Swanson

AN ABSTRACT OF THE THESIS OF

Kelli J. Van Norman for the degree of Master of Science in Forest Science presented on May 29, 1998. Title: Historical Fire Regime in the Little River Watershed, Southwestern Oregon.

Abstract Approved: Steven L. Garman

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Disturbances are a prevalent and important part of ecosystems. Many landscape patterns that we find today were created, maintained, and changed by natural disturbance regimes. This is especially true for fire, which has historically been a common, natural disturbance in the western U.S forests and grasslands and many other parts of the globe.

I reconstructed fire history and interpreted fire regime in 117 clearcuts distributed throughout a 45,000 ha study area within the Little River watershed, an Adaptive Management Area in southwestern Oregon. Tree rings were counted on over 3,000 stumps and provided a 683-year record of fire.

The study area fire regime can be characterized by its variability. The composite median fire return interval for the study area was approximately 123 years. Fire extents were not estimated, but historical fires tended to be relatively small, usually occurring within less than 2.5 km. Low and moderate severity surface fires appeared to have been more common than stand-replacement fires indicating a moderate severity fire regime with much spatial variability in severity.

The fire regime has changed temporally and spatially over the fire history record. Five distinct changes in the rate of fire occurrence were identified (1490-1569, 1570-1844, 1845-1899, 1900-1925, and 1926-1996) and associated with changes in climate and human fire ignition and fire suppression. Fires were dispersed throughout the study

Historical Fire Regime in the Little River Watershed, Southwestern Oregon

by

Kelli J. Van Norman

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

Kelli J. Van Norman, Author

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INTRODUCTION

Disturbances are a prevalent and important part of ecosystems. Natural disturbances, including floods, fires, landslides, volcanic eruptions, avalanches, hurricanes, and windstorms, reset succession in varying degrees. The hierarchy of temporal and spatial scales at which disturbances operate influences organisms and their evolution, communities, habitats, and stand and landscape structures (Pickett and Ostfeld 1995). Disturbances can be considered as distinct events or as a system of repeated events described in terms of disturbance regime. The type of disturbance and its frequency, severity, predictability, spatial distribution, and interaction with past disturbances make up the attributes of a disturbance regime (White and Pickett 1985).

Fire has historically been a prevalent natural disturbance in the Pacific Northwest and elsewhere (Morris 1934; Agee 1993). Although fire regime varies over the wide range of environments of Pacific Northwest Douglas-fir forests, these forests are dominant in the region due to fire disturbance and the adaptation of Douglas-fir to fire (Agee 1991). Historical patterns of repeated fire of distinctive frequency and magnitude have substantially influenced all levels of this ecosystem. Frequent, low intensity fire kills fire-intolerant species leaving older Douglas-fir within stands, whereas infrequent, high intensity fire creates open patches across the landscape, both interacting across time and space. In effect, the contemporary Douglas-fir forests and their landscape patterns in the Pacific Northwest were created, or until recently, maintained by wildfire disturbance.

Fire history reconstruction has been used to interpret past fire regimes for science and management purposes (e.g., Heinselman 1973; Agee 1993; Heyerdahl *et al.* 1995). Fire history studies reconstruct past fire events from tree-ring records to examine elements of fire regimes (Stokes and Smiley 1968; Heinselman 1973; Arno and Sneck 1977; Madany *et al.* 1982; Agee 1993). Many factors are believed to influence fire regimes: climate and weather, landforms and topography, and fuel loads and vegetation types (Swanson *et al.* 1988; Agee 1993). Climate influences regional variations of fire frequency, extent, and severity through influences on ignition, spread, vegetation types, and associated fuel loads (Agee 1993). Landforms and topographic factors interact with climate and short-term weather at local scales. North aspects, for example, are typically more cool and moist than south aspects and have lower fire frequencies.

Most fire history studies in the Pacific Northwest have been conducted in Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) - western hemlock (*Tsuga heterophylla*) (nomenclature follows Hickman 1993) forests affected largely by high-severity fires (Heyerdahl *et al.* 1995). Several studies along the central western slope of the Cascade Range in Oregon found some evidence for moderate and low severity fire (Teensma 1987; Morrison and Swanson 1990). For the most part, moderate severity fire regimes, however, have had little historical study because of their complexity.

In recent years there has been growing interest in using information on historic fire regimes in development of landscape management plans (Morgan *et al.* 1994; Swanson *et al.* 1994) in the context of ecosystem management (Grumbine 1994). The general concept is that the legal mandate to Federal land managers to sustain native species is more likely to be accomplished if habitat is maintained with the historic range of conditions. Therefore, studies of historic fire regimes are being used to help define "reference conditions" for management. This study was undertaken in part to provide such information for use in the Little River watershed Adaptive Management Area established under the Northwest Forest Plan.

This study examined the fire history of Douglas-fir forests in the Little River watershed in southwestern Oregon where historically fire has been one of the most prevalent disturbance elements in upland forests (USDA-USDI 1995). My primary goal was to characterize the historic fire regime, including its temporal and spatial variability, within the Little River watershed. For temporal variability, my main objective was to determine if and when the fire regime, as represented by fire frequency, had changed over the length of the fire history record. I had several objectives related to the spatial patterns of fire occurrence: (1) determine if fires have been clustered or randomly dispersed throughout the study area, (2) characterize the spatial distribution of site-level fire frequencies, (3) determine if historical fire frequencies are associated with topographic variables, and (4) if predicted relationship between fire frequency and topography was established at the site-level, extrapolate the relationships to the larger landscape. I also compared fire frequency results for the Little River watershed to those of nearby studies in the western Cascade Range of Oregon, contrasting frequency of large fires to smaller fires in the study area, and characterizing general fire severity patterns at the site-level and study area scales.

STUDY AREA

The Little River watershed is located near Glide, 29 km east of Roseburg in Douglas County, southwestern Oregon (Fig. 1). The study area occupies the eastern 45,000 ha of the Little River watershed (Fig. 2). The western portion (7,400 ha) of the Little River watershed was not included in the study because extensive alteration by Euro-American settlement and land use left a sparse pre-Euro-American record of fire history.

The study area lies within the western Cascades geologic province portion of the Little River watershed. It is a wide, deeply dissected belt of volcanic formations composed of layers of andesite and basalt deposits. Typical topography consists of long ridges with steep, long slopes and narrow valley bottoms (Peck *et al.* 1964). Elevation ranges from 250 to 1,600 m. A Mediterranean climate predominates, with cool, wet winters and hot, dry summers. Snow is common at upper elevations in winter.

The study area is located in an ecotone between southwestern Oregon's Mixed-Conifer Zone and the dry, southerly portion of the Western Cascades *Tsuga heterophylla* Zone (Franklin and Dyrness 1973). Douglas-fir is the dominant tree species at low to mid-elevations. Incense-cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), and grand fir (*Abies grandis*) occur on dry sites at low to mid-elevations. Western redcedar (*Thuja plicata*) and Pacific yew (*Taxus brevifolia*) are found on moist sites at low to mid-elevations, and western hemlock occurs at mid- to high elevations. Subalpine fir (*Abies lasciocarpa*), some noble fir (*Abies procera*), and western white pine (*Pinus monticola*) occur at high elevation sites. Hardwood trees and shrubs include canyon live oak (*Quercus chrysolepis*), Pacific madrone (*Arbutus menziesii*), bigleaf maple (*Acer macrophyllum*), golden chinquapin (*Chrysolepsis chrysophylla*), poison oak (*Toxicodendron diversilobum*), several species of manzanita (*Arctostaphylos* spp.), evergreen ceanothus (*Ceanothus velutinus*), ocean-spray (*Holodiscus discolor*), and Pacific rhododendron (*Rhododendron macrophyllum*).

Private and public land ownership occur within the study area (Fig. 3). Most private residences are located in the lower portion of the Little River watershed, but the

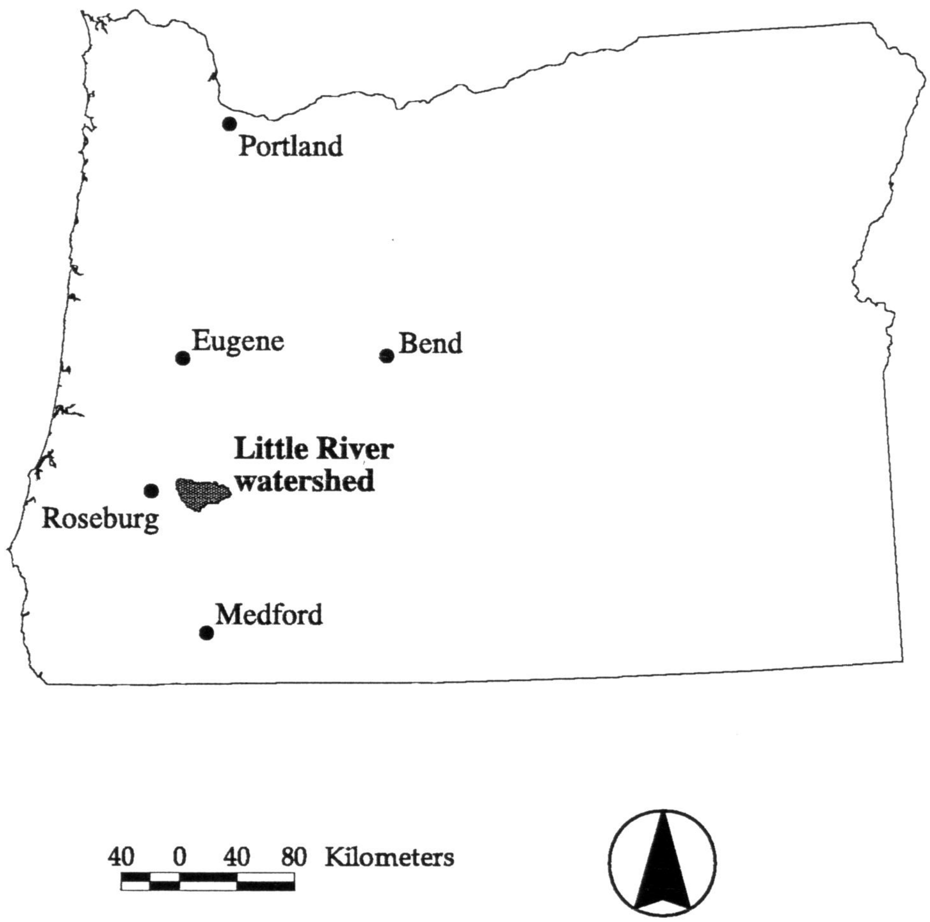


Fig. 1. Little River watershed location in Oregon.

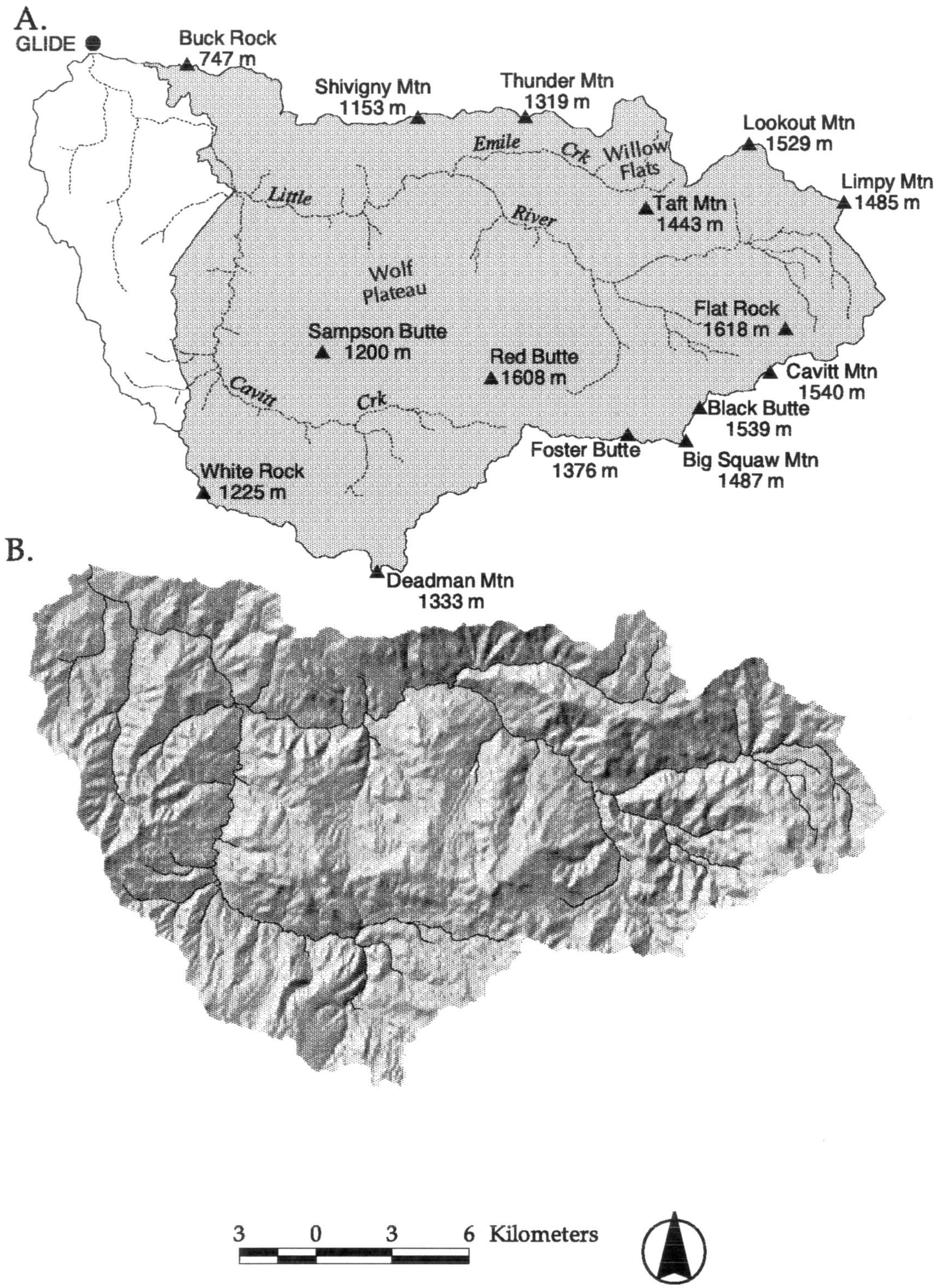


Fig. 2. A.) Prominent peaks, streams, and plateaus within the study area (gray-shaded).
B.) Topographic relief of the Little River watershed.

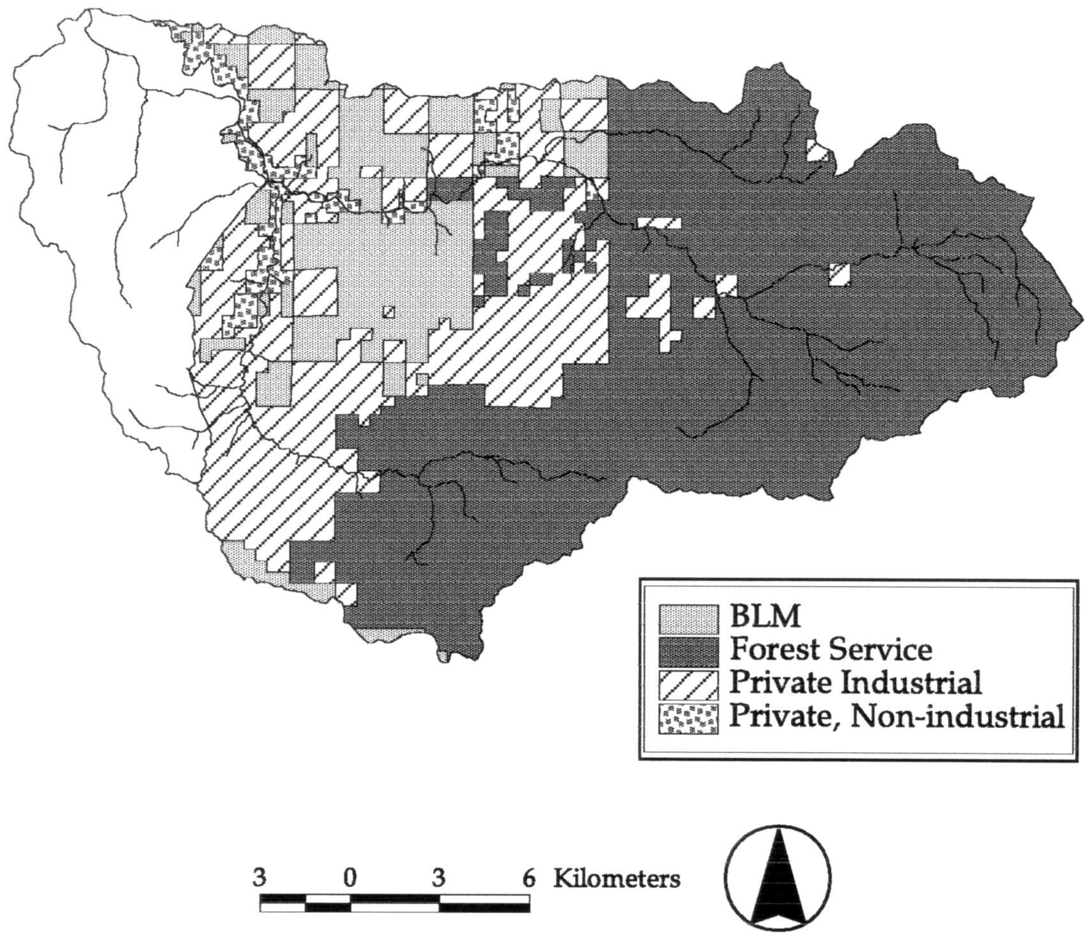


Fig. 3. Land ownership in the study area.

residential area extends upstream adjacent to Little River and Cavitt Creek within the study area. Non-industrial, residential private land occupies only 3% of the study area along Little River and Cavitt Creek. Private industrial forests occupy 26% of the uplands. The remaining portion of the study area is publicly owned with 57.5% managed by the North Umpqua Ranger District (NURD) of the Umpqua National Forest and 13.5% managed by the Roseburg District of the Bureau of Land Management (RBLM).

The Little River watershed is one of ten Adaptive Management Areas designated by the Northwest Forest Plan and intended to incorporate ecosystem and adaptive management ideas in developing new management approaches. In these Adaptive Management Areas, generally 34,000 to 162,000 ha in size, technical and social approaches are to be developed to achieve ecological, economic, and other social objectives (FEMAT 1993). The focus is on management as a learning process and a continual long-term experiment. Managers have the flexibility to adapt to uncertainty and incorporate new scientific knowledge, such as reference condition information.

