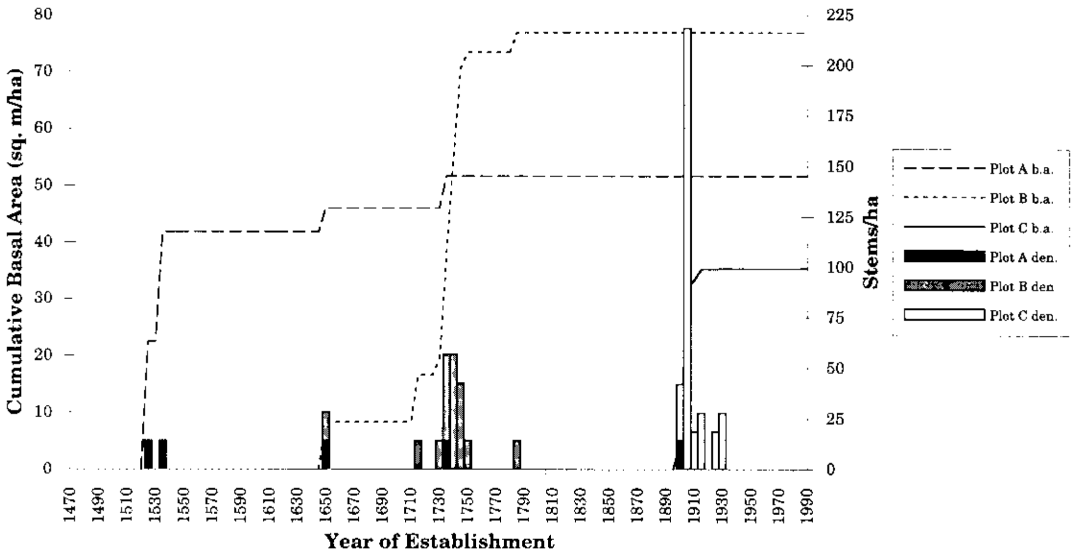

Figure 1. Age class and cumulative basal area distributions of trees established prior to the 1987 Yellow Fire from site 1, plots A-C. Data are compiled in 5-year classes.

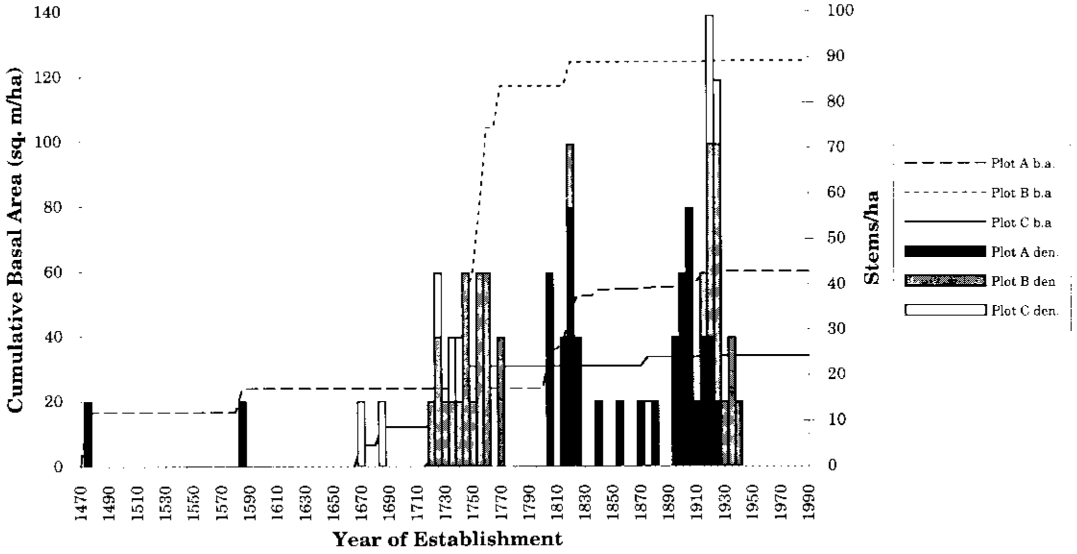

Figure 2. Age class and cumulative basal area distributions of trees estabished prior to the 1987 Yellow Fire from site 2, plots A-C. Data are compiled in 5-year classes.

