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Effects of Multiple Fires on the Structure of Southwestern Washington Forests

Abstract

Fire frequency, intensity, and size can influence the nature of forest development, with potentially profound effects on ecosystem processes and the abundance of native species. The effect of an intense wildfire and subsequent severe fires within a short period (reburns) on forest establishment, composition, and structure was examined in the 16,000 ha Siouxon Creek watershed in the western Cascades of southern Washington. Evidence of large intense fires and small patchy fires was found in the watershed, with 4 fires occurring since 1900. Tree establishment was rapid and abundant throughout most of the area burned in the 1902 fire, possibly from survival of on-site seed sources. Tree establishment was delayed on most reburns and corresponded with years of abundant regional Douglas-fir (*Pseudotsuga menziesii*) cone production, indicating off-site sources of seed. Western hemlock (*Tsuga heterophylla*) was less abundant on reburns than on the 1902 burn. The ranges of Douglas-fir ages within stands were greater on reburns than on single burns, but fire frequency effects could not be distinguished from potential stand age and composition effects. There were no clear patterns of tree species abundance related to presumed dispersal distances of up to 3 km from unburned forest. Fire frequency, topography, and seed source had important effects on forest structure and composition across the watershed.

Introduction

Wildfire is the primary natural disturbance in the forests of the Cascade Range (Munger 1930, Franklin and Hemstrom 1981), but little is known about the effect of fire frequency on forest composition and structure. Understanding the role of fire in forest development is crucial if we wish to maintain native species and ecosystem processes (Hansen et al. 1991). Although fire on the west side of the Cascade Range is usually described as infrequent and catastrophic, many large burns experienced repeated high-intensity fires ("reburns") within decades of the initial catastrophic fire (Agee 1993). Compared to forest development after single intense fire events, tree establishment on reburns is often sparse or nonexistent for decades after the last fire (Hofmann 1917, Isaac and Meagher 1936, Larsen 1925). It is unknown whether poor dispersal of tree seeds into large burns, poor tree regeneration caused by degraded soil properties, or some other factor are causes of slow forest development on reburns. Reburn fires can be more intense, and therefore may have greater effects, than the original burns in Douglas-fir forests because recently-burned forests often have greater amounts of fuel than mature forests (Agee and Huff 1987). Indeed, repeated wildfire has been hypothesized as a factor causing slow establishment of many of the old-growth forests in the Cascades that originated around 500 years ago (Franklin and Hemstrom 1981).

The size and shape of fires, and the composition of surrounding forests, may have important effects on forest development within large burns. Seed dispersal typically declines with distance from seed-bearing adults, but dispersal curves vary dramatically among species (Harper 1977), potentially influencing forest composition at large spatial scales. Although the density of natural tree regeneration on clear-cuts in the Cascades declines predictably with distance from the forest edge (Isaac 1943), some studies have found copious regeneration many kilometers from the edges of large burns (Hofmann 1917, Isaac and Meagher 1936).

The purpose of this study was to characterize 1) the fire history of a watershed in which multiple fire events were known to have occurred and 2) compare the age structure, size structure, and tree composition on sites that experienced a single severe fire in 1902 ("single burn" sites) with sites that burned in 1902 and in subsequent severe fires within 30 years of the 1902 fire ("reburn" sites). The focus of the study was on the Siouxon Creek watershed of southern Washington.

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Methods

Study Area Description

The Siouxon watershed is located on the west side of the southern Cascade Range of Washington, centered at 122°15'W latitude and 46°00'N longitude, about 24 km south of Mt. St. Helens. The study area of 16,000 hectares included most of the Siouxon Creek and North Siouxon Creek drainages and portions of the North Fork of the Lewis River drainage (currently Yale Reservoir) across from the town of Yale, WA. Both Siouxon creeks drain to the west into Yale Reservoir. Topography is moderately steep and dissected, with elevations ranging from 149 m at the surface of Yale Reservoir to 1271 m at the summit of Siouxon Peak. Glacial tills are found in the main Siouxon drainages and at the heads of many Siouxon tributaries (Mundorff 1984). The moist temperate climate is characterized by generally mild wet winters and warm dry summers. Annual precipitation near the town of Cougar averages 292 cm (National Climatic Center 1932-87), with a continuous winter snowpack forming above about 1000 m (Topik et al. 1986).

Vegetation in the study area falls into two zones. The *Tsuga heterophylla* Zone, dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), occurs below about 1000 m. The *Abies amabilis* Zone, dominated by Pacific silver fir (*Abies amabilis* Dougl. Forbes) and noble fir (*Abies procera* Rehder), occurs above 1000 m (Topik et al. 1986). The bulk of the study area had seen little forest management activity.