METHODS

Sampling Scheme

Fire history was interpreted from fire scars aged by counting tree rings on stumps sampled in clearcuts, rather than from increment cores collected from living trees. Topographic maps of the study area with existing clearcuts were overlaid with a 2 x 2-km grid (Fig. 4A). Clearcuts less than or equal to 12 years old were sampled because stumps tend to be rotten in older cuts. At least one clearcut from each 2 x 2-km cell was sampled (Fig. 4B). This sampling scheme provided coverage of most aspects, slopes, slope positions, and elevations in the study area. Of the 536 clearcuts ($\leq$12 years old) available for sampling (i.e., on RBLM or NURD lands), 117 sites were sampled in 1996. Thirty clearcuts were on RBLM land and 87 were on NURD land. The mean nearest-neighbor distances between sample sites for the 117 site locations was 1.35 km (Standard Deviation = 0.46 km).

The clearcuts that I sampled could be biased towards sites with large trees or high timber volume. However, the majority of the watershed was occupied by late seral (i.e., mature and old growth) stands during the late 1930's based on 1946 aerial photos (Fig. 5) (USDA-USDI 1995). Also, during the 12-year period from which clearcuts were selected, the general strategy was to geographically disperse clearcuts (Fig. 4A).

Data Collection

I used a belt transect to sample a swath through each clearcut. Transect location was based on topographic features (e.g., ravines, depressions, cliffs), knowledge of fire behavior, and the size of the clearcut. Swampy depressions, deep ravines, and riparian zones were avoided. Where the terrain was fairly homogeneous, I randomly located the transect. The width of each transect was 22.86 m (75 ft), and length varied from 60 to 300 m, depending on size of the clearcut, terrain, and amount of fire history data (i.e., tree regeneration and scar dates). Mean area of transects was 0.48 ha (S.D. = 0.15 ha).

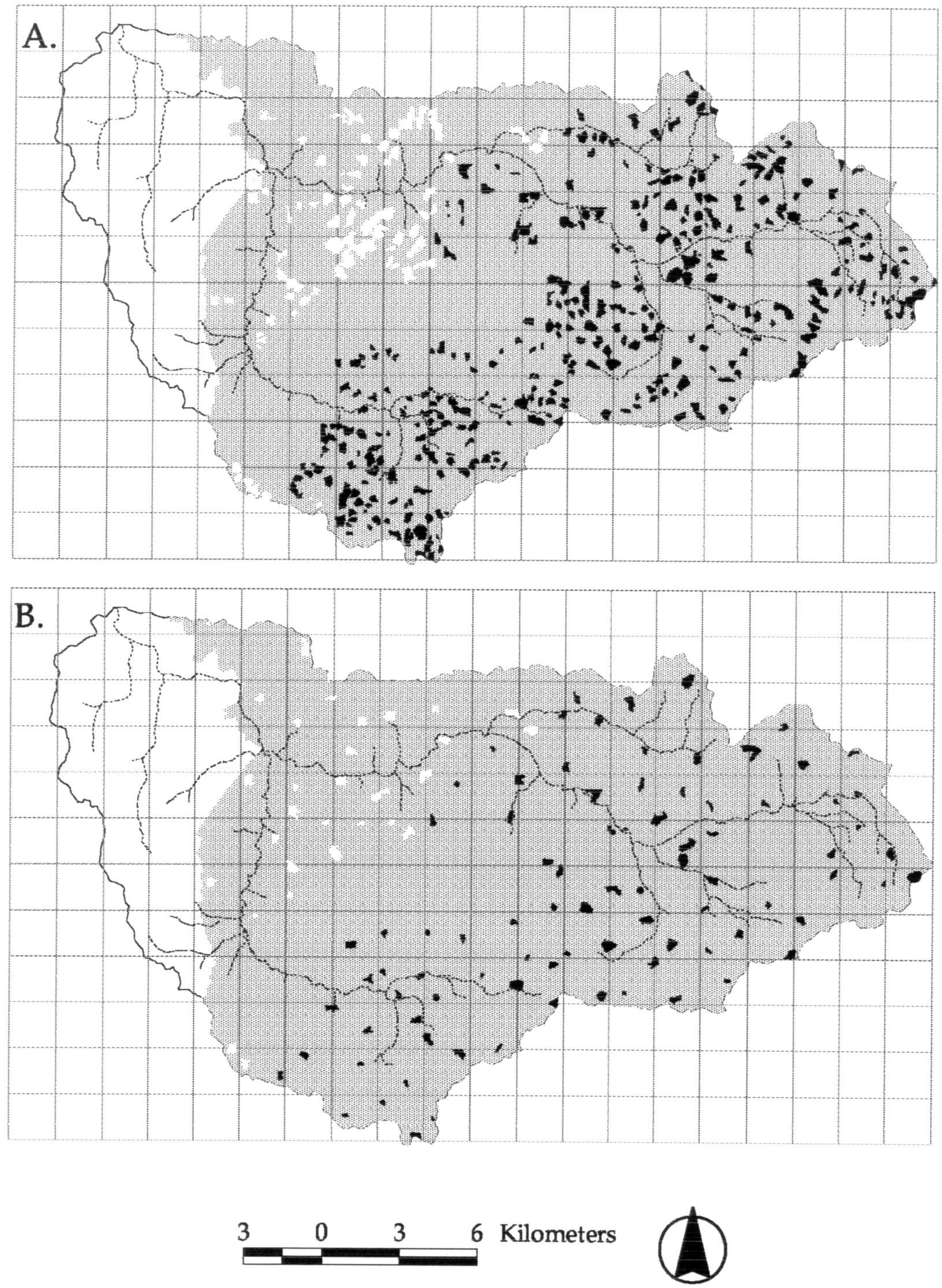


Fig. 4. A.) 2 x 2-km sampling grid with RBLM (white) and NURD (black) clearcuts harvested since 1984 in the gray-shaded study area.
B.) The 117 clearcuts sampled during the 1996 field season.

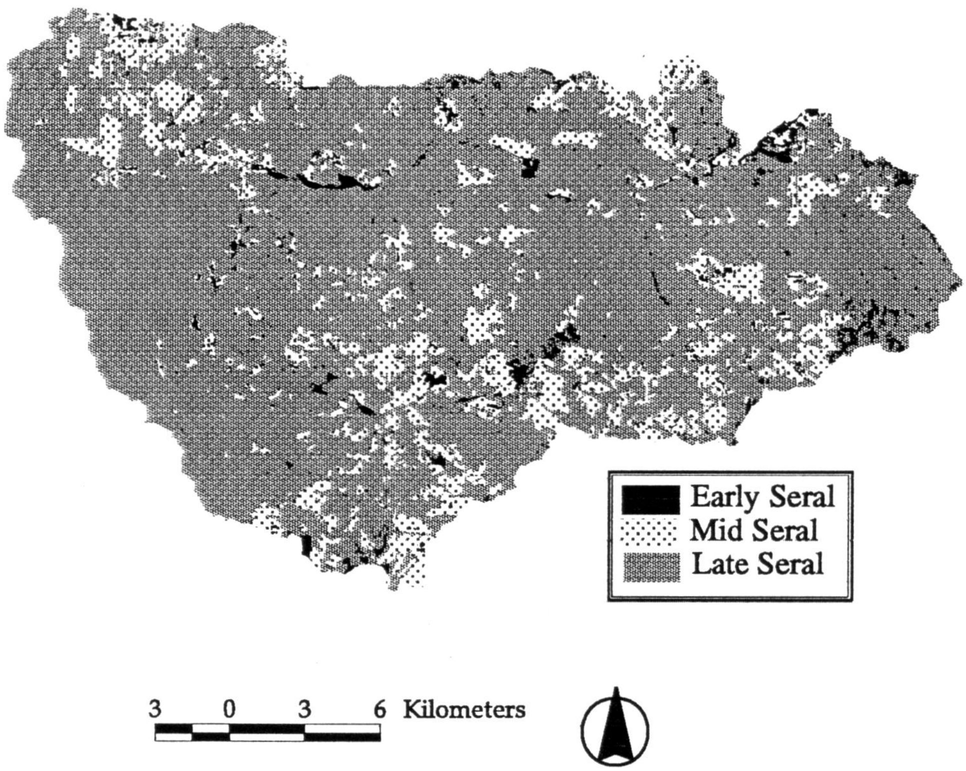


Fig. 5. Seral conditions in the Little River watershed forest during the late 1930's. Classes were estimated from 1946 aerial photographs (USDA-USDI 1995).

I used tree age classes and scars as evidence of fire events. Along each transect, I counted tree rings on stumps to age trees at time of harvest and to age scars. Tree rings were counted with dissecting needles and 16x magnification hand lens. Multiple counts per stump were performed to ensure accuracy. All size classes and all conifer species were sampled at the beginning of each transect, and additional stumps were sampled further along in the transect to confirm fire dates. Based on data from nearby fire history studies in clearcuts (Morrison and Swanson 1990; Connelly and Kertis 1992), I considered three correlating scars or at least eight regenerating trees originating within 20 years as strong evidence of the occurrence of a fire. Once these criteria were met, I de-emphasized recording additional data for the corresponding fire. However, sampling of other fire dates continued until the end of the transect.

Sampled stumps were chosen based on size, species, and evidence of scars. Because Douglas-fir tend to survive fires, develop scar tissue when injured, and regenerate after moderate and severe fires (Agee 1993), it was the primary species used to detect fires. Stumps outside the transect were occasionally sampled if additional fire history information, such as scar dates or very old regeneration dates, was needed. Usually, these were large, old, or scarred Douglas-fir whose age class was rare inside the transect. In total, I sampled 3,153 tree stumps; 82% were Douglas-fir. The mean number of stumps sampled per site was 26.2 (S.D. = 9.2). A total of 3,306 were used in my analyses. The 1,509 Douglas-fir with scars averaged 1.9 scars per individual (S.D. = 1.4).

Tree ages for all species were adjusted using Hall's equation for estimating age at stump height for Douglas-fir (Teensma 1987; Morrison and Swanson 1990; Connelly and Kertis 1992):

Calculated Age = 0.1582 * stump height / ring width (for inner 3 rings >2 mm), and

Calculated Age = 0.1582 * stump height / 2 (for inner 3 rings <2 mm)

As a general formula, it adds approximately 1 to 3 years to a tree's age at stump height. Calculated tree ages were subtracted from harvest year of a clearcut to obtain the calendar year of scars. The year of harvest was provided by NURD and RBLM.

Cross dating is considered to be the most accurate method of tree and scar dating. In this method, narrow and wide tree ring patterns are compared to date tree rings accurately to calendar year (Stokes and Smiley 1968). Data collection and analysis for cross dating is time-consuming. I chose not to cross date my tree ring counts because of the spatial extent covered by this study. Hence, to determine the broad temporal and spatial fire regime patterns of my study area, I sacrificed temporal accuracy.

Fire History Reconstruction

Fire Events at a Site

Previous studies have used various combinations of tree species; numbers of regenerating stems, scars, and pitch ring dates; years of growth suppression and release; the location of scar or pitch rings on a stump (e.g., side slope, upper, lower, scattered); and the percent circumference of the cambium covered by the injury to identify fire events (Teensma 1987; Morrison and Swanson 1990; Connelly and Kertis 1992; Brown and Swetnam 1994; Grissino-Mayer 1995; Impara 1997, Weisberg 1998). Characteristics, or "rules," vary with sampling intensity, assumed type of fire regime, and biological characteristics of major tree species.

Fire Event Rule Sets and Comparison

Because there is no standard method for determining fires from ring-counted data, I developed a three-step process to delineate fire events based on calendar year and numbers of scars and tree-regeneration (Fig. 6). The underlying feature of this process was the aggregation of scars and tree-regeneration dates into discrete time intervals for each site. This was necessary given the temporal inaccuracies of the scar and regeneration data. Frequency of scars and regeneration of the temporally aggregated

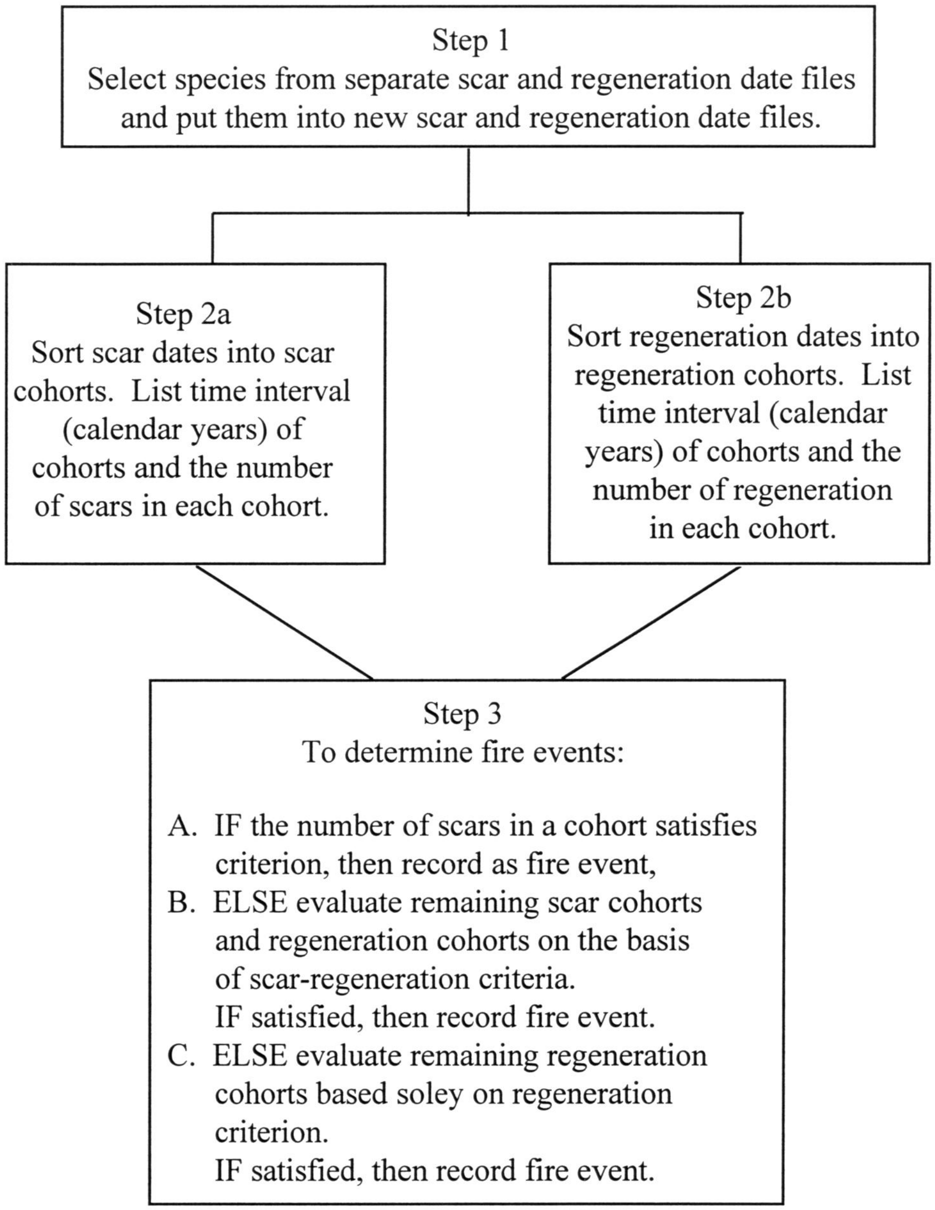


Fig. 6. Flow chart illustrating the steps used to determine fire events at a site.

information was then used to determine occurrence of a fire event based on specified criteria.

The first step of this process was the selection of data collected from early-seral, coniferous species (i.e., Douglas-fir, incense-cedar, sugar pine, ponderosa pine, western white pine, noble fir, and subalpine fir) from the overall data base (Fig. 6). Only these data were used in subsequent steps.

The second step applied criteria to aggregate scar and regeneration data (Fig. 6; Table 1). Criteria included several temporal intervals. The first specified the time period (e.g., 1300-1824) of the overall record to which the remaining criteria were applied. Within a time period, a temporal interval (i.e., scar time interval) determined aggregation of scar counts. Starting at the earliest part of the record, number of scars were totaled in every consecutive scar time interval. The start and end date of the resulting cohort, however, corresponded to the earliest and latest year with scar data. The result of this process was the delineation of aggregates or cohorts, and a record of the actual temporal interval (in terms of calendar years) and total number of scar counts in each cohort. Regeneration was grouped into separate cohorts based on consecutive temporal intervals (i.e., regeneration time intervals). Regeneration corresponding to the oldest on a site up to the specified regeneration time interval were aggregated into a single cohort. Regeneration younger than the oldest cohort were aggregated using a different regeneration time interval (i.e., Other temporal interval noted in Table 1). If a scar cohort was encountered prior to the end of a time interval, tally of regeneration for that interval terminated at the start date of the scar cohort. This was because regeneration dates were less precise than scar dates for determining fire events. The next interval was then initiated at the time of the next youngest regeneration. The start and end date of a resulting regeneration cohort corresponded to the earliest and latest calendar year with regeneration. Similar to the scar-tally process, the output from the examination of regeneration was the delineation of aggregates (or cohorts), and a record of the actual temporal interval (in terms of calendar years) and total number of regeneration counts in each cohort. Criteria associated with scar and regeneration were relaxed further back in time to account for counting error that was assumed to increase through time.

In the third step, a hierarchy of criteria were applied to the cohorts produced in step 2 to delineate a fire event (Fig. 6; Table 1). First, if the number of scars in a cohort equaled or exceeded a specified number, the cohort was classified as a fire event. Otherwise, the remaining scar data along with the regeneration data were evaluated. If the combined scar and regeneration criteria were satisfied, then a fire event was designated. If scar data were not available, then the regeneration-only criterion was used, in which a minimum number of regeneration per cohort to delineated a fire event. Step 3 produced for each site a list of fire events, which included the corresponding temporal interval (i.e., calendar years) and the type of evidence used to delineate an event (e.g., scars only, scars and regeneration only, regeneration only).

Fires that occurred within several years of one another were obscured and could not be separately identified. An interval of years could not be used in some of the analyses so a representative majority year was also designated for each fire event. A majority year was the year with the most fire evidence.

Because criteria used in delineating fire events were somewhat subjective, eight different sets of criteria were generated and evaluated (Table 1). These sets, hereafter referred to as rule sets, varied by: (1) time period, (2) temporal interval for aggregation , and (3) numbers of scar and regeneration required for a fire event. Rule sets ranged from conservative (A, Table 1) to liberal (H, Table 1). Results from the application of each rule set were compared to evaluate sensitivity to different criteria, and to determine the most appropriate set of criteria for delineating fire events in this study. Site-level fire events delineated by the selected rule set were used to determine unique fire events, fire-return intervals, in the examination of fire severity and spatial pattern of fire frequency, and in the regression analysis of topographic correlates of fire frequency (described below).

Table 1. Criteria of the eight rule sets used to delineate fire events at each site. See text for explanation of steps.

Table 1.