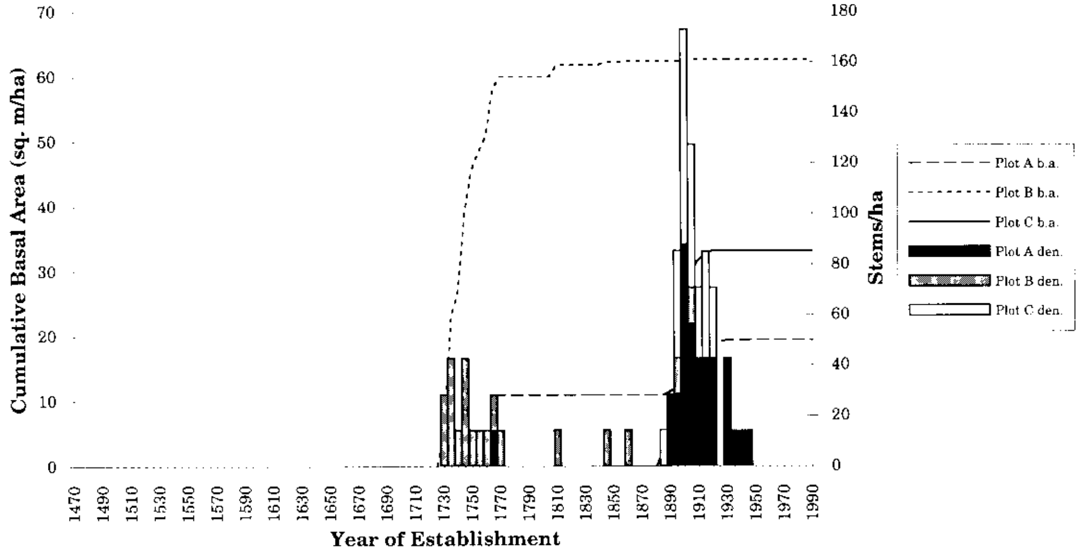

Figure 3. Age class and cumulative basal area distributions of trees established prior to the 1987 Yellow Fire from site 3, plots A-C. Data are compiled in 5-year classes.

the southern range of Douglas-fir. Our pre-suppression mean fire intervals of 10 to 17 years were considerably shorter than the 15-50 yr range reported for southern Oregon (Atzet and Wheeler 1982, Agee 1991b) and the 95-149 yr range in west-central Oregon (Means 1982, Stewart 1986, Morrison and Swanson 1990).

Our fire-free intervals were similar to those reported for mixed conifer forests in the Sierra Nevada (Show and Kotok 1924, Wagener 1961, Kilgore 1973). Reasons for this include comparable summer fire weather and sub-canopy and understory layers having sclerophyllous, pyrolytic species.

Natural establishment and survival of Douglas-fir on these sites was only occasionally successful. The combination of factors necessary for success may be relatively rare. Establishment may follow a pattern similar to that found in southwestern ponderosa pine (*Pinus ponderosa* Laws.). Cooper (1961) and White (1985) found that successful ponderosa pine regeneration was mainly dependent on appropriate soil moisture conditions and seedbed availability. Similar conditions may be prerequisite for successful Douglas-fir establishment on our sites. Douglas-fir's shade intolerance (Minore 1979) and need for mineral soil or burned seed beds (Stewart 1986) may explain the episodic pattern of regeneration on the sites examined in our study.

Age class distributions indicated that seedling establishment occurred frequently enough to allow perpetuation of these Douglas-fir dominated forests. On our sites, forest fires on about a 140 year interval provided sufficient growing space for the initiation of patches of Douglas-fir. On some plots it appeared that no residual trees survived fire, while on others the apparent fire severity was low enough to allow the survival of some overstory trees. The resulting multi-aged structures resembled those found in the Oregon Cascades (Means 1982). In our study, even-aged groups became established following liberation of growing space by moderately severe forest fires. Size distributions of these stands and fairly long recruitment periods account for the mosaic of even-aged groups of trees established after fires.

Age class distributions in plots on our sites were uni-modal or bi-modal. Similar patterns have been described in developing Engelmann spruce (*Picea engelmannii* Parry ex Engelm.; Day 1972, Whipple and Dix 1979) and Douglas-fir (Stewart 1986) stands. In these studies, deviation from a negative exponential size distribution was correlated with the spatial scale of disturbance and gap formation. Cumulative age and size curves are shaped at least as much, if not more by establishment patterns as by mortality (Parker and Peet 1984). The high fire frequency on our sites may inhibit the development of negative exponential size distributions.