Fire History

The fire history of the study area was reconstructed using historical forest-type maps, written accounts, aerial and panoramic photographs, and field samples of dominant tree ages. The objective was to identify the boundaries of, and tree ages within, fires occurring since 1900. Forest-type maps of Washington made early in the century (Plummer et al. 1902, USDA 1936) and fire atlases (USDA Forest Service n.d.—no date—1) were useful starting points. Aerial photos from 1959, 1976, and 1984 and panoramic photos taken from lookout stations in the early 1930s (USDA Forest Service n.d. 2) were studied for evidence of large remnant trees, tree seedlings and saplings, and edges between forests with different tree sizes. Features were drawn onto a base map, using visible landmarks in the photos to match those on topographic maps.

Ages of dominant trees from plots (described below) and point samples were used to date the most recent fire (after Hemstrom and Franklin 1982, Agee 1993); tree stems, increment cores, and stumps were carefully examined for post-establishment fire scars. Forty-six "reconnaissance" points were located in areas where fire boundaries on air photos were unclear; recently logged sites were preferentially examined. Three or more dominant trees or large stumps at each reconnaissance point were aged by counting rings on increment cores or on stump surfaces scraped clean with a pocket knife. Rings on young trees were distinguishable and readily counted in the field, otherwise cores were collected for later analysis. Clear-cutting dates were known in most cases from direct observation, or were estimated from the annual height increment of planted trees.

The age of the oldest tree at a sample point was considered to date the origin of the stand. Stands which established within eight years of each other and were contained within fire boundaries identified in historical documents and photos were interpreted as being cohorts following a common fire. The eight year criterion was chosen to accommodate estimated errors in aging stands (Gray 1990). Stand ages, stand boundaries visible in aerial and lookout photographs, and fire dates from historical sources were combined to produce a single map of the burns in the study area (see Gray 1990 for mapping details).

Stand Structure

Forest structure data was collected in 1988-9 in two different ways: "survey" plots were placed throughout the study area to sample stand types and ages, and paired "detail" plots were placed on areas of adjacent single and multiple burns. Fifty survey plots were distributed over five elevation zones and two general aspects (north and south) to match the relative area of those zones and aspects in the study area (Gray 1990). Some areas far from roads and trails were under-sampled. Plots were located in stands with a concentration of conifers, which excluded most riparian areas. Survey plots were circular with an area of 250 m^2 (8.9 m radius). Within each plot, diameter at breast height (DBH, at 1.38 m) was measured on all live trees greater than 5 cm DBH and tree height was measured on the largest tree using tape and clinometer. Increment cores were taken from three large early-seral trees (usually Douglas-fir). The presence of charred snags and logs on a site proved to be a reliable indicator of a reburn (Klopsch 1985). They are created by burning of trees which died and shed their bark after the first fire. While some of the large snags in single- burn areas were charred, almost every large snag in multiple-burn areas was heavily charred.

Seven pairs of detail plots were established on sites dominated by Douglas-fir, with one of each pair located in an area burned in 1902 ("single burn"), and the other located in an area burned in 1902 and burned again within 30 yrs ("reburn"). The plots in a pair had similar elevation, aspect, slope, topography, soil type, and plant association (Gray 1990). The environmental conditions sampled by these paired plots ranged from moist low elevation flat sites to drier, moderate elevation steep sites. Pairs were designated by letter (A-G) and plots within a pair differentiated by number (e.g. A1 and A2 are paired single burn and reburn plots, respectively). Tree DBH was measured on all standing live and dead trees taller than breast height (1.38 m) in circular 250 m^2 plots around each detail plot center. Ages were determined for up to 25 Douglas-fir trees within a 500 m^2 circular plot around each detail plot center; trees were randomly selected if more than 25 Douglas-fir were present. Increment corings of selected trees were taken up to three times in an attempt to hit the pith of each tree. Heights of three cored large-diameter trees were measured. Increment cores were also taken on up to five trees of each of the other species present over the range of tree sizes present.

Data Analysis

Tree age (since seed germination) was estimated from stump and increment core samples by the following methods (see Gray 1990 for details). Collected increment cores were mounted in wood blocks and sanded and rings were counted with a hand lens or dissecting microscope. For those cores that did not intersect the pith of the tree, the curvature of the innermost rings on the cores was used to estimate years to the pith (Arno and Sneck 1977). Of 143 cored trees on survey plots, 38% hit the pith and 44% were estimated to have missed the pith by 3 years or less. Of 264 trees cored on detail plots, 49% hit the pith and 42% were estimated to have missed the pith by 3 years or less. Age estimates for 11 very large trees found on moist, sheltered sites which could not be cored near to the pith were developed by calculating the inner diameter which had not been cored and the age at which the average Douglas-fir in a productive (site class I) stand would reach that breast-height diameter (McArdle and Meyer 1930).