RULE SET	STEP 2: SORTING DATA				STEP 3: EVALUATING FIRE EVENTS						
	Scar Cohorts		Regeneration Cohorts		Scars		Scars & Regeneration			Regeneration	
	Time period[a]	temporal interval[b]	Old temporal interval[c]	Other temporal interval[d]	Time period[a]	Scars[e]	Time period	Trees[e]	Scars[e]	Time period[a]	Trees[e]
A	1300-1824	8			1300-1996	4	na			1300-1996	na
	1825-1996	3									
	1300-1996		na	na							
B	1300-1824	8			1300-1996	3	1300-1699	2	1	1300-1699	3
	1825-1996	3					1700-1996	2	2	1700-1799	5
	1300-1996		40	20						1800-1996	8
C	1300-1824	8			1300-1996	3	1300-1699	2	1	1300-1699	3
	1825-1996	3					1700-1996	2	2	1700-1824	4
	1300-1996		40	20			1300-1996	4	1	1825-1996	7
D	1300-1824	8			1300-1929	3	1300-1699	2	1	1300-1775	3
	1825-1929	3			1930-1996	2	1700-1996	2	2	1776-1824	4
	1930-1996	2					1300-1996	4	1	1825-1996	7
	1300-1996		40	20							
E	1300-1824	5			1300-1829	2	1300-1829	3	1	1300-1996	2
	1825-1996	3			1830-1996	3	1830-1996	3	2		
	1300-1996		5	5							
F	1300-1699	20			1300-1996	3	1300-1996	2	1	1300-1996	3
	1700-1799	12									
	1800-1996	8									
	1300-1996		40	20							
G	1300-1824	8			1300-1996	3	1300-1996	2	1	1300-1549	2
	1825-1996	3								1550-1769	3
	1300-1996		50	40						1770-1844	5
										1845-1996	8
H	1300-1824	8			1300-1996	2	na			1300-1996	na
	1825-1996	3									
	1300-1996		na	na							

Table 1. (Continued)

a. Time period is the specific set of years being evaluated.
b. Temporal interval is the maximum number of years within which scars were aggregated into cohorts.
c. Old temporal interval is the maximum number of years within which the oldest regeneration data at a site were aggregated into a cohort.
d. Other temporal interval is the maximum number of years within which regeneration younger than the oldest cohort at a site was aggregated.
e. Scars refers to the minimum number of scar origin dates in a cohort required to classify a cohort as a fire event.
f. Trees refers to the minimum number of tree regeneration origin dates in a cohort required to classify a cohort as a fire event.

Unique Fire Events

Individual fires could have occurred over multiple sites. Counting each site-level fire as an individual fire may overestimate the number of unique fire events. On the other hand, grouping all fires that occurred at multiple sites within a particular time interval may underestimate the number of unique fire events. For temporal analysis of the number of fires, such over- or under-estimates could be problematic.

Using the site-level fire event information generated from the above procedure, I used inter-site distance and degree of temporal overlap to delineate 'unique' fire events and the time interval (i.e., calendar years) of each unique event. In this process, fire events were compared between or among sites, not within a site since the fire-event delineation procedure had already separated the fire-occurrence information into discrete events. The distance criterion reduced the potential to combine fires of different ignitions that occurred at about the same point in time. Assessment of a well-mapped fire in the study area in 1987 suggested the use of an inter-site distance of 3 km. As an uncertainty assessment of this measure, I additionally used distance criteria of 4 and 5 km. For each distance measure, I applied the same sets of temporal criteria to the fire-event record. Starting with a site, adjacent sites (i.e., within the specified threshold distance) meeting one of the following criteria (described below) were initially aggregated for further evaluation. Sites adjacent to those sites aggregated with the initial starting point, and which satisfied a temporal criterion, were added to the initial aggregate. This continued until no more sites were both spatially and temporally 'connected.' Thus, although the distance requirement pertained only to adjacent sites, widely spaced sites could in fact be aggregated and classified as the same unique fire event if a stepping-stone of sites in between met both the spatial and temporal requirement. I compared results of the three analyses to determine the most appropriate approach for this study.

Temporal criteria varied by the type of evidence used to delineate the site-level events being compared. If the time interval of site-level events of nearby sites (i.e., sites within the specified inter-site distance) overlapped, all site-level events were classified as the same unique fire event. If site-level events had been delineated solely from scar data, then the time interval assigned to the unique event was set to the time interval of the event with 2 scar dates in consecutive years or the event with the greatest number of scar dates (Fig. 7A). If an event was based on scar data and others solely on regeneration information, then a unique fire event was designated only if the start date of the regeneration-interpreted events was within a specified number of years of the start date of the scar-interpreted event (Fig. 7B). Specifically, these criteria were 5 years for 1300-1599, 3 years for 1600-1799, and 1 year for 1800-1996. When evaluating two nearby site-level events with each based solely on regeneration information and with no nearby scar-interpreted events, events could be classified as a unique fire event even though time intervals did not overlap (Fig 7C). I used this approach to account for the greater uncertainty of delineating fire-events with only regeneration data. From 1300-1699, the start years of the two events had to be within 15 years for aggregation into a unique fire event. From 1700-1996, this difference was reduced to 10 years. The beginning year of the unique event was equal to the earliest calendar year plus one-half the difference, in years, between the earliest and most recent calendar year of the two events. The end year of the interval was simply the beginning year plus 10. If the time interval of an event on a site (1) overlapped with that of two nearby events (2,3), and these two events had non-overlapping time intervals, the fire evidence of site 1 was first separated on the temporal and spatial proximity to sites 2 and 3, then the previously described criteria were applied to determine sites forming a unique event and the time interval of the event (Fig 7D).

The unique fire events were used in further analyses of fire extents and in combination with the standardization for site-level record erasure to examine temporal variation of fire frequency (described below).

A.

Site 1

Fire Event 1872-73

Site 1 Fire Evidence		
Year	Scars	Regeneration
1872	2	0
1873	2	0

Site 2

Fire Event 1873

Site 2 Fire Evidence		
Year	Scars	Regeneration
1873	5	0

Time interval of unique fire event = 1873

B. 1726-1728

Site 1

Fire Event 1726-28

Site 1 Fire Evidence		
Year	Scars	Regeneration
1726	1	0
1727	2	0
1728	1	0

Site 2

Fire Event 1723-28

Site 2 Fire Evidence		
Year	Scars	Regeneration
1723	0	1
1724	0	0
1725	0	2
1726	0	1
1727	0	0
1728	0	1

Time interval of unique fire event = 1726-1728

Fig. 7. Example of how unique fire events were generated. Sites represent hypothetical sample sites within 3, 4, or 5 km (See text for explanation).

C.

Site 1 Site 2

Fire Event 1644-54
Start Year = 1644
End Year = 1654

Fire Event 1656-66
Start Year = 1656
End Year = 1666

Unique fire event interval calculation:
1. (1656-1644/2) = 6
2. 1644+6 = 1650 (start year)
3. 1650+10 = 1660 (end year)

Time interval of unique fire event = 1650-1660

D.

Site 1 Site 2 Site 3

Fire Event 1815-1820 Fire Event 1819-1825 Fire Event 1812-1816

Site 1 Fire Evidence

Year	Scars	Regeneration
1815	1	0
1816	0	0
1817	2	0
1818	1	0
1819	1	2
1820	0	1

Site 2 Fire Evidence

Year	Scars	Regeneration
1819	1	0
1820	0	0
1821	0	2
1822	0	0
1823	0	0
1824	0	1
1825	0	1

Site 3 Fire Evidence

Year	Scars	Regeneration
1812	1	0
1813	0	0
1814	2	0
1815	1	0
1816	1	0

Time interval of unique fire event between sites 1 and 2 = 1817-1819

Fig. 7. (Continued)

Fire Regime Descriptors

Fire Return Intervals

Fire return interval is the number of years between two successive fire events (Agee 1993). I used five methods to calculate an arithmetic mean (MFRI) and median fire return interval (medFRI) for each site (Table 2). Methods varied by the required number of fires and the time since the last recorded fire event. In the first three methods, I calculated a mean return interval only if at least four fires were recorded (i.e., providing at least three intervals). The first method excluded the last interval. The last interval is the time-since-the-last-fire-interval (TSLFI) during which no fires were recorded at a site. Among the second and third methods, the TSLFI was included only if the interval was >71 years or if the interval was ≥200 years. Including or excluding the TSLFI emphasizes different aspects of the fire return interval, such as TSLFI's within 71 years of 1996, which is the fire suppression period, or TSLFI's ≥200 years, which emphasizes long return intervals. The last two methods lacked a minimum number of fires and either included or excluded the last fire interval. Because the time tag of a fire event was an interval, I used the average or majority year in calculating return intervals.

Table 2. Methods for estimating fire return intervals.

Method	Criteria
1	Sites with at least 4 fire events not including the time-since-last-fire interval (TSLFI).
2	Sites with at least 4 fire events including the TSLFI whose last fire occurred before 1925 (i.e. TSLFI >71 years).
3	Rule set 2 plus sites with a ≥200 year interval, which includes TSLFI's ≥200 years.
4	All intervals not including the TSLFI.
5	All intervals including the TSLFI.

Where applicable, I also calculated Weibull median probability intervals (WMPI's), another measure of central tendency. The Weibull distribution is generally a better fit than the normal distribution for fire intervals, since fire return interval distributions are usually skewed toward short intervals (Johnson and Gutsell 1994). The WMPI was calculated using FHX2 software with sites having at least 4 fire events (Grissino-Mayer 1997).

Watershed averages, referred to as composite measures of MFRI, medFRI, and WMPI, were calculated by averaging across site-level measures.

Fire Extent

Explicit delineation of the spatial extent of fires was not possible owing to my sampling scheme. However, I characterized minimum extent of large fires (i.e., unique fires recorded at $\geq$3 sites) by number of sample sites and the number of 2-km^2 grid cells recording the event.

Fire Severity

I also could not directly quantify severity of individual fire events. Instead, I used several indirect measures. I assumed that fire severity was inversely related to fire frequency (Table 3) (Heinselman 1973; Agee 1993). I mapped site-level MFRI (using Table 2, Rule Set 5) and fire frequency, and assessed patterns. Also, I graphed selected regeneration and fire scar data to assess trends.

Temporal Patterns

Standardization for Site-level Record Erasure

The tree-ring-interpreted fire history of each site extended back in time only as long as a site's oldest tree. Across the watershed, the number of sites available to record events decreased with increasing time since the present. Of the 117 sampled sites, 15%

Table 3. Fire regime types defined by frequency and severity (Heinselman 1973; Agee 1993).

Description of fire regime
1. Infrequent light surface fire (more than 25 year return intervals).
2. Frequent light surface fires (1-25 year return intervals).
3. Infrequent, severe surface fires (more than 25 year return intervals).
4. Short return interval, crown fires (25-100 year return intervals).
5. Long return interval, crown fires and severe surface fires in combination (100-300 year return intervals).
6. Very long return interval, crown fires and severe surface fires in combination (over 300 year return intervals).

provided records by the year 1510, 45% by 1600, 75% by 1700, and 100% by 1878 (Fig. 8). Without accounting for site-level record erasure, fire frequency estimates can artificially decrease from the present to the past. I used the following to adjust numbers of unique fire events:

Number of standardized fire events per unit time at time T =

No. of fire events per unit time * (cumulative no. of available sites at time T /total no. of sites)

where the cumulative number of available sites at time T was the sum of sites available to record fire events prior to time T (Table 4). I assumed that detectability of a fire was directly dependent on the number of sites with trees old enough to record.

Standardized fire events were used to examine temporal variation of fire frequency (described below).

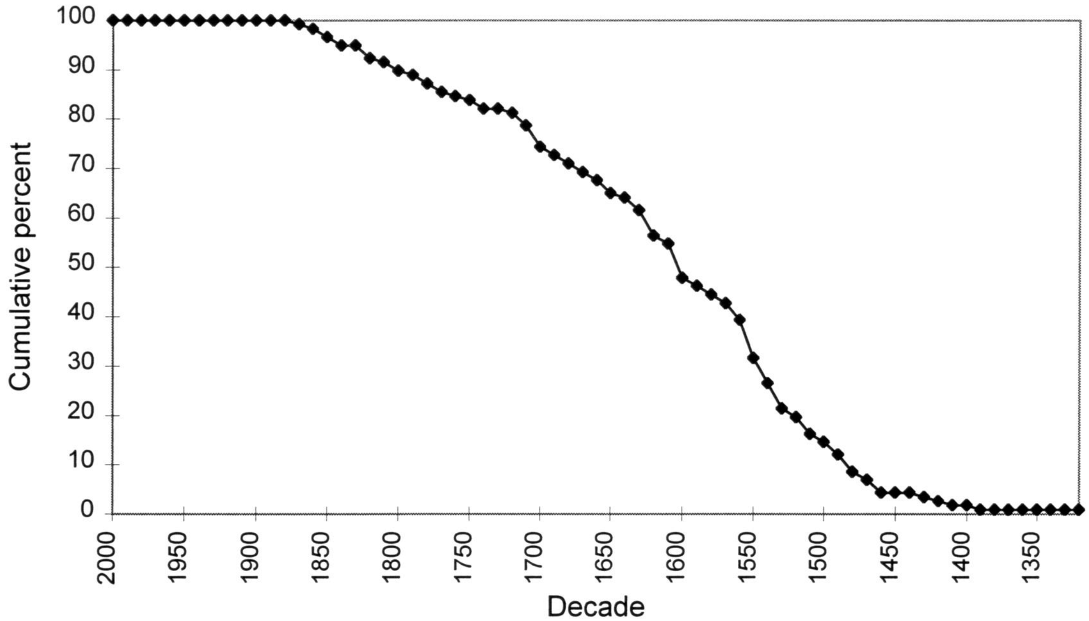


Fig. 8. Cumulative percentage by decade of the number of sampled sites containing evidence of fire.

Table 4. Example of standardization of fire events, 1800-1890.

Decade	No. fire events	Cumulative no. available sites	Standardized no. fire events
1890	26	117	26.00
1880	29	117	29.00
1870	25	117	25.00
1860	16	116	16.14
1850	36	115	36.63
1840	33	113	34.17
1830	16	111	16.86
1820	19	111	20.03
1810	15	108	16.25
1800	12	107	13.12

Temporal Variation of Fire Frequency

I used the relative change in fire frequency to identify temporal periods in the fire regime. I first compared cumulative frequency trends based on non-standardized and standardized, unique fire events. Results were similar with only slight differences during the 1300-1400's when much of the record was limited. Given this similarity, I used standardized unique fire events in assessment of temporal variation. I used a chi-square test to evaluate differences in numbers of fires per year among delineated time periods.

Fire frequency may be underestimated during the most recent time periods. There was a potential bias against sites that burned severely since 1900, and even during the 1845-1899 period, to not be sampled. Fire history sampling occurred in harvested areas. Any stands that may have burned severely since approximately 1900 may not have had enough timber volume to harvest.

Spatial Patterns

Dispersion of Fires

I evaluated dispersion of historical fires using point pattern analysis. This analysis uses the ratio of observed to expected mean minimum distance to determine type of dispersion (Krebs 1989). A ratio equal to 1 indicates randomness, aggregated patterns result in a ratio <1, and a regular pattern produces a ratio >1. For each decade, minimum distances between all possible pairs of sites recording fires were calculated using the centroid UTM of sites, and averaged to generate an observed mean nearest neighbor distance (MNND). Because sampled clearcuts were not randomly located, and not every 2-km^2 cell of the sampling grid was sampled, I used a Monte Carlo method (Krebs 1989) to calculate expected MNND. An average, expected MNND was generated from 300 replicates of n randomly selected sites for each decade, where n equaled the number of recording fires.

Fire Frequency

Spatial patterns of historical fires provide evidence of one or more spatially distinctive fire regimes for a given area. I compared site-level fire frequencies to their site-level topographic variables for the length of the record and for the time periods delineated in the temporal analysis. To do this, I used descriptive statistics and Spearman's rank correlation between numbers of fires per 100 years and topographic variables, and maps of fire frequency. Spearman's rank correlation could not be calculated for the 1900-1925 and 1926-1996 periods because the fire frequencies lacked adequate variation.

Topographic variables included elevation, slope position, percent slope, and aspect. Except for aspect, the topographic variables were calculated in a Geographical Information System (GIS) (ESRI 1997) using a 30-m resolution digital elevation model (DEM). Elevation was the average elevation of all pixels within each sampled clearcut. Slope position was calculated as a relative value from valley bottom to ridgetop (1 = valley; 100 = ridgetop) (Hatfield 1996), averaged across pixel-level values for each sampled clearcut. Landscape slope was calculated from percent slope. Using the 30 x 30-m percent slope coverage, a 41 x 41-pixel moving window generated a new percent slope value for each centroid pixel. At interfaces between plateaus and steep terrain, percent slopes were calculated with a 9 x 9-pixel moving window. Mean landscape slope for sites was derived by averaging the new percent slope values at each clearcut. For aspect, I used the cosine of the field-measured aspect averaged at each site (Beers *et al.* 1966). North equaled +1, south equaled -1, and east and west both equaled zero.

Regression Analysis

I used regression analysis to evaluate the relationship between fire frequency and topographic variables. I used site-level elevations, slope position, landscape slope, and aspect as explanatory variables and examined all two-way interactions. The best final regression model for all analyses was selected with a backwards elimination stepwise procedure using a entry level p-value of 0.05. Although I tried other variations of the aspect transformation (i.e., east and west as opposite values) (Beers *et al.* 1966), only north and south as opposites was selected by the regression analyses. Type III contrasts were computed for each effect.

Analyses were carried out for the full record from 1313 to 1996 with the GLM Procedure of SAS (SAS 1990). The response variable was the natural log of the number of fires per site divided by the years of the site record. A log transformation gave the response variable a normal distribution. Graphs of residuals were examined to assess goodness-of-fit.

For each time period, analyses were carried out with the GENMOD Procedure of SAS (SAS 1997). The response variable was the number of fires per site per time period. The temporal length of each site's record was included as an "offset" variable. When a response variable is not normally distributed, such as with these data, a nonlinear "link function" is chosen for the generalized linear model based upon the distribution of the response variable and thereby allowing a "linear" regression analysis (Ramsey and Schafer 1997). Data were best modeled with a Poisson link function. With the GENMOD Procedure, scale parameters, deviance, and AIC tests were used to assess goodness-of-fit.

Predicted Landscape Pattern of Fire Frequency

I input the final regression analysis models into a GIS raster module (ESRI 1997) and predicted the number of historical fires for every pixel in the study area. Topographic measures of each pixel were calculated using the same methods employed to generate explanatory variables in the regression analysis. The resulting map spatially illustrated the predicted relationships between fire frequency and topography.

RESULTS

Fire History Reconstruction

Fire Event Rule Sets and Comparison

Mean numbers of fires per site varied from 2.9 fires to 6.2 fires among the eight rule sets evaluated (Fig. 9). Rule Set A was conservative because it distinguished fires only when 4 scars were in a scar cohort. Rule Set H was liberal because it distinguished fires whenever 2 scars were in a scar cohort. Most of the rule sets fell between these two extremes. Mean numbers of fires per site for Rule Sets B, C, D, and E were similar, ranging from 4.2 to 4.8. These four rule sets required similar numbers of scar and regeneration dates for fire events (Table 1) resulting in only slight differences in the numbers of fires per site.