Douglas-fir dominated stands in Idaho and Montana have been reported to be initially even-aged (Larson 1925, Shearer 1976, Tesch 1981). This was also true for some plots within our study sites. Full site occupancy by Douglas-fir was probably reached in 15 to 50 years following disturbance. Similar time periods were found in Douglas-fir forests of Oregon and Washington (Isaac 1943, Oliver 1981, Agee 1991a,b). Other workers have indicated that 60 to 150 years are required for full occupancy of Douglas-fir dominated mesic sites (Franklin and Waring 1980, Franklin and Hemstrom 1981, Means 1982). A shorter stand initiation phase may be expected in the southern range of Douglas-fir (Agee 1991a).

Site 2 had the greatest basal area. This is probably due to site 2 having fewer overstory killing fires and therefore more older trees. Frequent low severity surface fires may have also contributed to greater basal area by reducing competition for surviving overstory trees. In contrast, most of the basal area in site 1, plot C and site 3, plots A and C was associated with relatively young trees. It is likely that these ecologically dominant cohorts became established following fires intense enough to kill both the understory as well as most of the overstory.

Understories of Douglas-fir had been reinitiated on site 2 and site 3. Six of the nine plots examined had little or no regeneration present for periods of up to 240 years. Two explanations are possible for this condition. First, growing space may have been dominated by the first tree species to regenerate following disturbance (Egler 1954). In our stands, invading shrubs and residual hardwoods were likely early dominants following fire (Stuart *et al.* 1993). Shorter mean fire intervals, like those of site 2, may have favored establishment of Douglas-fir, because of the possible elimination of stored seed and residual sprouts of hardwoods. A second possibility is that higher intensities of the 1987 fire were experienced on sites 1 and 3 consuming all Douglas-fir seedling or saplings that may have been present, making them unavailable for sampling.

Spies and Franklin (1989) described gap dynamics in Pacific Northwest Douglas-fir forests, characterizing gaps as coarse or fine in scale. They defined coarse-scale gaps as having originated from large scale disturbances and as having relatively uniform even-aged stands of Douglas-fir. Fine scale patches result from small scale mortality such as self-thinning or pathogen infection. A forest subjected to fine scale mortality for a long enough period of time will result in a mosaic of openings and size classes typical of multi-aged stands.

The stands in our study differ from either alternative described by Spies and Franklin. Our data, instead represents a third gap type that can be characterized as medium scale resulting from low to moderate severity fires following a stand replacing disturbance. These fires left much of the Douglas-fir canopy intact and inhibited the progression towards fine scale dynamics by periodically killing small trees. The age distribution of these forests are the effect of both fire and stand development. As a result, the age structure in our stands is multi- modal and correlated with fire events rather than being all aged.

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Literature Cited

Adams, S. 1980. A fire history study. Unpublished report. The Redwood Sciences Laboratory, USFS. Pacific Southwest Forest and Range Experiment Station, Arcata, CA.

Agee, J. K. 1991a. Fire history of Douglas-fir forest of the Pacific Northwest. *In*: Wildlife and vegetation of unmanaged Douglas-fir forests. Edited by L. F. Fuggiero, K. B. Aubry. A. B. Carey. and M. H. Huff. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-285. pp. 25-38.

Agee, J. K. 1991b. Fire history along an elevational gradient in the Siskiyou Mountains, Oregon. Northwest Science 65: 188-199.

Arno, S. F. and K. M. Sneck. 1977. A method for determining fire history in coniferous forest of the mountainous west. USDA, For. Serv. Gen. Tech. Rep. INT-42.

Atzet, T., and D. L. Wheeler. 1982. Historical and ecological perspectives on fire activity in the Klamath Geological Province of the Rogue River and Siskiyou National Forests. USDA For. Serv., Pac. Northwest Reg.. Portland, OR, Pub. R-6-Range-102. 16p.

Bingham, B. B., and J. O. Sawyer. 1991. Distinctive features and definitions of young, mature and old- growth Douglas-fir/hardwood forest. *In*: Wildlife and vegetation of unmanaged Douglas-fir forests. Edited by L. F. Ruggiero, K. B. Aubry, A. B. Carey. and M. H. Huff. USDA For. Serv. Gen. Tech. Rep. PNW-CTR-285.

Cooper. C. F. 1961. Pattern in ponderosa pine forest. Ecology 42: 493-499.