Estimates of the time it took for sampled trees to grow from germinants to the height at which increment cores were taken or stumps were cut (mean height of 47 cm for all samples) were developed using information on Douglas-fir seedling height growth as a function of site class (McArdle and Meyer 1930). Site class and site index are measures of an area's growth potential for trees, and were derived for the plots in this study using tree height and breast-height tree age (King 1966); reconnaissance sites were assumed to be of intermediate site class III, the median for the study area. The same seedling growth relationship was used for western hemlock, Pacific silver fir, and noble fir trees, since little detailed information on height growth below breast height exists for these species (Hanzlik 1925 and Williams 1968 did find similar early height growth for open grown noble fir, silver fir, hemlock, and Douglas-fir). All red alder (*Alnus rubra* Bong.) and bigleaf maple (*Acer macrophyllum* Pursh.) were assumed to be 2 yrs old at core height based on personal observations of early growth on disturbed mesic sites. Estimated errors for individual tree ages ranged from ±2-5 years, depending on method, sample height, and presence of the pith in the sample (Gray 1990).

Differences in the time required for Douglas-fir establishment between single burns and reburns was evaluated with an F-test on the within-stand variance in tree ages from detail plots. The effect of a range of environmental factors and indicators on tree species composition in survey and detail plots was analyzed for Douglas-fir and hemlock with stepwise multiple linear regression (Zar 1984). The proportion of total plot basal area for each species was regressed on elevation, slope, aspect (transformed to the cosine of aspect-45°), slope*aspect, stand age, the shortest distance from pre-1900 age stands (measured from the fire map), and site index (from King 1966). Significance levels for inclusion of variables in the regression models were set at $p=.15$. Analyses of residuals (with proc univariate in SAS Institute 1987) indicated that proportional basal area data for Douglas-fir and western hemlock did not violate assumptions of homoscedasticity and normality (as is common when most data are between .30 and .70—Zar 1984). Proportional basal area data for other species appeared to violate these statistical assumptions, so the importance of the different site factors were tested individually on species presence using the non-parametric Wilcoxon-Mann-Whitney rank sums method (Zar 1984). Differences in species abundance between single burns and reburns was evaluated with a t-test on proportional basal area for Douglas-fir and western hemlock (because they were present on most plots) using the Satterwaithe approximation for unequal variances (SAS Institute 1987). Linear regressions of tree density per plot (log-transformed to normalize residuals) on distance from pre-1900 stands were also calculated for Douglas-fir and western hemlock.

Results

Fire History

Four separate, high intensity fires occurred in the Siouxon drainage in the 1900s and evidence of earlier fires was also apparent (Figure 1). Douglas-fir trees established within a few decades of 1480 in five stands and in the late 1500s and mid-1600s in five other stands throughout the study area. Three separate fire events around 1803, 1824, and 1848 may have preceded the establishment of stands in the southwest, west, and northwest portions the study area, respectively. Any fires which did occur in the early 1800s must have been relatively small, since observations indicated that most of the snags created by the 1902 fire were greater than 100 cm in diameter, which is larger than the size of the average 100 yr old Douglas-fir on even the best of sites (70 cm—McArdle and Meyer 1930). Thus most of the stands in the Siouxon drainage were probably old-growth forests over 300 years old when the fire of 1902 killed most of the trees in the drainage. The few trees which survived the 1902 fire and were still alive in 1959 (the date of the earliest air photos examined) were located along valley bottoms and headwalls (Figure 1). Historical maps, documents, photos, and stand ages concur that smaller intense fires occurred within the 1902 burn in 1919, 1927, and 1932. A 120 ha 1918 fire was mapped on Mt. Mitchell (USDA n.d. 1) but field evidence of it would have been destroyed in the subsequent 1919 and/or 1932 fires (the amount of overlap of these later events is not known).

Stand Structure

The timing of forest establishment after fire differed between single burns and reburns. Tree regeneration was prompt after the 1902 fire, with 51 of 59 survey and reconnaissance points within the 1902 burn dated between 1902 and 1909 (Figure 1), and regeneration on all 7 single burn detail plots dated between 1901 and 1906 (Figure 2). Tree regeneration was delayed up to 5 years on two of the three reburns, with most stands in the 1919 reburn initiating after 1923 and most stands on the 1927 reburn initiating after 1932 (Figures 1 and 2). Stands on the 1932 reburn apparently established within 1-2 years of the fire.

Douglas-fir on single-burn sites established over a shorter period of time than Douglas-fir on reburn sites, indicated by comparing the variance in tree ages on the detail plots ($F_{.05(1),139,111}= 1.38$, $p= .042$)(Figure 2). There was considerable variation in stand age structures within burns, however. Douglas-fir on wetter sites in the single burn (A1, B1, C1, and D1) apparently established more rapidly (over about 12 yrs) than Douglas-fir on drier sites in the single burn (24 yrs or more for E1, F1, and G1) (Figure 2). In addition, the largest western hemlock tended to establish sooner after fire on the wetter sites (A1 and A2) than on the drier sites (G1 and G2).