Both Rule Set D and E had almost the same total number fires (Fig. 9), but their criteria were quite different (Table 1). Rule Set E had less stringent scar criteria and more stringent regeneration criteria. I used Rule Set D for further analyses. Rule Set D reflected matches between recent fire events and the fire records and aerial photos. Also, most of the rules operated on a sliding time scale, relaxing the rules further back in time, accounting for decreasing data due to record erasure. Numbers of scars and regeneration over time were used to determine when and how much to relax the rules. This rule set identified 501 fire events at the 117 sites over approximately 683 years.

Unique Fire Events

The three distance rule sets produced similar results (Fig. 10). Trends in the unique numbers of fires followed that of the non-standardized data. There were few fires in the 1300's and 1400's as a result of record erasure. The number of fires increased gradually through 1850 and dropped sharply after 1900. Peaks on numbers of unique fire events were lower for the site-level data. This was probably because at times when more fires occurred, both large and small fires were likely. During decades with fewer than 5 fires, such as during the 1300's, 1400's, and 1900's, the number of unique fires was similar to the number of site-level fires.

I based unique fires used in further analyses on the 4 km rule set. This rule set usually distinguished unique fires at sites adjacent to each other. It resulted in 35% fewer fires than the site-level fires (Table 5). Only one fire event was interpreted as occurring across seven sites, the maximum number of sites recording a unique fire event.

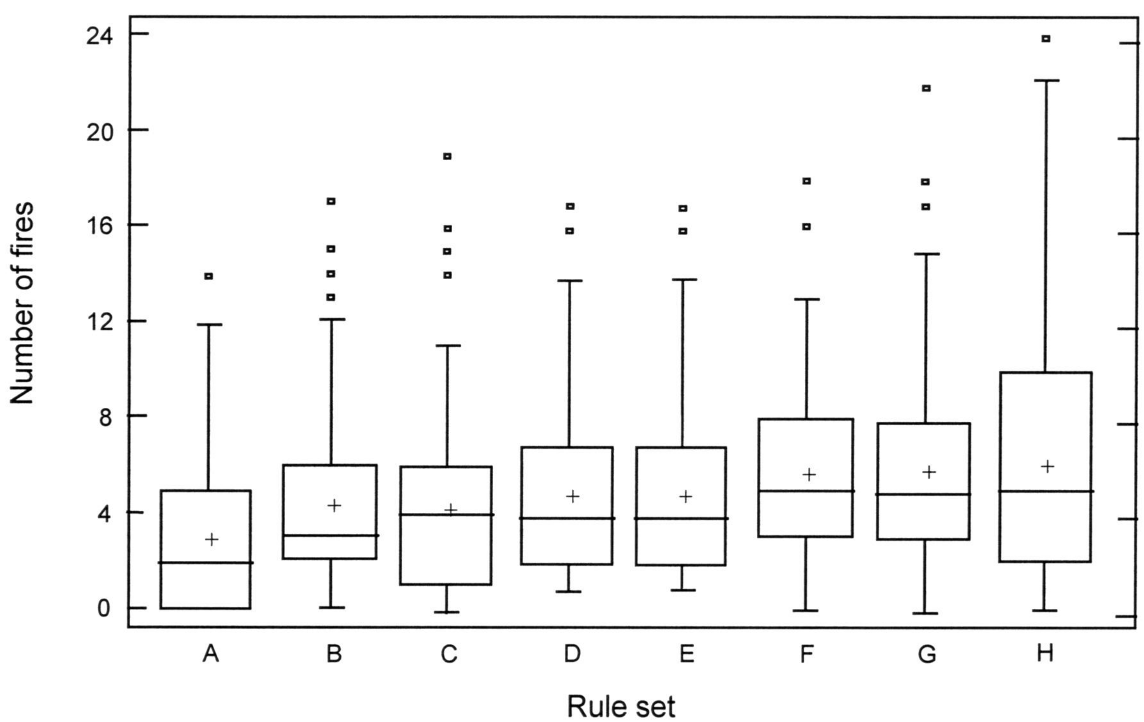


Fig. 9. Box-and-whisker plot of fire counts per site from eight fire event rule sets. The line within each box represents the median, the plus sign is the mean, and the small squares above each set of boxes are outliers.

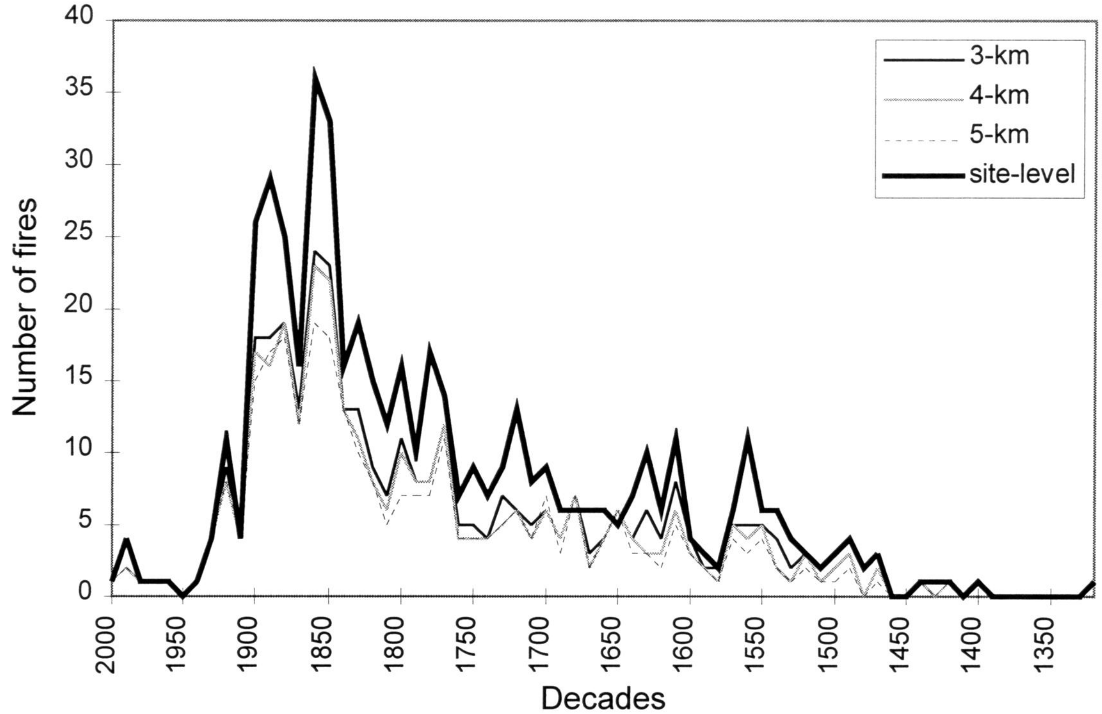


Fig. 10. The number of unique fires adjusted by three distances compared to the site-level number of fires per decade.

Table 5. Unique fire events based on the 4 km method (see Methods for description).

No. sites recording the same fire event	No. unique fire events	%
1	201	62
2	70	21
3	33	10
4	12	4
5	3	1
6	6	2
7	1	<1
Totals	326	100

Fire Regime Descriptors

Fire Return Intervals

Fire return intervals pooled among all sites, ranged from 2 to 520 years with most of the intervals between 2 and 125 years (Fig. 11). The fire return intervals approximated a Poisson distribution. The composite MFRI's, medFRI's, and WMPI's fire return intervals averaged among sites varied among the different methods for calculating fire return intervals (Table 6). MFRI's ranged from 61 to 136 years. MedFRI's ranged from 44 to 123 years. The WMPI for sites with at least three return intervals, ranged from 45 to 72 years. WMPI was only applicable at the sites with highest fire frequencies as were Rule Sets 1 and 2, hence these do not represent fire frequency for the whole study area. Individual site-level fire return intervals using Rule Set 5 was quite variable (24 to 520 years) (Fig. 12).

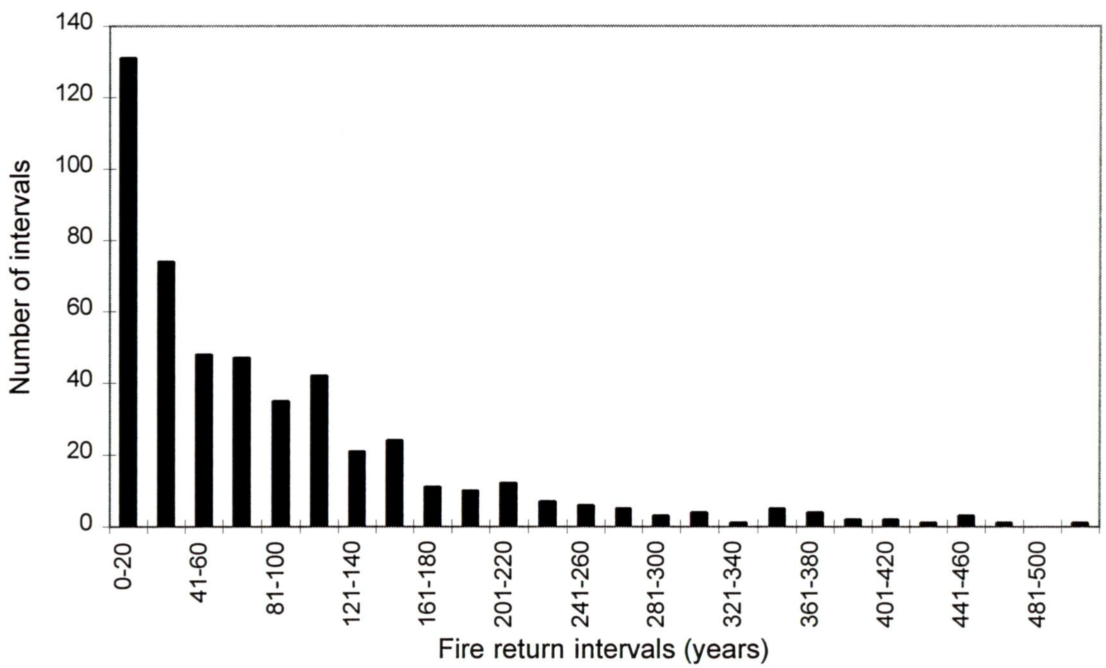


Fig. 11. Number of fire return intervals of all fires, irrespective of site, including the time-since-last-fire interval.

Table 6. Results of the different fire return interval rule sets calculated for the length of the record (see Table 2 for rule set descriptions).

Rule set	Mean fire return interval[a]	Median fire return interval[a,b]	Mean S.D.[c]	Weibull mean probability interval	Number of sites	Mean number of intervals per site
1	61	44	58	45	58	5.6
2	103	71	73	72	80	5.5
3	141	115	76	na	97	4.8
4	101	90	77	na	96	4.0
5	136	123	78	na	117	4.3

[a] Means and medians for sites with only one interval are equal to that interval. These numbers are included in the composite MFRI and medFRI calculations.

[b] Medians calculated with two values are the same as the mean and are included in the composite medFRI calculations.

[c] Standard deviation.

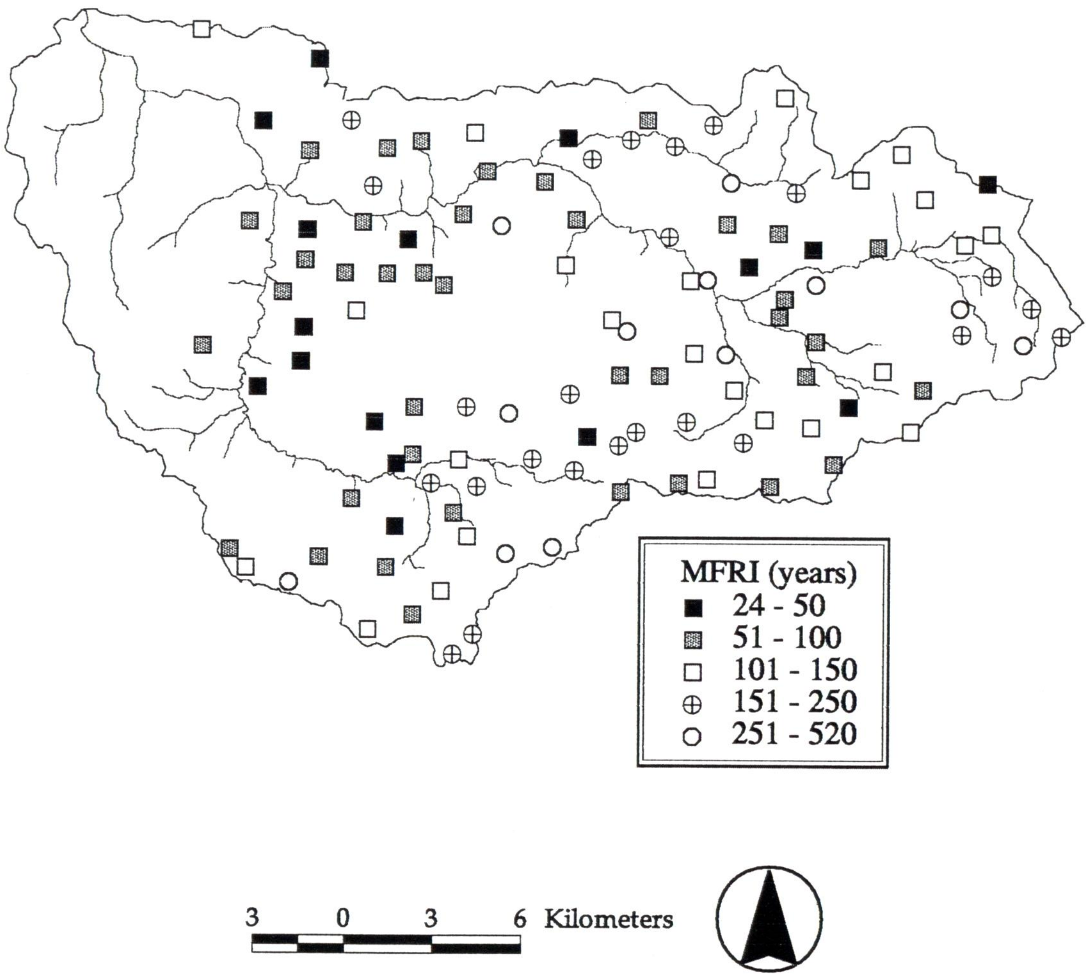


Fig. 12. MFRI at each site using fire return interval Rule Set 5.

Fire Extent

Compared to the number of small fires (i.e., fires detected at fewer than three sites), there were few large fires, and even they were relatively small. Less than 18% of all sampled fires were classified as large (Table 5). Of these, 78% occurred among three to four sampled sites. Large fires were more frequent during the 1800's (Fig. 13). The 1840's experienced four large fires, the highest number of large fires throughout the fire history record. The large fires during the 1800's were not the most extensive (Table 7). The most extensive fire detected spanned seven sites, with a maximum distance of 5.9 km between the farthest sites. The maximum average distance between sites of large fires was 4.6 km. Small fires detected at two sites were required by the unique 4 km rule set to be within 4 km, but the average distance between sites recording the same fire event was 2.5 km.

Large fires were small relative to the extent of the study area (Figs. 14-17). In several cases, such as the 1600-1609 fires (Fig. 14), I found one large fire with intervening sites that did not record the fire. The lack fire evidence at intervening sites may be due to; (1) actual absence of the fire, (2) lack of a detectable record, or (3) undersampling (i.e., fire occurred and left a record, but I did not pick it up in my sample). Also, during years with many fires, non-contiguous fires appear to have burned multiple sites, as indicated by several discrete patches of contiguous sites recording an event (Figs. 14-17).

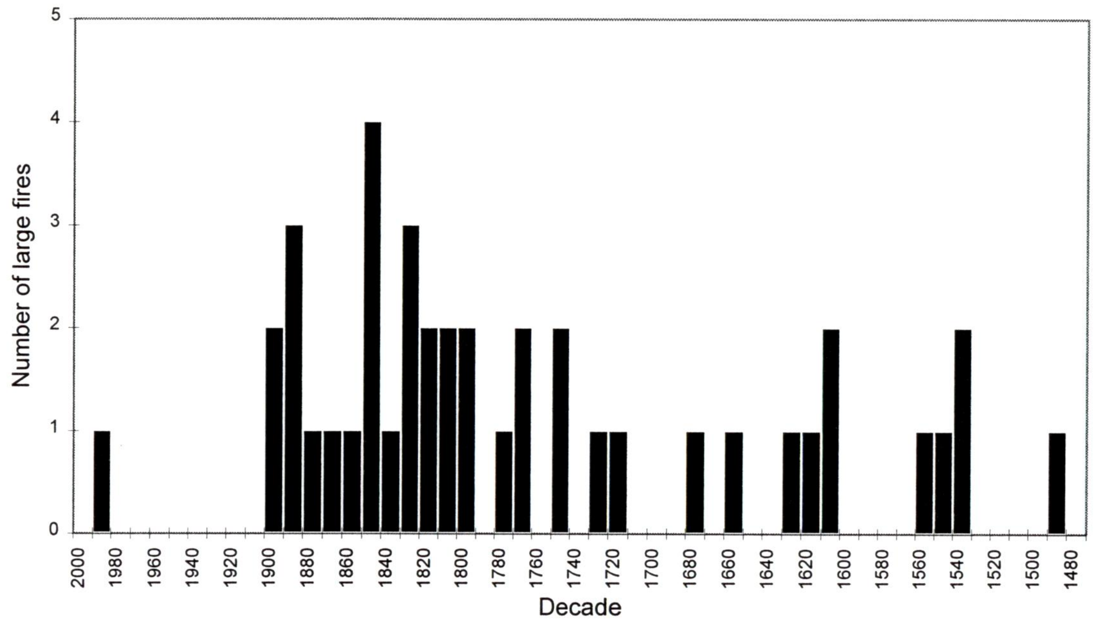


Fig. 13. Frequency distribution of large fires (i.e., fires detected at ≥3 sites) by decade.

Table 7. Number of sites detecting large fires (i.e., fires occurring at ≥3 sites). Large fires were determined from the 4 km and unique fire rule sets. Number of 2-km^2 grid cells is an approximate index of fire extent.