Day R. J. 1972. Stand structure, succession, and use of Southern Alberta's Rocky Mountain forest. Ecology 53: 472-478.

Egler, F. E. 1954. Vegetation science concepts I. Initial floristic composition. A factor in old-field vegetation development. Vegetatio 4: 412-417.

Franklin, J. F.. and M. A. Hemstrom. 1981. Aspects of succession in coniferous forest of the Pacific Northwest. *In*: Forest succession, concepts and application. pp. 212-229. Edited by D. C. West, H. H. Shugart, and D. B. Botkin. Springer-Verlag, New York.

Franklin, J. F., and R. H. Waring. 1980. Distinctive features of the northwestern coniferous forest: development, structure, and function. *In*: Forest: fresh perspectives from ecosystem analysis. Proceedings of the 4th Annual Biology Colloquium. pp. 59-88. Edited by R. H. Waring. Oregon State University Press. Corvallis. OR.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forest in Mount Rainier National Park. Quat. Res. 18: 32-57.

Issac, L. 1943. Vegetative succession following logging in the Douglas-fir region with special reference to fire. J. For. 38: 716-721.

Kilgore, B. 1973. The ecological role of fire in Sierran conifer forest: its application to national park management. Quat. Res. 3: 496-513.

Larson, J. A. 1925. Natural reproduction after forest fires in northern Idaho. J. Agric Res. 30: 1177-1197.

McBride, J. R. 1983. Analysis of tree rings and fire scars to establish fire history. Tree Ring Bull. 43: 51-67.

Means. J. E. 1982. Development history of dry coniferous forest in the central western Cascade range of Oregon. *In*: Forest succession and stand development research in the Northwest. Proceedings of the symposium of the northwest Scientific Association Annual Meetings, March 26, 1981. Edited by J. E. Means. Forest Resource Laboratory, School of Forestry, Oregon State University. pp. 142-158.

Minore, D. 1979. Comparative autecological characteristics of northwestern tree species: A literature review, USDA For. Serv. Gen. Tech. Rep. PNW: 87.

Morrison, P., and F. Swanson. 1990. Fire history in two forest ecosystems of central western Cascades of Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-254.

Oliver, C. D. 1981. Forest development in North America following major disturbances. For. Ecol. Manage. 3:153-168.

Parker, A. J., and R. K. Peet. 1984. Size and age structure of conifer forest. Ecology 65: 1685-1689.

Shearer, R. C. 1976. Early establishment of conifers following prescribed broadcast burning in western larch/Douglas-fir forest. Proceedings of Tall Timber Fire Ecology Conference. 14: 481-500.

Show, S. B., and E. I. Kotok. 1924. The role of fire in the California pine forest. USDA Bull. 1294.

Spies, T. A., J. F. Franklin 1989. Gap characteristics and vegetation response in coniferous forests of the Pacific Northwest. Ecology 70: 543-545.

Stewart, G. H. 1986. Population dynamics of a montane conifer forest, western Cascade Range, Oregon, USA. Ecology 67: 534-544.

Stokes, M. A. and T. L. Smiley. 1968. An introduction to tree-ring dating. Univ. Chicago Press, Chicago. 73 pp.

Stuart, J. D., M. Grifantini, and L. Fox III. 1993. Early successional pathways following wildfire and subsequent silvicultural treatment in Douglas/fir hardwood forests, NW California. For. Sci. 39(3):561-572.

Tesch, S. D. 1981. Comparative stand development in old growth Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) forest in western Montana. Can. J. For. Res. 11: 82-89.

Thornburgh, D. A. 1969. Dynamics of the true fir-hemlock forest of the western slope of the Washington Cascade range. Ph.D. dissertation, University of Washington, College of Forest Resources, Seattle, WA.

Wagener, W. W. 1961. Past fire incidence in Sierra Nevada forest. J. For. Oct. 1961. pp. 739-747.

Whipple, S. A., and R. L. Dix. 1979. Age structure and successional dynamics of a Colorado subalpine forest. American Midland Naturalist, 101: 142-157.

White, A. S. 1985. Pre-settlement regeneration patterns in a Southwestern ponderosa pine stand. Ecology 55:589-594.

Yamaguchi, D. K. 1986. The development of old-growth Douglas-fir forests northeast of Mount St. Helens, Washington, following an 1480 eruption. Seattle: University of Washington. 100p. Ph.D. dissertation.

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