Western hemlock was less abundant (as a fraction of total stand basal area) in reburn stands than in single burn stands ($t_{.05(2),59}= 2.31$, $p= .0242$), and tended to be more common in the largest diameter classes present in single burn stands (Figure 3). Douglas-fir, on the other hand, was more abundant in reburn stands than in single burn stands ($t_{.05(2),59}= -4.36$, $p= .0001$). The structure of most stands consisted of Douglas-fir clumped in the largest diameter classes and shade-tolerant western hemlock in a range of diameter classes, and standing dead stems in the smallest diameter classes (Figure 3). These characteristics indicate stand growth following catastrophic disturbance and self-thinning mortality of dense populations.

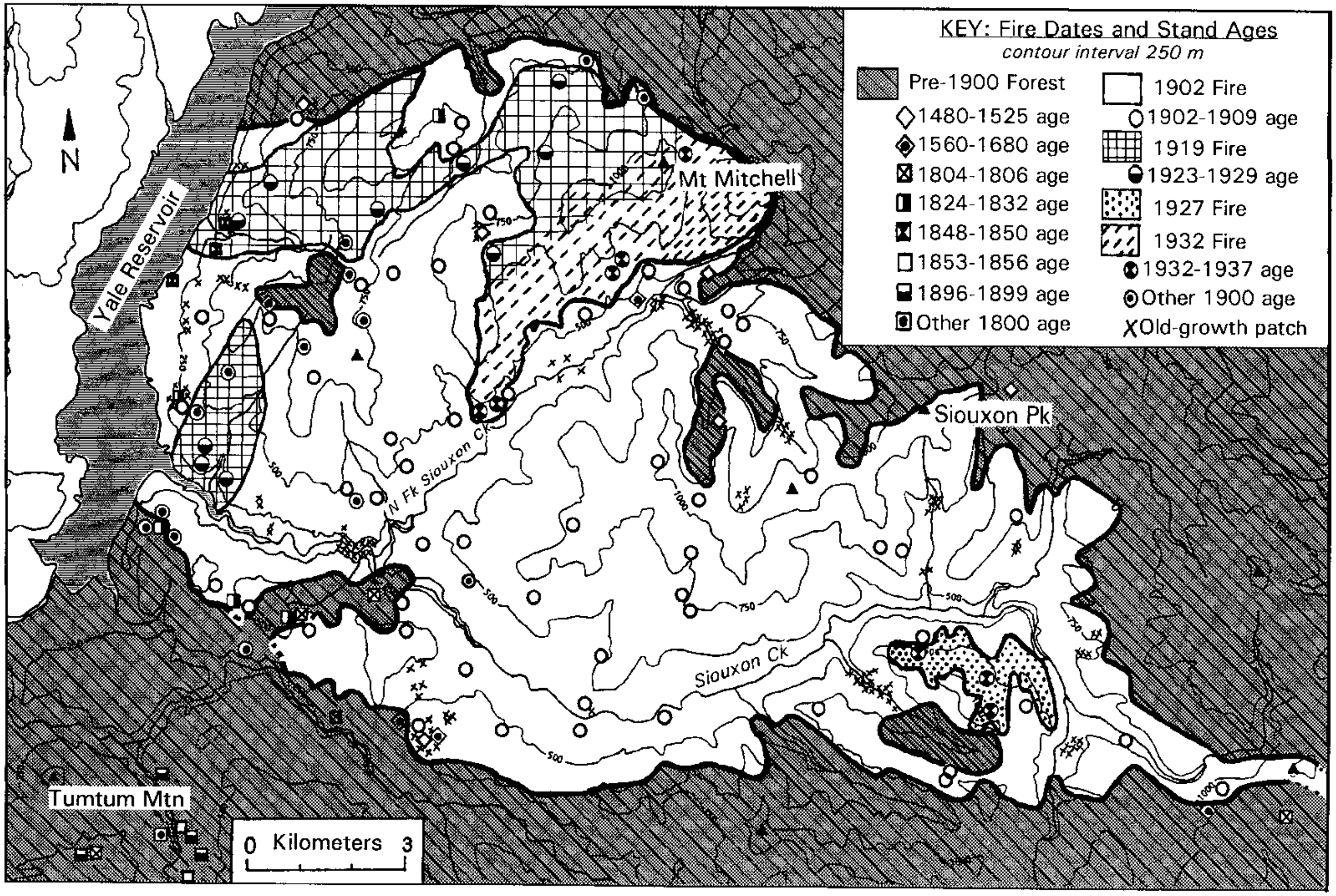

Figure 1. Map of fires occurring after 1900 and stand ages in the Siouxon drainage. The 1902 fire is unshaded, and the precise boundaries of the 1927 and 1932 reburns on Mt. Mitchell are unknown. Stand age symbol shapes vary among centuries: circles=1900s, squares=1800s, and diamonds=pre-1800.