Majority fire event year	Number of sites	Number of 2-km^2 grid cells
1481	4	3
1530	3	3
1531	4	4
1540	4	4
1544	3	2
1551	3	3
1604	6	6
1604	3	3
1619	6	6
1622	6	5
1654	3	3
1675	4	4
1711	5	4
1726	4	3
1744	3	3
1744	3	3
1764	3	3
1770	7	6
1778	3	3
1794	3	3
1797	5	5
1803	3	3
1805	3	3
1818	3	3
1820	4	4
1821	3	3
1826	4	3
1827	4	3
1836	3	3
1845	4	3
1849	4	4
1849	3	3
1849	4	4
1852	5	4
1860	3	3
1872	3	3
1883	3	3
1884	4	4
1887	6	6
1897	3	3
1897	3	3
1987	3	2

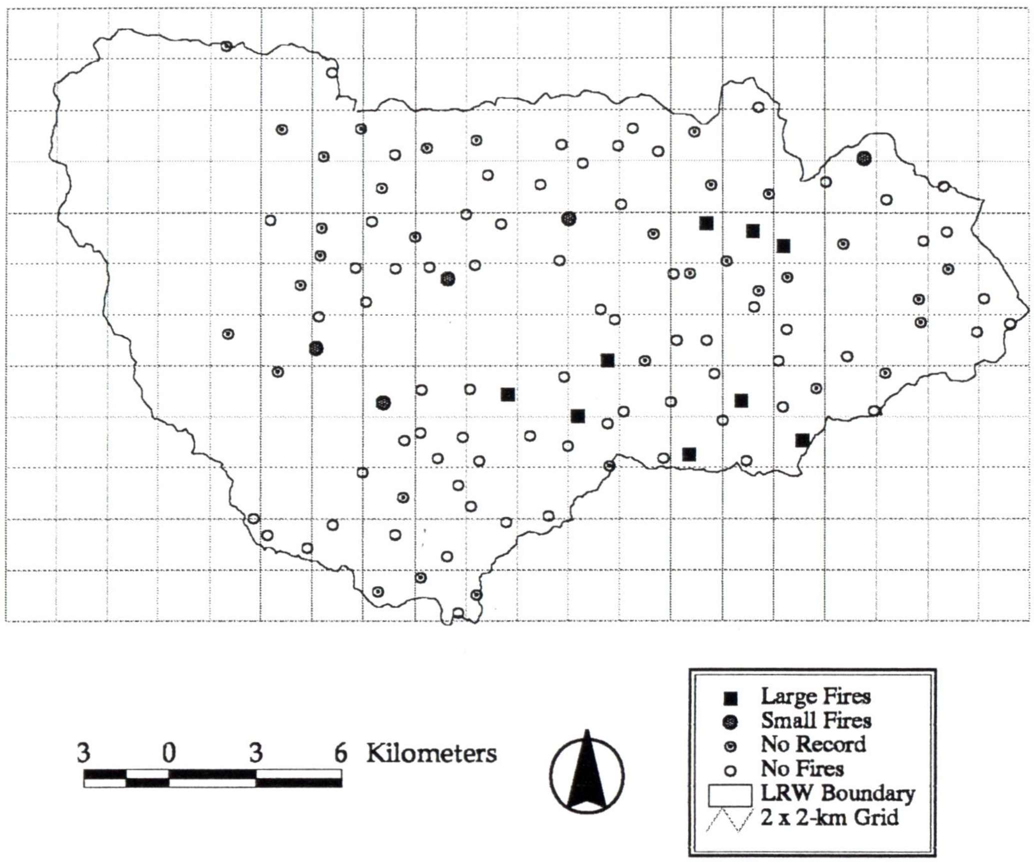


Fig. 14. Small fires and two large fires between approximately 1600-1609. No record sites lacked data due to site erasure.

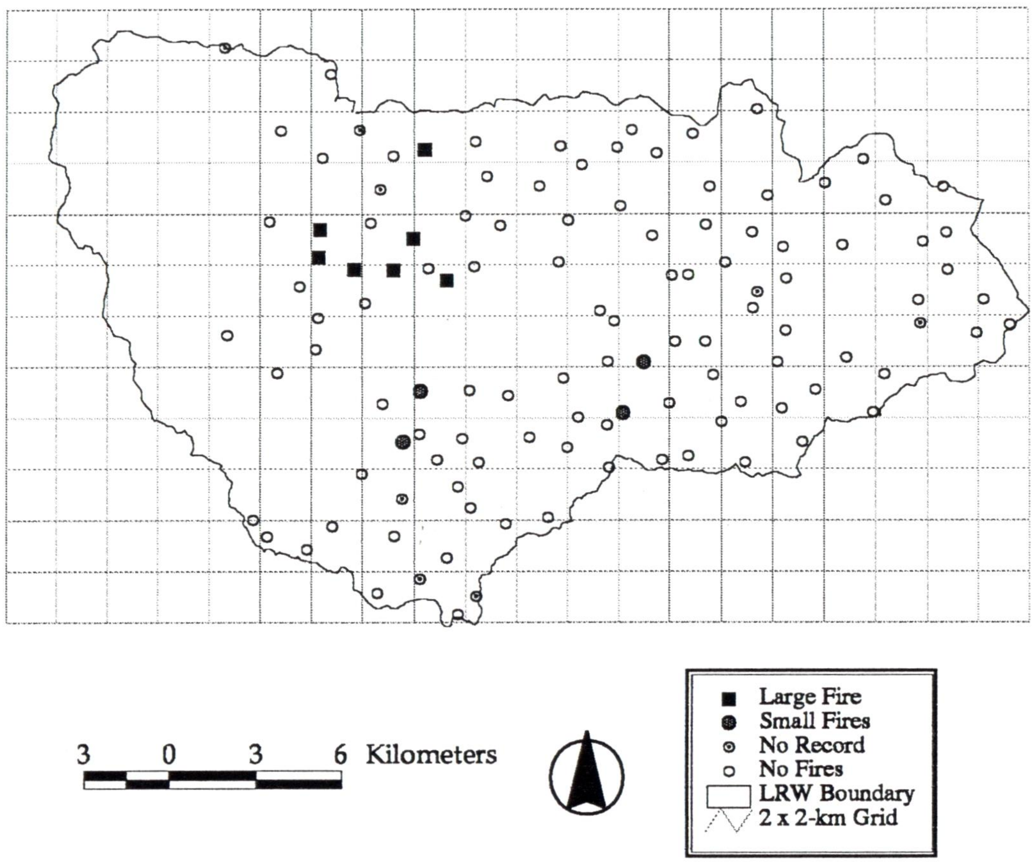


Fig. 15. Small fires and one large fire between approximately 1769-1771. No record sites lacked data due to site erasure.

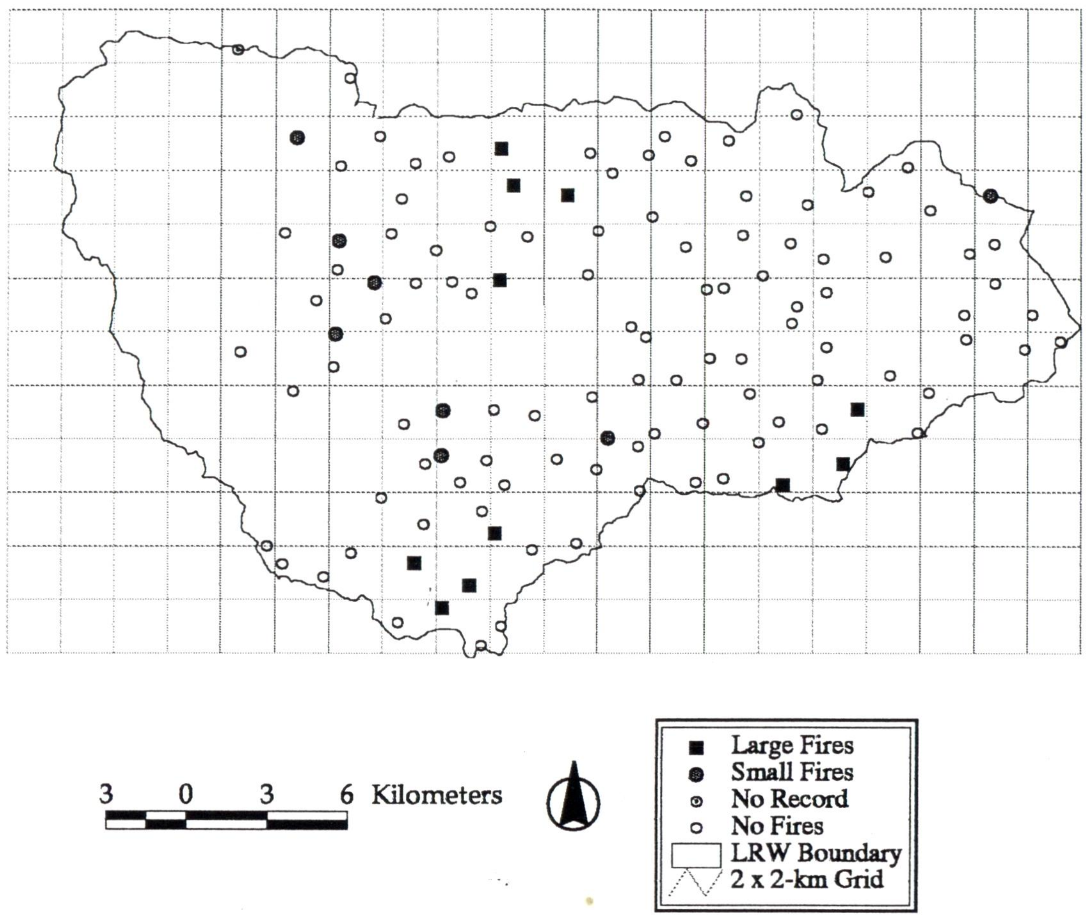


Fig. 16. Small fires and three large fires in approximately 1849-1850. No record sites lacked data due to site erasure.

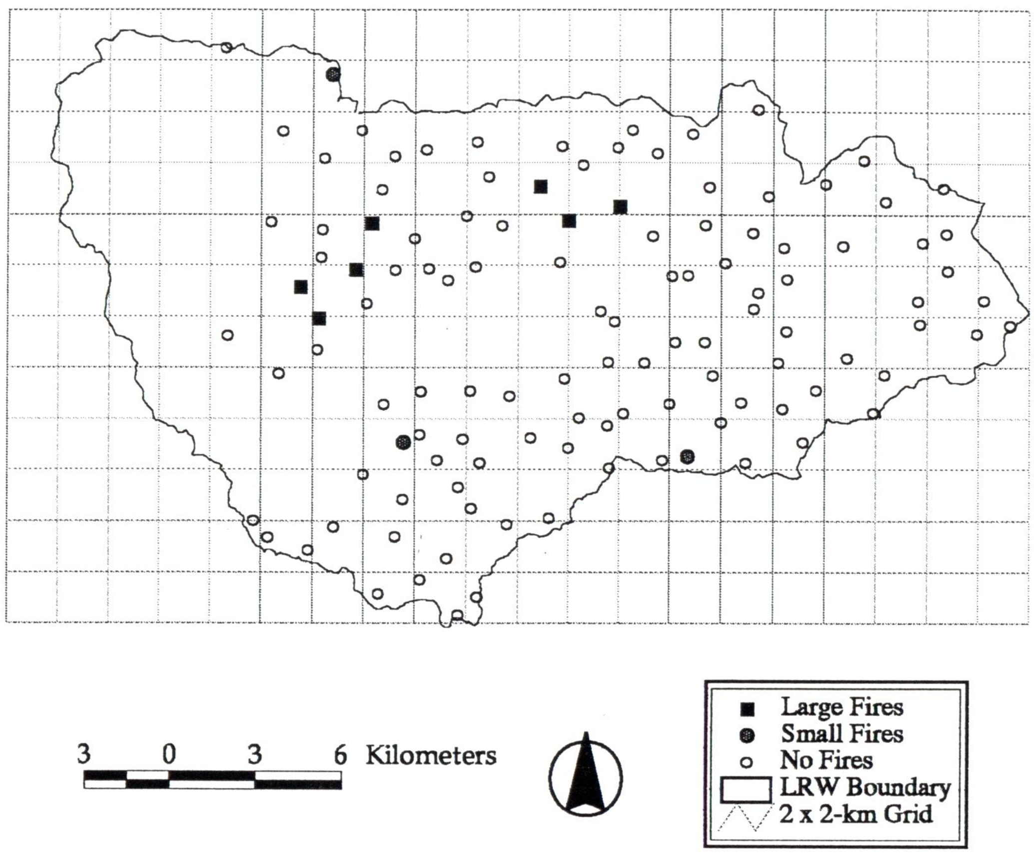


Fig. 17. Small fires and two large fires in approximately 1883-1884.

Fire Severity

The fire record was variable from site-to-site evidenced by the site-level MFRI's (Fig. 12), numbers of fires per site (Fig. 18), and examples of scar and regeneration distributions (Figs. 19-22). The mean number of fires recorded per site was 4.3 (S.D. = 2.8) (Fig. 18), which suggests low to moderate severity burning.

Sometimes it is assumed that the earliest fire recorded at a site was a severe, stand-replacement event because a large cohort of regenerating trees is present and there are no survivors. Among the 117 sampled sites, only 18% of the sites recorded only one fire. These are assumed to have been high severity. The earliest fire recorded at the remaining 82% of sites may have been stand-replacement, but these sites experienced non-severe fires as well, since they recorded more than one fire. Another consideration is that 33% of all 117 sites had remnant old-growth trees that survived the earliest recorded fires. These sites had no evidence of high severity fire.

Sites recording numerous fires had many regeneration and scar dates in various combinations. Although much uncertainty is involved in interpreting the severity level of individual historical fires, severity interpretations can be inferred from the regeneration and scar date distributions. Site 280041, for example, recorded three fires over 450 years (Fig. 19). The first fire was distinguished based on regeneration dates, and the following two on scar dates alone, so that the first fire was interpreted as a stand-replacement event and the following fires were of lower severity. Of the four fires recorded by site 380034 (Fig. 20), two were distinguished on the basis of both regeneration and scar dates. Twelve fires were distinguished from the site 290055 record (Fig. 21). Based on scar date evidence, many of the fires occurred within several years of one another, which is interpreted as indicating low severity fires. Sites recording only one fire usually had only regeneration, and suggested a stand-replacement event with no subsequent fires (Fig. 22).

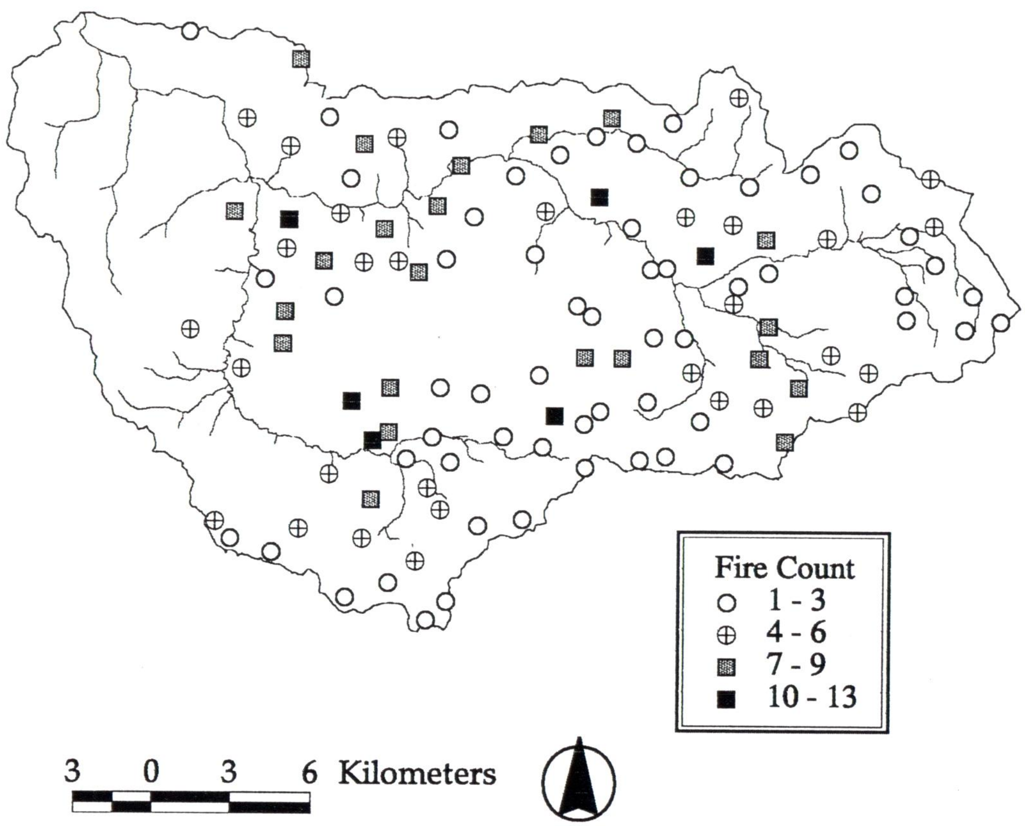


Fig. 18. The number of recorded fires at each site.

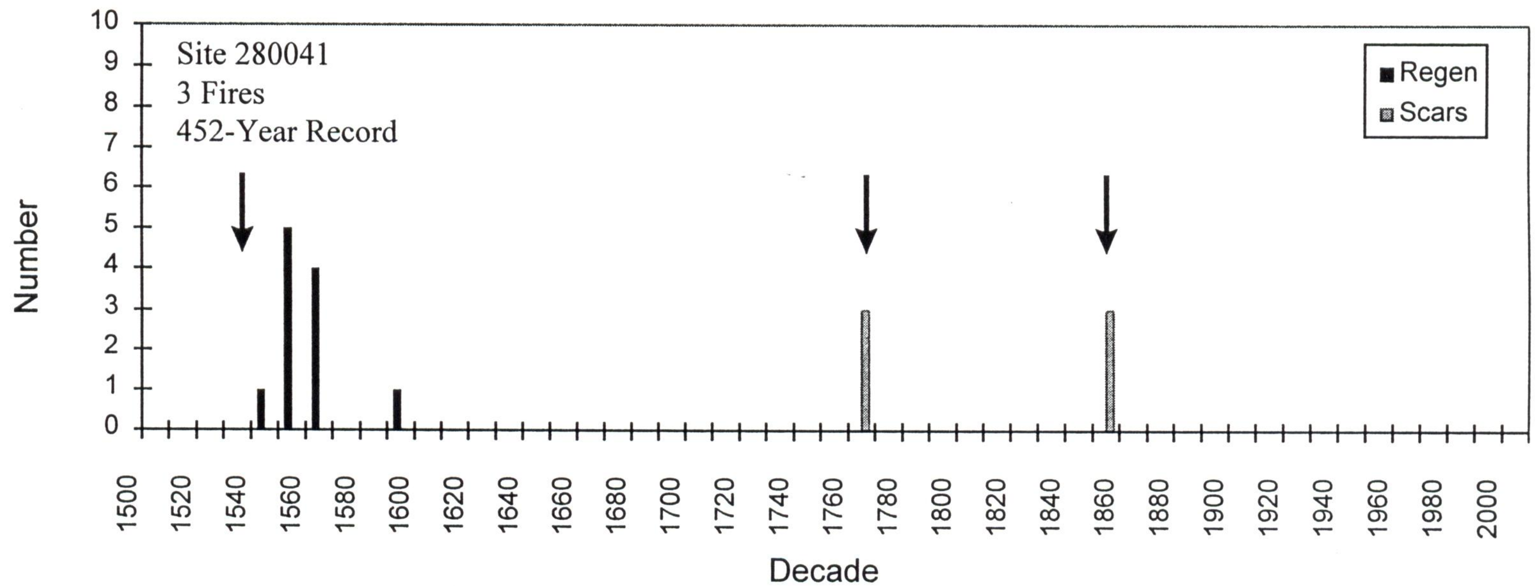


Fig. 19. Site 280041 regeneration and fire scar distribution. Fires are indicated by arrows.