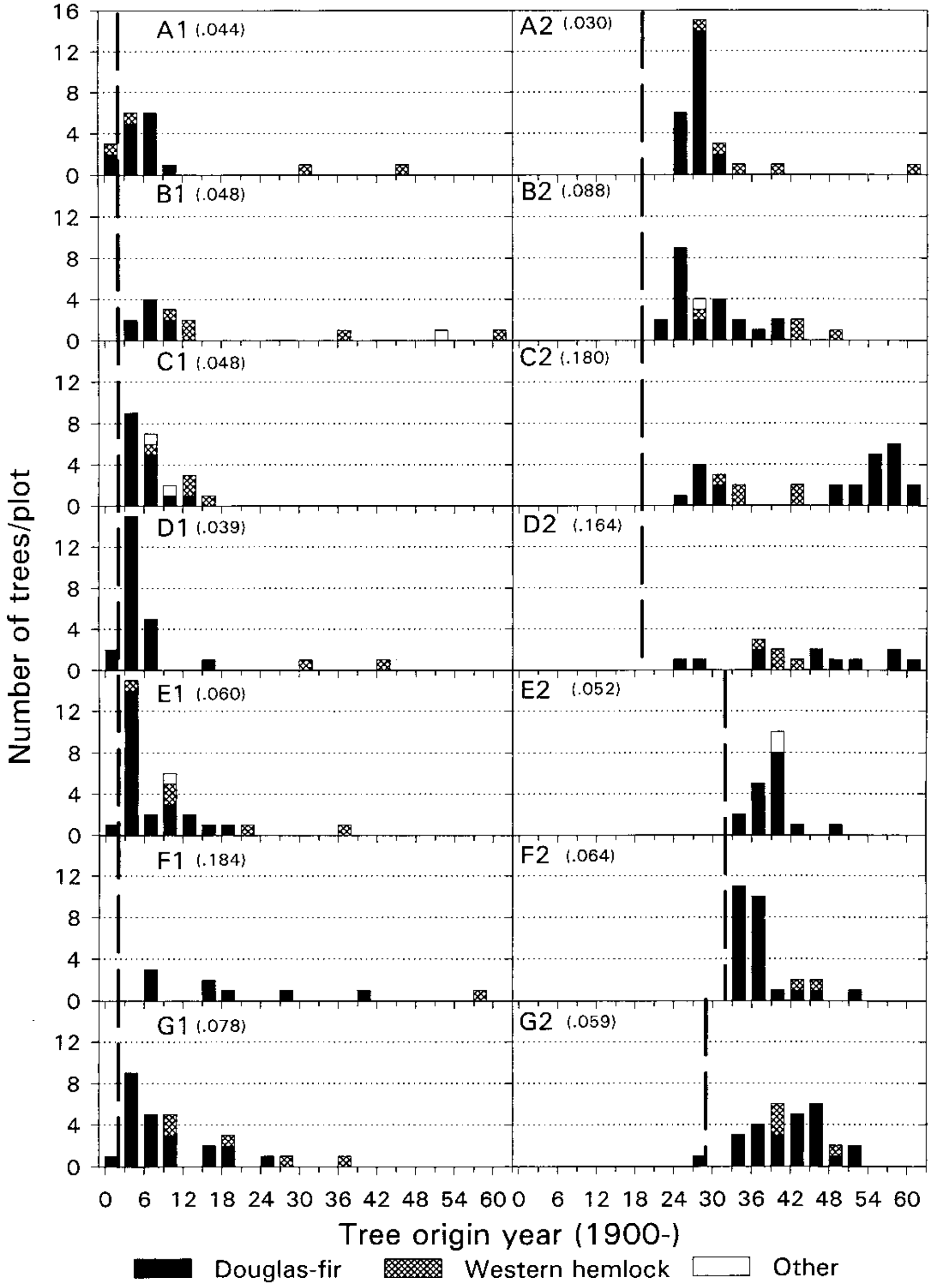

Figure 2. Estimated germination dates of Douglas-fir and selected individuals of other species on paired detail plots, showing variance in Douglas-fir age in parentheses and a dotted line indicating the year of the last fire for each plot. "Other" species include western redcedar, noble fir, and red alder.