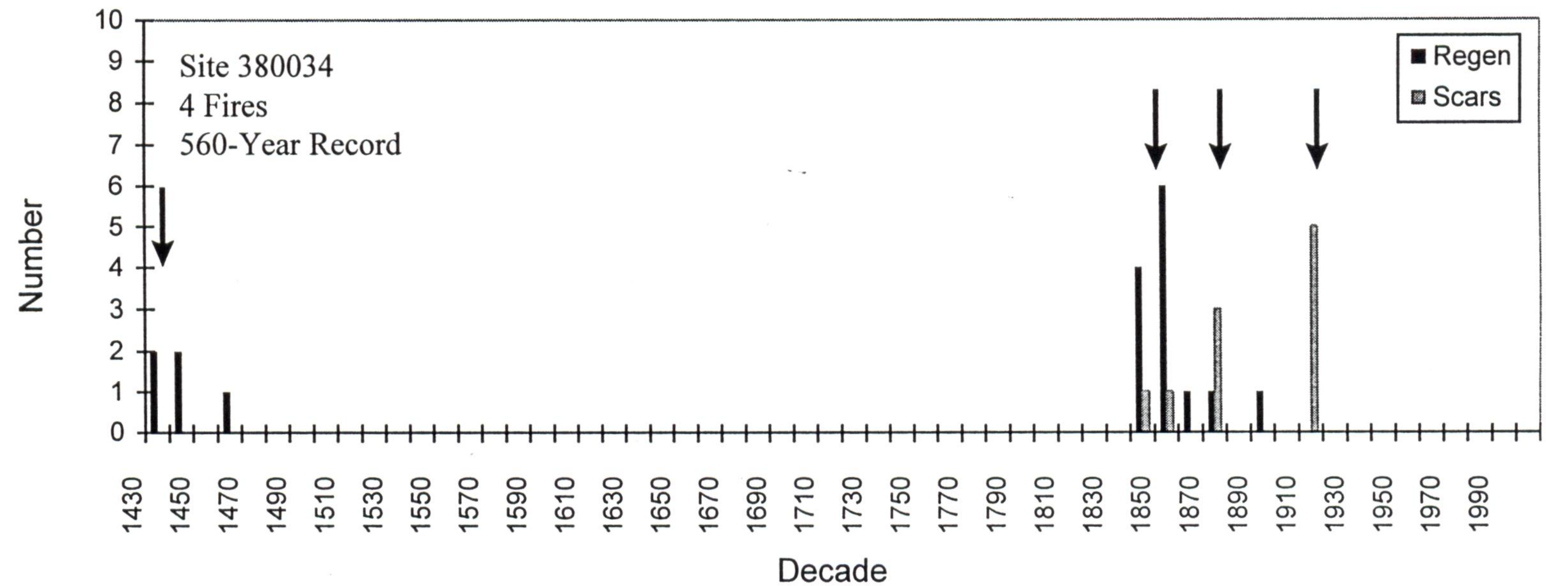


Fig. 20. Site 380034 regeneration and fire scar distribution. Fires are indicated by arrows.

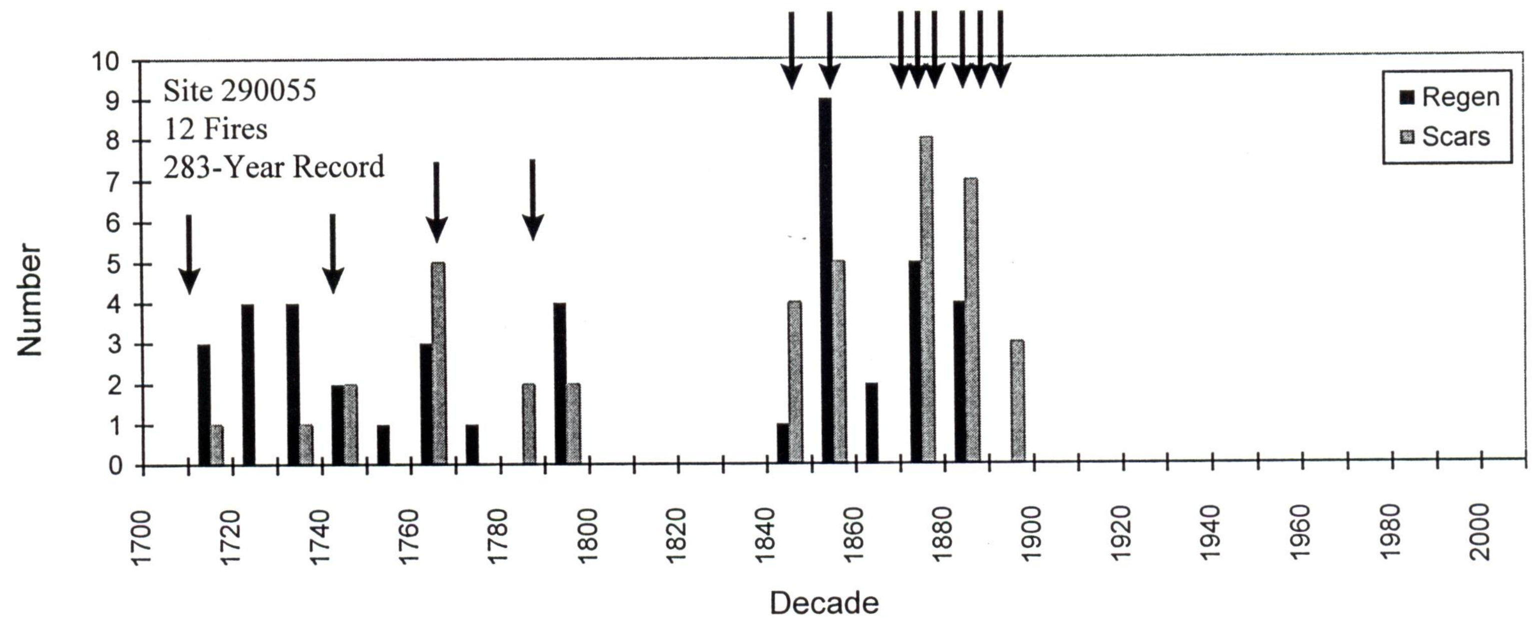


Fig. 21. Site 290055 regeneration and fire scar distribution. Fires are indicated by arrows.

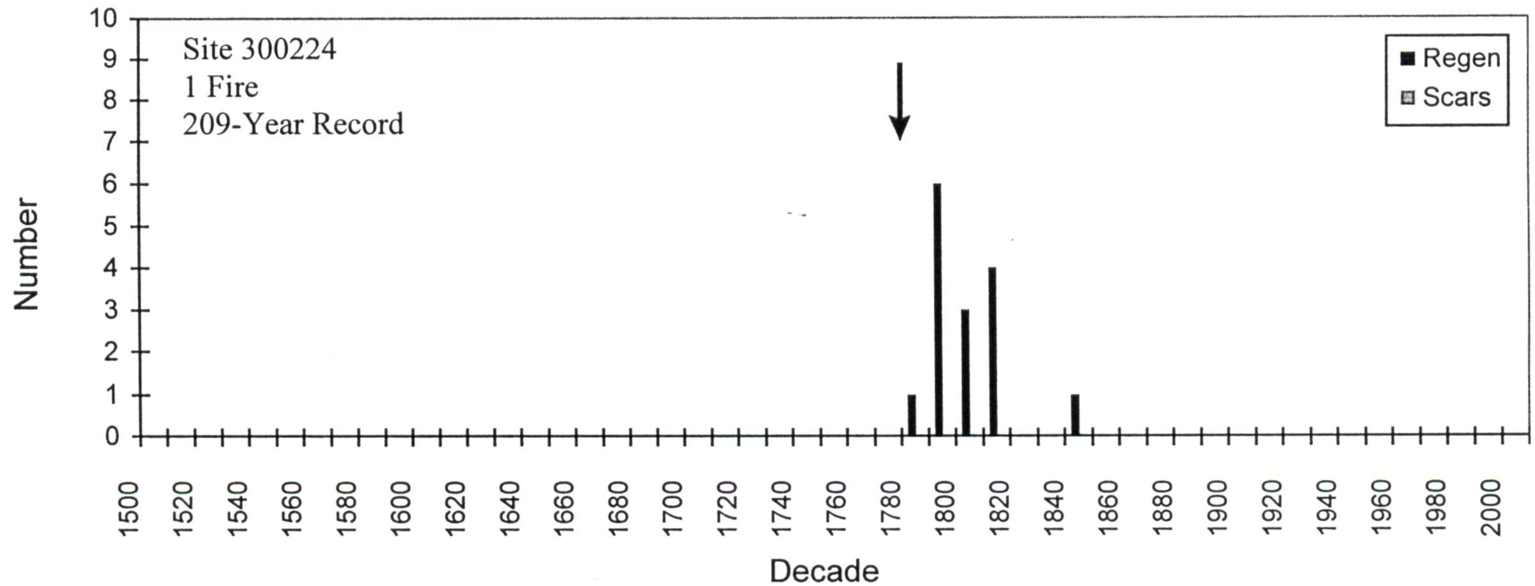


Fig. 22. Site 300264 regeneration and fire scar distribution. Fires are indicated by arrows.

<u>Temporal Patterns</u>

Standardization for Site-level Record Erasure

The standardization approach proportionately added fires to decades which had less than the total 117 sites available (Fig. 23). During the 1300's and 1400's, the standardized number of fires surpassed the number of non-standardized fires found at any time (Fig. 23), due to fewer sites available to record fire (Fig. 8). The non-standardized values showed some change in the number of fires during the 1500's. By the mid-1600's, over 50% of the sites were recording fires, and the standardized and non-standardized data were similar.

These results demonstrate the inadequacy of the early fire history record for temporal analysis. To avoid using exaggerated values of fire frequency, I established 1490 as the earliest year for temporal analysis.

Temporal Variation of Fire Frequency

Trends in the cumulative number of fires between 1490 and 1996 suggested five time periods of different fire frequencies (Fig. 24; Table 8), approximately 1490-1569, 1570-1844, 1845-1899, 1900-1925, and 1926-1996. Fires occurred at a high rate of 11.7 fires per decade from 1490 to 1569 and 19.8 fires per decade from 1844 to 1899. The 1570 to 1844 time period was relatively long, and the rate of fire occurrence was lower, at 7.5 fires per decade. From 1900 to 1925, the fire occurrence rate was similar to 1570-1844, but it dramatically decreased to 1.0 fire per decade from 1926 to the present, the lowest fire occurrence rate during the 506-year record. The Chi-square test between the number of fires for the five time periods indicated a significant difference ($X^2 = 142$, 4 d.f.; $P < 0.0005$).

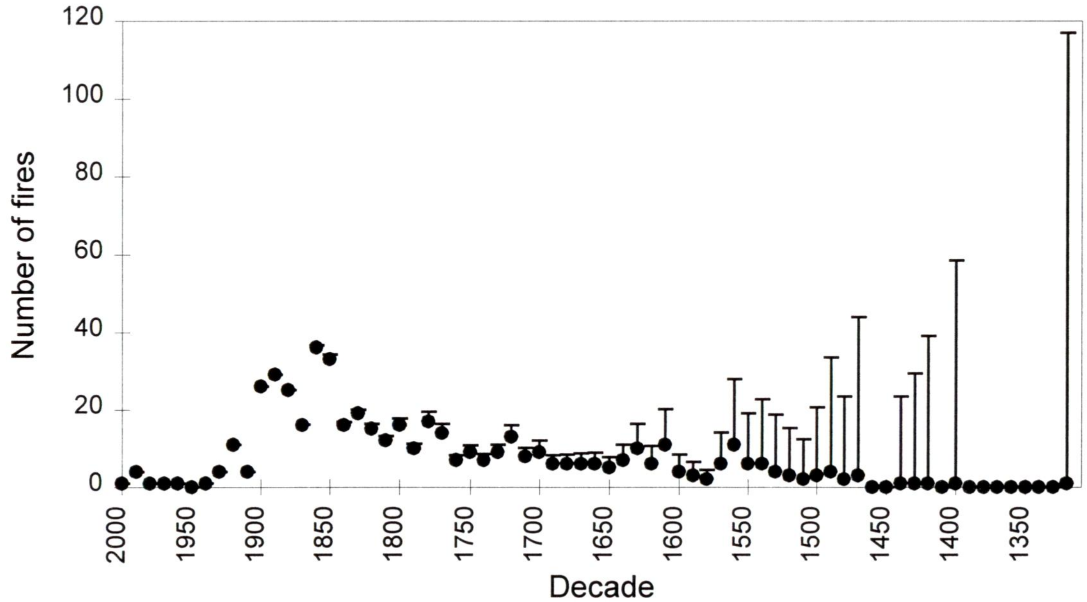


Fig. 23. Non-standardized (●) and standardized (shown by the bar) number of fires per decade.

Table 8. Number of fires, duration of time period, and fires per decade for each time period delineated from the cumulative distribution of unique, standardized fire counts.

	Time Periods				
	1490-1569	1570-1844	1845-1899	1900-1925	1926-1996
Fires	93.4	205.7	106.7	16	7
Years	80	275	55	26	70
Fires/decade	11.7	7.5	19.8	6.2	1.0

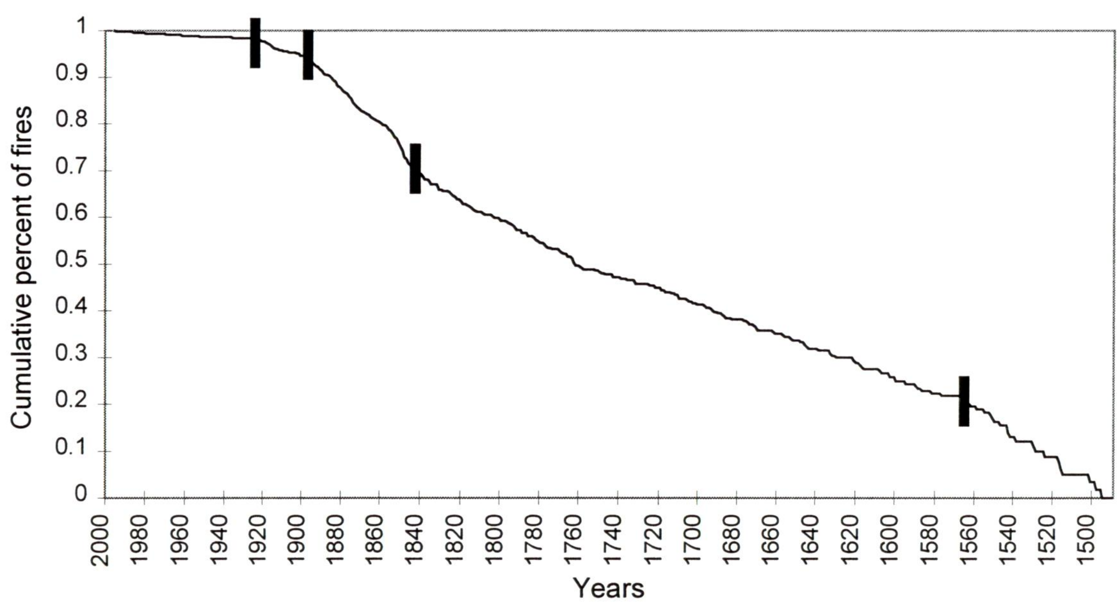


Fig. 24. The cumulative proportion of fires for the combined unique, standardized data set, 1490-1996. The vertical bars indicate changes in the slope of the curve.

Spatial Patterns

Dispersion of Fires

The mean dispersion index for fire events summed by decades suggested a spatially random pattern (mean = 0.88; S.D. = 0.37) (Fig. 25). Several decades, such as 1500, 1570, 1660, 1920, and 1980, had low dispersion index values, suggesting an aggregated pattern, but these decades had only two to four sites recording fires within approximately 2.4 km of one another. In other decades, relatively few sites experienced fire, but those sites were farther apart, and their dispersion indices were closer to one. Thus, when few fires occurred during a decade, the fires were randomly dispersed. Decades with many small fires and several large fires, such as the 1840's, also had a randomly dispersed pattern.

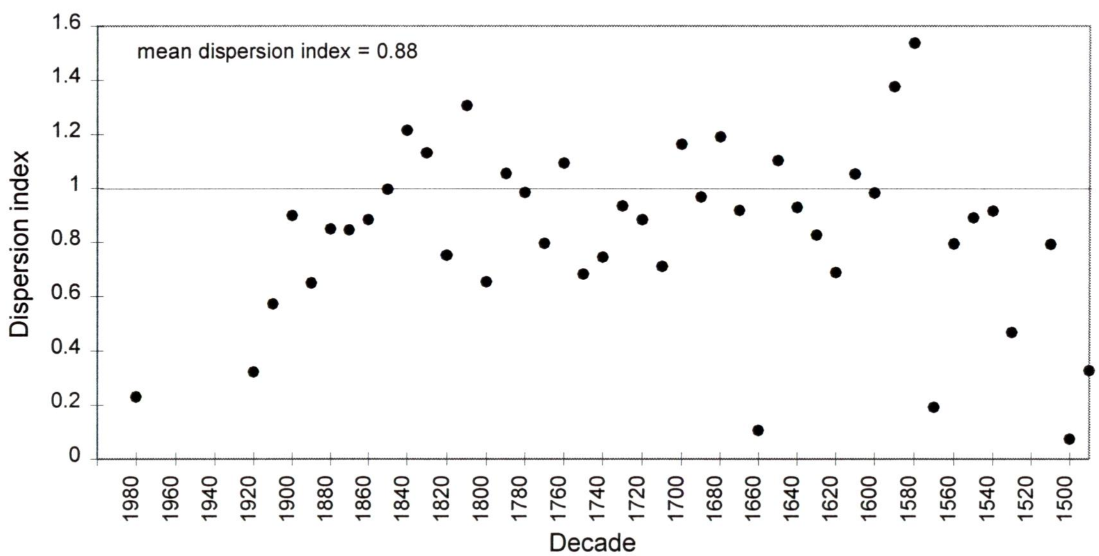


Fig. 25. Dispersion indices for decadal fire events. A decade must have at least 2 sites with fires for a dispersion index to be calculated. A dispersion index of 0 indicates a clustered pattern, 1 indicates a random pattern, >1 indicates a regular pattern. Standard error bars were not displayed as they were not larger than the dots.