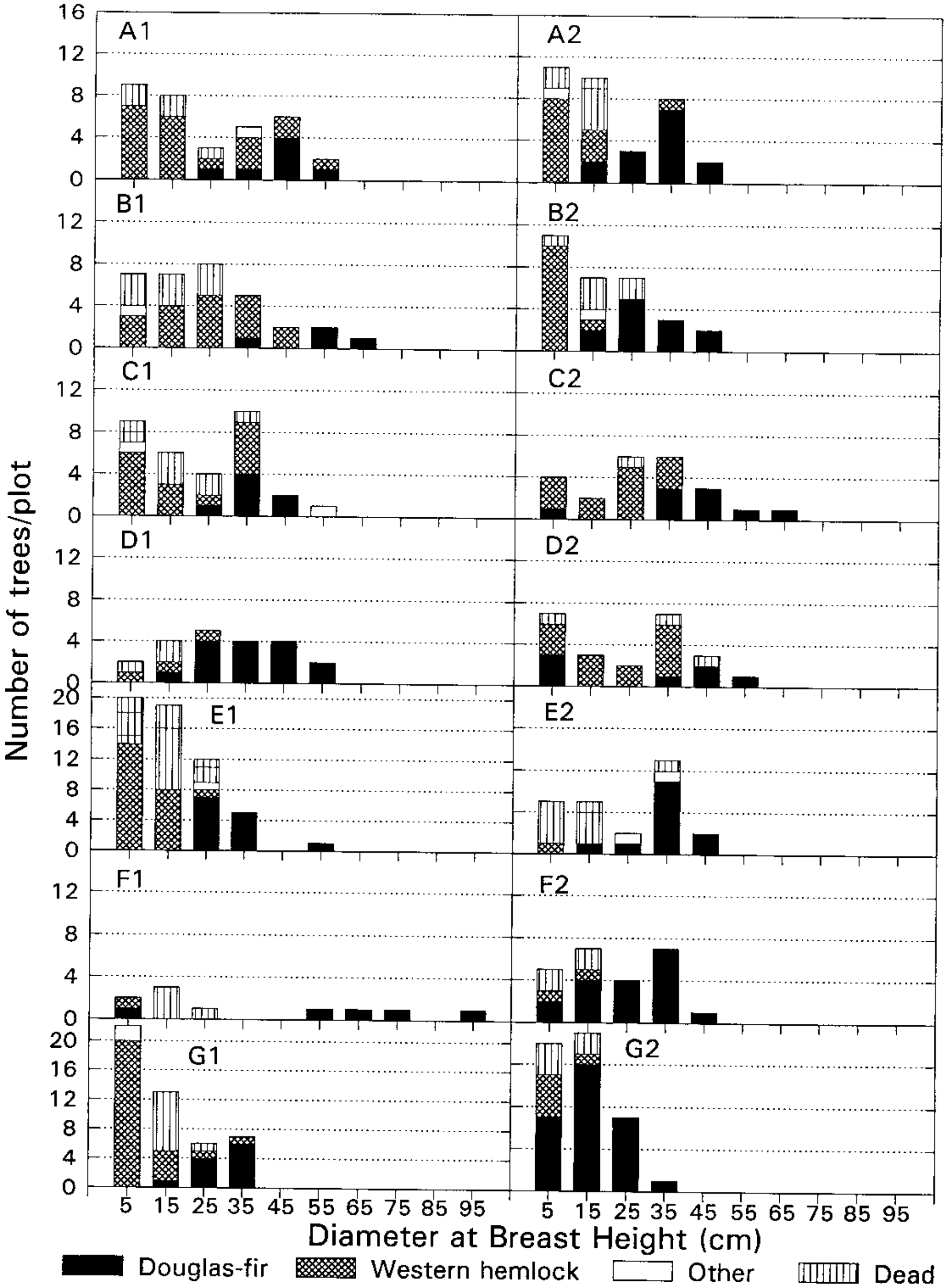

Figure 3. Diameter distributions of all species on paired detail plots (1/40 ha). "Other" includes western redcedar, Pacific silver fir, noble fir, and red alder; "dead" refers to standing dead stems of Douglas-fir, western hemlock, and red alder. Note change in scale for plots E1 and G1, but not for E2 or G2.

TABLE 1. Relationship between plot characteristics and species composition. Coefficients (ß) and p-values of significant factors selected by stepwise multiple linear regressions on proportional basal area are shown for Douglas-fir and hemlock. Rank-sum test Z and p values for individual factors are shown for presence of the other species. Number of plots (out of 61) with species present is shown under species name. Elev=elevation (m), age=stand age, dist=distance from pre-1900 stands, Site Ind=site index (King 1966).

Species		elev (m)	slope (%)	slope* aspect	stand age	dist (m)	Site Ind
Douglas-fir n=57	ß:	-0.068 (.0001)	0.60 (.0018)		-0.74 (.0038)	0.0071 (.0508)	
hemlock n=56	ß:		-0.51 (.0018)	0.27 (.0026)	0.60 (.0048)		-0.28 (.0089)
silver fir n=7	Z:	3.8 (.0001)				-2.0 (.0437)	-2.6 (.0086)
noble fir n=6	Z:	3.5 (.0004)					-2.3 (.0227)
redcedar n=19	Z:		-2.4 (.0160)		3.1 (.0021)		
alder n=11	Z:	-2.8 (.0052)		-2.6 (.0094)			
bigleaf maple n=8	Z:	-2.7 (.0062)				-2.0 (.0488)	2.4 (.0162)

The age and diameter structures of some stands differed substantially from those found in the majority of stands (Figures 2 and 3). Douglas-fir in single-burn detail plot F1 were relatively large, had established over a 34 year period, and were growing at low density in a relatively open stand. Slow establishment may have been a result of poor regeneration caused by summer drought on the coarse, cobbley substrate at this site, which apparently was an old glacial deposit (Mundorff 1984). Douglas-fir age and size distributions in reburn plot C2 suggest two distinct cohorts of trees, which appeared to be spatially distinct. Periodic, semi-continuous establishment of fire-sensitive hemlock in this stand suggests that the young Douglas-fir saplings did not establish following a second disturbance; instead, they may have established in gaps in the dense, mature stands of brush which occupied parts of this site. The broad age and size distribution of Douglas-fir on reburn plot D2 may be related to the mortality of the larger-diameter trees (Figure 3), which may have maintained sufficient light levels in the stand for survival of the smaller, younger Douglas-fir. Large basal scars oriented in various directions were found on many of the larger live and dead trees in this stand, suggestive of feeding by bear or porcupine (fire scars usually face in the same uphill direction—Brown and Davis 1973).

The presence and abundance of several tree species were significantly related to one or more environmental factors that were sampled by the distribution of survey and detail plots across the watershed (Table 1). The multiple linear regression for Douglas-fir (r^2=.48) indicated greater abundance on sites at lower elevations, on steeper slopes, in younger stands, and at greater distances from old-growth stands. The regression model for western hemlock (r^2=.37) indicates greater abundance on gentle, north-facing slopes, older stands, and sites of relatively low productivity for Douglas-fir (low site index). Both Pacific silver fir and noble fir were found primarily at higher elevations, which also tended to be sites with lower site indices. Pacific silver fir was also associated with sites that were relatively close to old-growth stands. Western redcedar (*Thuja plicata* Donn.) tended to be present on flatter slopes and in older stands. Red alder tended to occur on steeper, south-facing low elevation sites, while big-leaf maple tended to occur on productive, low elevation sites that were relatively close to old-growth stands. Distance from old-growth stands was at best only a marginally significant factor for species' proportional basal area or presence (Table 1). Tree density was weakly related to distance from old-growth for both Douglas-fir and western hemlock (r^2=.005 and .074 and p = .60 and .086, respectively).

Discussion

Fire history

Evidence of both large intense and small patchy fires was found in the Siouxon Creek watershed. The oldest Douglas-fir occurred throughout the study area and were established around 1500 A.D., which is approximately when most remaining old-growth stands in the Washington and northern Oregon Cascades became established (1450-1550 A.D.—Franklin and Hemstrom 1981, Agee 1993), suggesting widespread and/or recurrent fire at that time. The relatively small fires that may have occurred at the western end of the study area in the early 1800s could reflect localized ignitions by humans. The Cowlitz tribe inhabited the Lewis River valley (Ray 1974) and maintained prairies by regular burning (Leopold 1987); one of these prairies (known as Chelatchie Prairie) is located only 5 km southwest of the study area and is clearly depicted in Plummer et al.'s (1902) historical map. Ignition by European trappers and explorers, which were travelling through southern Washington by the 1820s, is also possible, however. The large 1902 fire was simultaneous with many intense human-caused fires which burned in western Oregon and Washington in September 1902 (Oregonian 20/9/02, Holbrook 1943). The few trees surviving the 1902 fire in the Siouxon were only found in clumps in sheltered valleys or individually along creeks. The cause of the more recent fires in the Siouxon is unknown; although of catastrophic intensity, they were significantly smaller than the 1902 burn. In summary, it appears that most of the study area consisted of mature and old-growth forest that burned intensely in 1902, portions of which burned once again in smaller high-intensity fires. An undefined area around Mt. Mitchell may have burned two or three times since the 1902 burn, and the western edge of the study area may have experienced multiple patchy burns in the early 1800s.

Some of the fire events examined in this study correspond well with the infrequent, high-intensity fire cycles described for moist Douglas-fir forests, in which fire intervals exceed 200 years and regenerating forests are even-aged (Hemstrom and Franklin 1982, Agee 1993). Considerable variation in fire frequency and intensity can occur within an area, however (e.g. Yamaguchi 1986, Morrison and Swanson 1990), thus the range of fire size and frequency found in the Siouxon may be representative of many areas in western Washington.

Stand Structure

Douglas-fir trees on single burn sites established over a shorter period of time than Douglas-fir trees on sites that burned again within 30 years (reburns), but the difference was not dramatic and therefore may have been caused by differences in stand development rather than effects of fire frequency on tree regeneration. Because single burn stands were older than reburn stands, the narrower age distributions in the older stands may have been caused by longer periods of self-thinning, in which the youngest, smallest individuals in a population die as dominant individuals develop (Harper 1977). Differences in animal-caused mortality or soil composition may also have contributed to the evident difference in age distributions between single burn and reburn sites. The apparently smaller range in tree ages on moist sites compared to drier sites may also have been due to site differences as opposed to differences in regeneration, because the intensity of thinning mortality increases with site productivity (Harper 1977).