Fire Frequency

Fire frequencies varied among sites. Summed over the entire observed record, the number of fires per sampled site ranged from 1 to 13 (Fig. 18). There were 0.1 to 4.2 fires per 100 years per site (Fig. 26). At 51% of the sites, less than 1 fire occurred per 100 years (Table 9). Only 4% of sites had as many as 3 to 4.2 fires per 100 years. These higher fire frequencies occurred at sites below 930 m in elevation. Sites with more than 2 fires per 100 years were located closer to ridgetops than mid-slope positions on average. Sites with 2 to 2.9 fires per 100 years occurred more on south aspects. Although mean landscape slope steepness values were similar for all fire frequency categories, the correlation between fire frequency and landscape slope was significant ($P = 0.007$).

Fire Frequency by Time Periods

Relationships between fire frequency and topography varied among time periods. From 1313 to 1569, 69 sites had no record because of site-level record erasure. Fewer than 10% of recording sites experienced less than 1 fire per 100 years, 27% experienced 1 to 1.9 fires per 100 years, and 63% experienced more than 2 fires per 100 years (Fig. 27; Table 10). The sites with fires and no records were located throughout the study area (Fig. 27) and at all topographic positions (Table 10). Sites with less than 1 fire per 100 years occurred at moderately high elevations and north aspects. Higher fire frequencies occurred at a wide range of elevations, slope positions, aspects, and slope steepness, but only elevation was slightly correlated with fire frequency ($P = 0.06$).

During the 1570-1844 time period, sites experienced 0 to 6.7 fires per 100 years (Fig. 28). Five percent of sites had no record during this period. There was little discernible difference between fire frequencies and mean site-level topographic variables (Table 11). Only landscape slope was slightly correlated with fire frequency ($P = 0.06$).

Between 1845 and 1899, many fires occurred throughout the study area. All sites could record fires during this time (i.e., there was no evidence of large, site-erasure fires beyond 1899), but 36% of the sites did not record any fires (Fig. 29; Table 12). Fire frequencies were strongly correlated with elevation ($P = 0.0001$), but not slope positions,

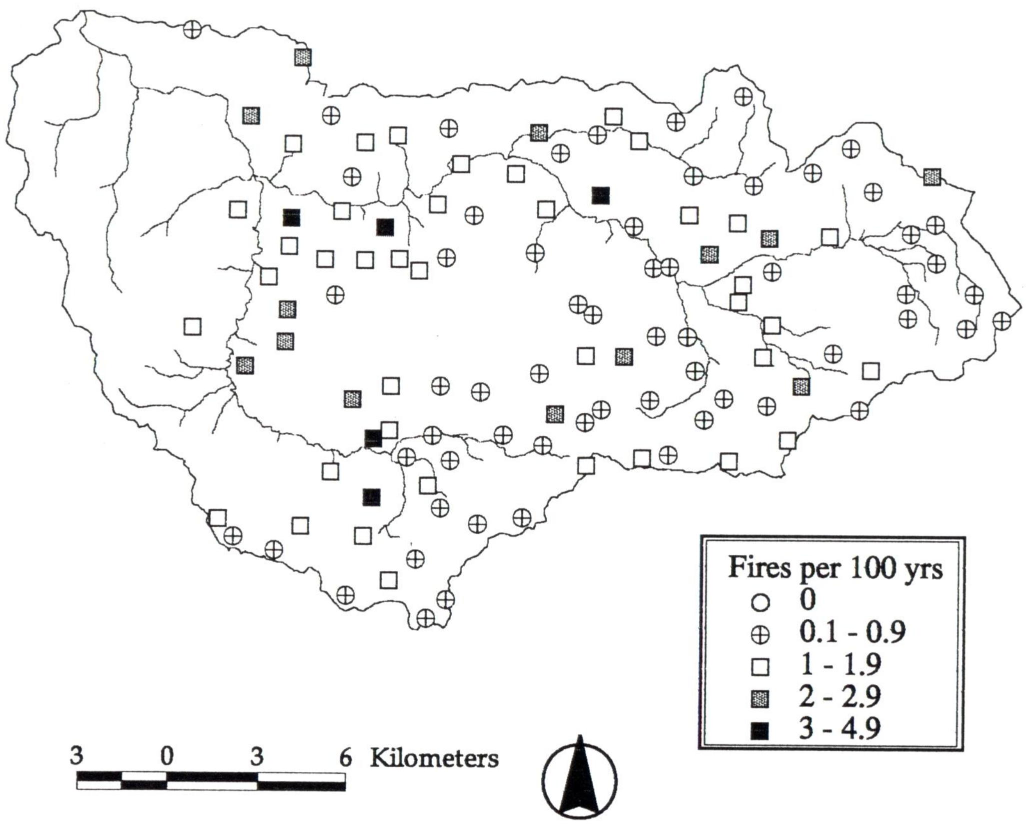


Fig. 26. Fires per 100 years at each site, 1313-1996.

Table 9. Descriptive statistics of fire frequency and site-level topographic variables for the entire length of the observed record.

Number of fires per 100 years	Number of sites	Elevation (m)					Slope position[a]					Landscape slope (%)[b]					Aspect[c]				
		mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max
0.1 - 0.9	60	995	1021	254	457	1509	48	49	31	2	100	29	28	8	10	47	0.10	0.17	0.71	-1.00	1.00
1 - 1.9	39	815	793	282	366	1372	53	55	25	5	99	34	35	9	17	50	0.19	0.19	0.68	-0.99	0.99
2 - 2.9	13	901	884	286	427	1402	62	61	25	13	100	33	32	7	20	45	-0.46	-0.29	0.46	-1.00	0.24
3 - 4.9	5	690	665	143	549	930	66	81	31	23	92	34	35	6	26	41	0.05	0.45	0.95	-0.99	0.97
Spearman's Rank Correlation		-0.32 ($P = 0.004$)					0.10 ($P = 0.27$)					0.25 ($P = 0.007$)					-0.12 ($P = 0.21$)				

a. Slope positions of 100 = ridgetop; Slope Position of 1 = valley bottom
b. Slope steepness of 0 = flat
c. South = -1; North = 1; East/west = 0
d. Standard deviation

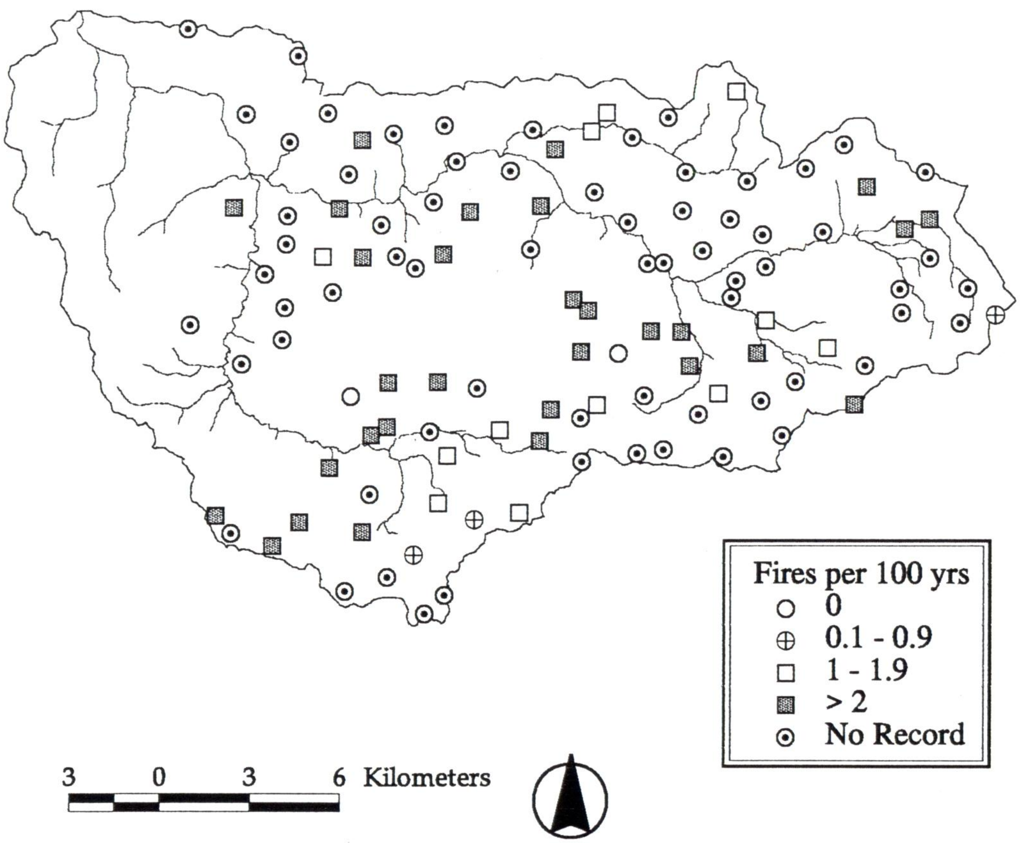


Fig. 27. Fires per 100 years at each site, 1313-1569.

Table 10. Descriptive statistics of fire frequency and site-level topographic variables from the pre-1569 time period.

Number of fires per 100 years	Number of sites	Elevation (m)					Slope position[a]					Landscape slope (%)[b]					Aspect[c]				
		mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max
0.1 - 0.9	5	1126	1098	253	890	1509	49	61	37	7	98	29	28	6	21	36	0.55	0.59	0.31	0.04	0.82
1 - 1.9	13	932	854	213	640	1296	46	30	36	5	100	29	27	11	10	46	0.03	0.24	0.85	-0.99	0.99
> 2	30	874	899	263	366	1402	47	49	27	4	91	32	32	9	17	48	0.06	0.13	0.69	-0.99	0.99
no record	69	908	844	293	396	1402	56	57	27	2	100	31	30	8	16	50	0.04	0.10	0.70	-1.00	1.00
Spearman's Rank Correlation		-0.27 ($P = 0.11$)					-0.08 ($P = 0.33$)					0.12 ($P = 0.23$)					-0.17 ($P = 0.46$)				

a. Slope positions of 100 = ridgetop; Slope Position of 1 = valley bottom
b. Slope steepness of 0 = flat
c. South = -1; North = 1; East/west = 0
d. Standard deviation

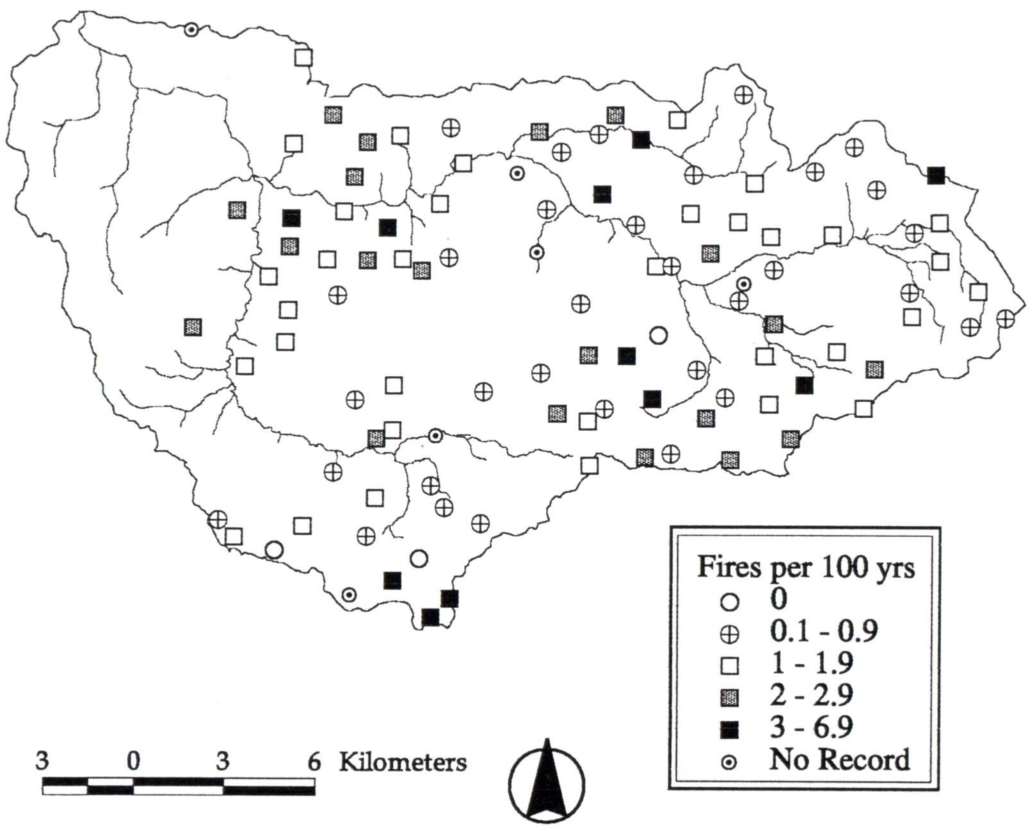


Fig. 28. Fires per 100 years at each site, 1570-1844.

Table 11. Descriptive statistics of fire frequency and site-level topographic variables from 1570-1844.

Number of fires per 100 years	Number of sites	Elevation (m)					Slope position[a]					Landscape slope (%)[b]					Aspect[c]				
		mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max
0	3	960	945	55	915	1021	45	59	34	7	70	28	27	4	25	32	0.89	0.86	0.10	0.82	1.00
0.1 - 0.9	42	948	953	248	534	1509	48	51	29	2	100	31	32	9	10	49	0.01	0.03	0.67	-1.00	1.00
1 - 1.9	35	908	930	309	366	1402	58	62	30	6	100	30	28	8	16	48	0.12	0.19	0.68	-1.00	1.00
2 - 2.9	20	835	762	314	427	1402	45	47	26	5	90	34	36	8	17	49	-0.17	0.05	0.71	-1.00	1.00
3 - 6.9	11	984	1067	271	549	1341	59	58	26	24	100	33	35	7	26	45	0.16	0.45	0.83	-0.96	0.97
no record	6	777	732	194	518	1021	58	50	61	20	96	28	26	12	16	50	0.35	0.61	0.76	-0.97	0.97
Spearman's Rank Correlation		-0.12 (*P* = 0.033)					0.04 (*P* = 0.98)					0.18 (*P* = 0.3)					-0.09 (*P* = 0.38)				

a. Slope positions of 100 = ridgetop; Slope Position of 1 = valley bottom
b. Slope steepness of 0 = flat
c. South = -1; North = 1; East/west = 0
d. Standard deviation

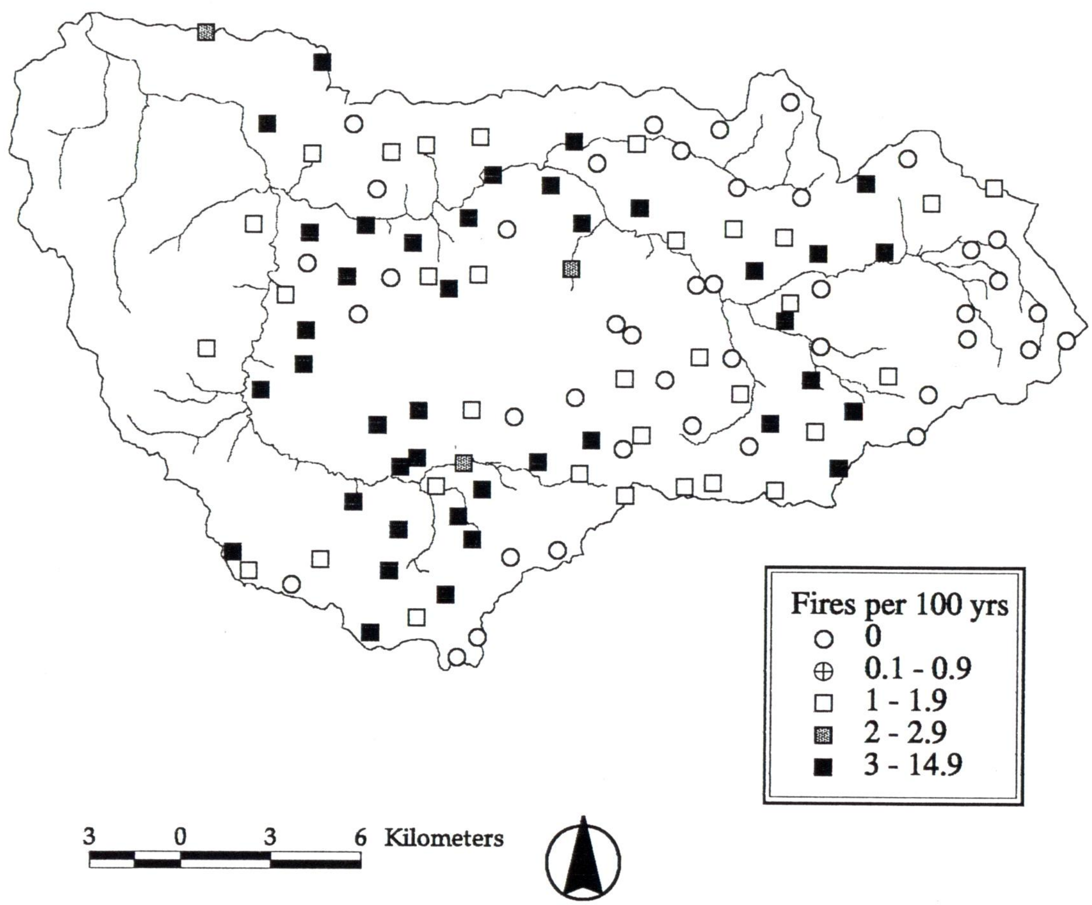


Fig. 29. Fires per 100 years at each site, 1845-1899.

Table 12. Descriptive statistics of fire frequency and site-level topographic variables from 1845-1899.

Number of fires per 100 years	Number of sites	Elevation (m)					Slope position[a]					Landscape slope (%)[b]					Aspect[c]				
		mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max
0	42	1034	1082	280	457	1509	50	57	30	2	100	29	28	9	10	47	0.12	0.13	0.70	-0.99	1.00
0.1 - 0.9	0																				
1 - 1.9	32	907	997	277	427	1372	51	56	28	7	96	26	28	6	19	30	0.04	0.18	0.69	-1.00	0.98
2 - 2.9	3	711	701	47	671	762	51	36	40	20	96	26	28	6	19	30	0.13	0.40	0.99	-0.96	0.97
3 - 14.9	17	802	841	232	366	1402	55	56	27	7	100	32	32	9	16	49	0.03	0.06	0.73	-1.00	0.99
Spearman's Rank Correlation		-0.36 (*P* = 0.0001)					0.12 (*P* = 0.2)					0.14 (*P* = 0.13)					-0.06 (*P* = 0.55)				

a. Slope positions of 100 = ridgetop; Slope Position of 1 = valley bottom
b. Slope steepness of 0 = flat
c. South = -1; North = 1; East/west = 0
d. Standard deviation

aspects, and landscape slope values (Table 12). The mean elevation for sites with zero fires during this time period was relatively high. Sites at the upper elevation Hemlock Lake and Willow Flats areas (see Fig. 2), for example, recorded zero fires. Fifteen percent of all sites had more than 3 fires per 100 years, and these mostly occurred at relatively low elevations.