Speed of establishment and within-stand density of Douglas-fir was not affected by distances of over three kilometers from unburned stands. Since Douglas-fir seed dispersal and regeneration declines to very low levels within 800 m of seed-bearing trees (Isaac 1930, Isaac 1943), seed sources must have been readily available after the 1902 Siouxon burn. Seeds can survive in green cones on trees that are killed by fire (Hofmann 1924, Isaac 1943); the 1902 fire occurred in mid-September, just prior to the onset of Douglas-fir seed dispersal (Reukema 1982). Seed production by Douglas-fir is irregular, however; whether seed was abundant in 1902 is not known. Alternatively, mature trees may survive catastrophic fires for a few years before succumbing to fire injuries or outbreaks of Douglas-fir bark beetle (*Dendroctonus pseudotsugae*) which breed in the forest of fresh snags (Isaac and Meagher 1936, Agee and Huff 1987). Survival for only two years after fire would be sufficient time for a large "stress crop" of Douglas-fir seeds (Allen and Owens 1972).

The delay in establishment after fire for Douglas-fir on at least two of the reburns suggests a lack of on-site seed sources. Stands on the 1919 and 1927 burns established after 1923 and 1934, respectively, which were the first years of abundant regional Douglas-fir seed crops after each fire (Isaac 1943). Potential on-site seed sources may have been destroyed by the reburns, which may have been more intense than the 1902 burn because of greater amounts of fuel in the form of deep litter and understory plants (Agee and Huff 1987) and dense canopies of young trees close to ground fuels, which make intense crown fire highly likely (VanWagner 1977). Seed trees which survived the 1933 Tillamook fire were killed by subsequent reburns (Andrews 1944), and the same apparently happened on the Siouxon burn.

Despite the delay in establishment and the apparent lack of on-site seed sources, the rapid establishment of Douglas-fir on reburn sites indicates that regeneration was not impeded. Although most reburn sites were over 1 km from pre-1900 forest, all were within 600 m of extensive post-1902 stands. Dispersal from the large number of trees in the 1902 forest may have compensated for the light cone production characteristic of young trees. Herbs and shrubs apparently did not develop sufficiently on most reburn sites to compete with seedlings germinating 3-4 yrs after fire, possibly because vegetation recovery is often slow after intense fires (Halpern 1989, Dyrness 1973).

The density of western hemlock was not greatly affected by distances of over three kilometers from unburned stands, but it is unlikely that there were abundant sources of on-site seed after the 1902 fire. The small cones of western hemlock are probably less heat-resistant than those of Douglas-fir, and hemlock trees are much less fire-resistant than Douglas-fir (Minore 1979), so it is doubtful that hemlock seed survived the 1902 fire or was produced within the burn after the fire. However, hemlock seed can disperse much further than Douglas-fir (Isaac 1930), and its shade-tolerance (Minore 1979) allows it to establish in existing forests. Thus hemlock in the 1902 burn may have established from seed which dispersed from the edges of the burn over many years. Since seed dispersal was apparently not limiting, the reduced abundance of western hemlock on single burn sites compared to reburn sites could be attributed to soil degradation by repeated fire. The repeated intense fires on the reburn sites probably reduced soil organic matter and coarse woody debris to a much greater extent than the isolated fire on the single burn sites. Woody debris and soil organic matter represent important reservoirs of moisture (Harmon et al. 1986, Kimmins 1987) which are important to drought-intolerant hemlock during the summer drought of Cascade Douglas-fir forests (Gray 1995). For most species in this study, however, topography appeared to be of greater importance than fire frequency or distance from potential seed source.

The speed and density with which the forest established on both single burn and reburn sites in the Siouxon suggests that mesic Douglas-fir forests are quite resilient with respect to intense natural disturbances. This is in contrast to regeneration problems reported on the larger Tillamook and Yacolt reburns (Andrews 1944, personal observation) and on large clearcuts (Isaac 1943). The adequate stocking of stands in the Siouxon seems attributable to on-site seed sources after the 1902 burn, which are not present on large clearcuts, and proximal seed sources for reburns, which would not be the case after large fires. Poor tree establishment may also occur after greater fire frequency than was found in the Siouxon; many areas on the Yacolt and Tillamook burns experienced intense fire 3-5 times within 30 years (Felt 1977). Despite adequate forest establishment, less frequent reburning may have important effects on forest composition, as was detected for hemlock in this study. Future studies of reburns might focus on soil characteristics important to plant composition, since fire can reduce soil organic matter, decrease porosity, destroy mineral soil structure, and increase susceptibility to soil erosion (Swanson 1981). Loss of decaying wood in the soil, which is important for growth of mycorrhizal-forming fungi and nitrogen-fixing soil microbes may be a limiting factor to tree regeneration on reburns (Barrett 1982).

Understanding the nature and rate of forest development after large, intense forest fires has important implications for forest ecosystems in the region. Most naturally-established Douglas-fir forests in the western Cascades developed after large, intense forest fires, many of which burned several times over a few decades (Agee 1993). The results of this study suggest that the size, intensity, and frequency of these past fires affected forest development and composition. Current forest management, however, tends to be patterned on simple models of stand development occurring after a limited range of disturbance types, and may not sustain the species adapted to more complex natural habitats (Hansen et al. 1991).

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