From 1900-1925 and 1926-1996, the sampled sites experienced relatively few fires. Of the 117 sites, 89% had no fires from 1900-1925 (Fig. 30; Table 13). The 11% of sites that had fires were located at a wide range of elevations, slope positions, aspects, and landscape slope values (Table 13). These sites occurred throughout the study area (Fig. 30).

From 1926-1996, only 7% of the sites experienced fires (Fig. 31). No clear relationships existed between site-level topography and fire occurrence (Table 14). There was a slight geographic pattern as five sites were located near the middle reaches of Little River (Fig. 31), but three of these were burned in the 1987 Clover Fire.

Regression Analysis

From 1313-1996 fire frequency was weakly correlated with topography (adjusted $R^2 = 0.20$). All four topographic variables used in the regression analysis were significant, including an interaction between elevation and aspect. Fire frequency increased slightly with increasing slope position and landscape slope (Table 15). For the interaction term, fire frequencies at all elevations on south aspects were similar (Fig. 32A). As aspect shifted from south to north at mid- to high elevations, fire frequency decreased; as aspect shifted from south to north at low elevations, fire frequency increased. The highest fire frequencies were found at low elevation, north aspects, steep slopes and ridgetops. The lowest fire frequencies were found at high elevation, north aspects, gradual slopes and along valley floors.

The 1490-1569, 1900-1925, and 1926-1996 time periods could not be evaluated since an overwhelming proportion of sites during these period had zero or one fire. Only the 1570-1844 and 1845-1899 time periods could be analyzed by regression analysis.

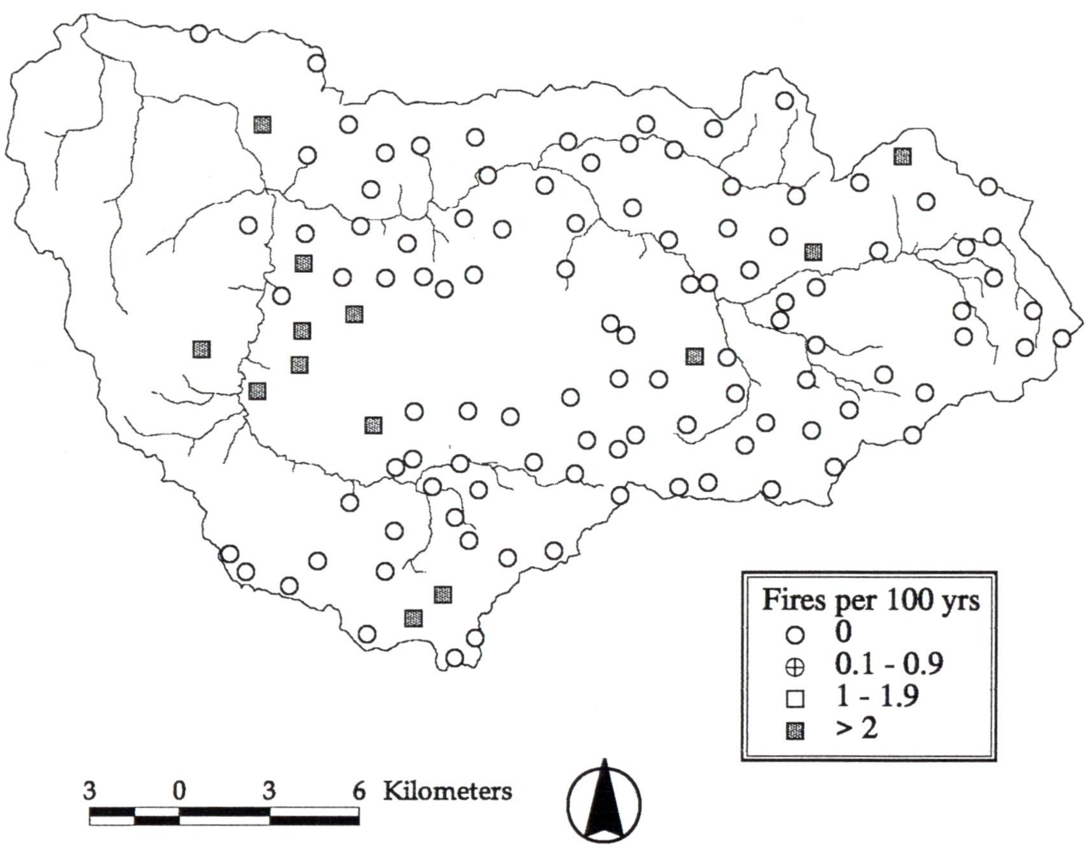


Fig. 30. Fires per 100 years at each site, 1900-1925

Table 13. Descriptive statistics of fire frequency and site-level topographic variables from 1900-1925.

Number of fires per 100 years	Number of sites	Elevation (m)					Slope position[a]					Landscape slope (%)[b]					Aspect[c]				
		mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max
0	104	922	938	283	366	1509	51	54	29	2	100	31	30	9	10	50	0.07	0.16	0.72	-1.00	1.00
0.1 - 0.9	0																				
1 - 1.9	0																				
> 2	13	825	838	221	427	1195	60	61	28	7	100	31	31	7	20	40	0.07	-0.02	0.54	-0.98	0.86

a. Slope positions of 100 = ridgetop; Slope Position of 1 = valley bottom
b. Slope steepness of 0 = flat
c. South = -1; North = 1; East/west = 0
d. Standard deviation

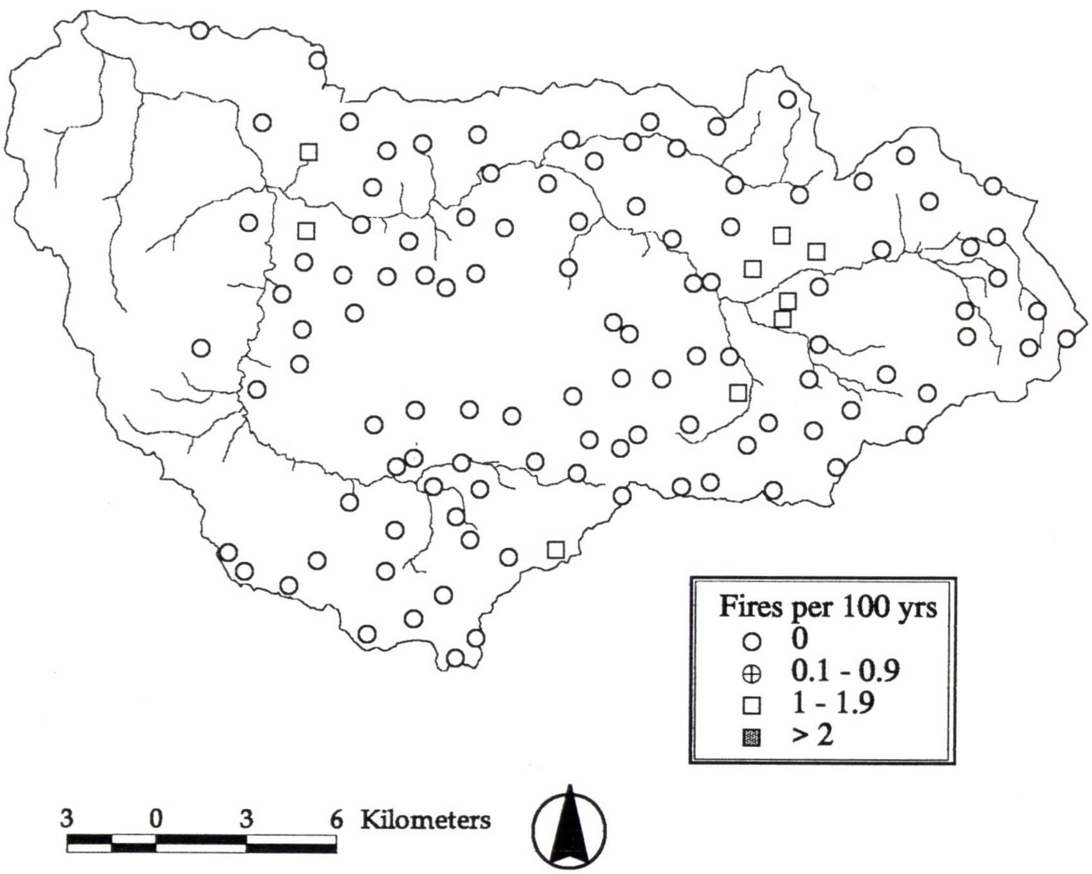


Fig. 31. Fires per 100 years at each site, 1926-1996.

Table 14. Descriptive statistics of fire frequency and site-level topographic variables from 1926-1996.

Number of fires per 100 years	Number of sites	Elevation (m)					Slope position[a]					Landscape slope (%)[b]					Aspect[c]				
		mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max	mean	median	SD[d]	min	max
0	108	917	922	281	366	1509	52	57	29	2	100	31	30	8	10	49	0.08	0.13	0.71	-0.99	1.00
0.1 - 0.9	0																				
1 - 1.9	9	850	808	240	503	1265	56	45	27	20	100	35	38	11	19	50	-0.07	-0.12	0.69	-0.99	0.97

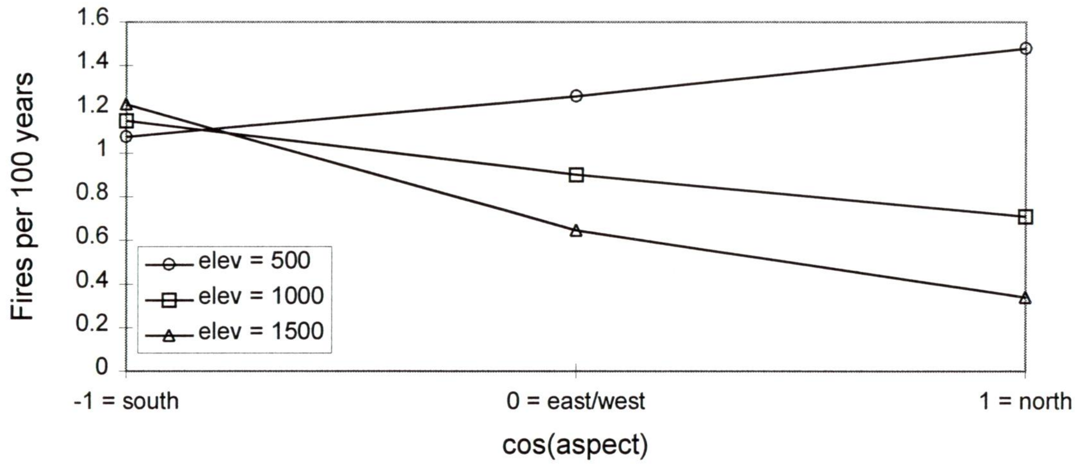
a. Slope positions of 100 = ridgetop; Slope Position of 1 = valley bottom
b. Slope steepness of 0 = flat
c. South = -1; North = 1; East/west = 0
d. Standard deviation

Table 15. Regression model of ln (fire frequency) and four topographic variables for the entire length of the fire history record.

Parameter	Parameter estimates	Standard errors	F-values	*P*
Intercept	-4.79	0.30		
Elevation	-0.00067	0.0002	9.43	0.0027
Slope position[a]	0.006	0.002	8.37	0.0046
Landscape slope[b]	0.015	0.006	5.48	0.0210
Cos(aspect)	0.56	0.27	4.38	0.0386
Elevation*Cos(aspect)	-0.0008	0.0003	6.56	0.0117
Adjusted R^2 = 0.20				

a. Location measure between valley bottom and ridgetop.
b. Coarse-scale measure of slope steepness.

A. 1313-1996



B. 1845-1899

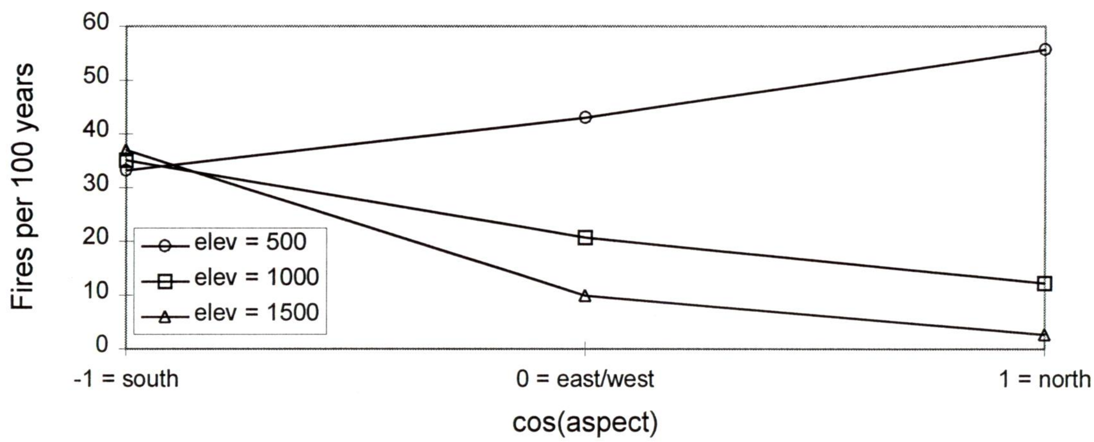


Fig. 32. Interaction effects between elevation and cos(aspect) for three elevations from 1313-1996 (A) and 1845-1899 (B). Mean site values for slope position and landscape slope were used in calculations.

For the 1570-1844 time period, only aspect ($P = 0.05$) was slightly associated with fire frequency (Table 16). During this time, the sampled sites experienced slightly more fires on south aspects than on north aspects. Fire frequency for the 1845-1899 time period was associated with slope position and a two-way interaction between elevation and aspect (Fig. 32B). The 1845-1899 results were similar to the 1313-1996 results (Fig. 32), except the landscape slope variable was not included and fire frequencies were much higher.

Predicted Landscape Pattern of Fire Frequency

Predicted numbers of fires per 100 years over the study area for the length of the record illustrates the pattern of fire frequency over the study area (Fig. 33). The regression model predicted less than one fire per 100 years, mainly at high elevations, and fewer fires at high elevation plateaus (Fig. 33). High elevation north aspects, valleys, and flat areas also had less than one fire predicted per 100 years. Low elevation north aspects, and south aspects, ridges, and steep areas had one to two predicted fires per 100 years. Several small areas where these factors converge, such as steep grades, low elevations, north aspects, and ridgetops, had two to three predicted fires per 100 years.

Fire frequency and topography correlated weakly from 1570-1844 with only a slight relationship between aspect and fire frequency (Fig. 34). The predicted number of fires per 100 years was unrealistically small, ranging from 0.003-0.004 on north aspects to 0.004-0.005 on south aspects.

The correlation between fire frequency and topography from 1845-1899 revealed a clear pattern influenced by aspect, elevation, and slope position (Fig. 35). The pattern using the regression model for the 1845-99 period was similar to that of the full length of record (Fig. 33). Because fire frequency was calculated as numbers of fires per 100 years to facilitate comparison, predicted fire frequencies were slightly larger than observed frequencies during this 55-year period. The lowest predicted fire frequencies of less than two fires per 100 years were located at high elevations on north aspects and

Table 16. Regression model of fire frequency and four topographic variables for 1570-1844 and 1845-1899.

1570-1844 TIME PERIOD

Parameter	Parameter estimates	Standard errors	Chi-square values	*P*
Intercept	-4.53	0.06		
Cos(aspect)	0.18	0.09	4.38	0.0386

1845-1899 TIME PERIOD

Parameter	Parameter estimates	Standard errors	Chi-square values	*P*
Intercept	-0.79	0.29		
Elevation	-0.0014	0.003	19.82	0.0001
Slope position[a]	0.013	0.003	19.53	0.0001
Cos(aspect)	1.05	0.37	7.99	0.0047
Elevation*Cos(aspect)	-0.0015	0.0004	11.11	0.0009

a. Location measure between valley bottom and ridgetop.

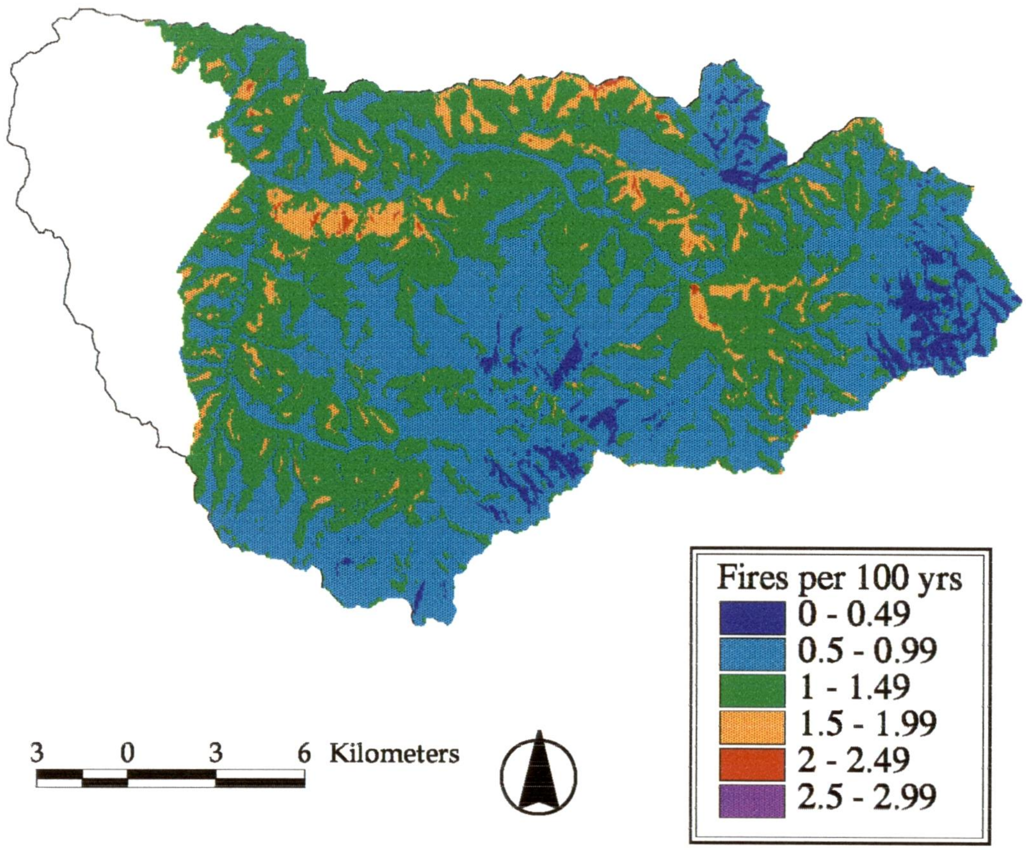


Fig. 33. Predicted number of fires per 100 years for the length of the record, 1313-1996.

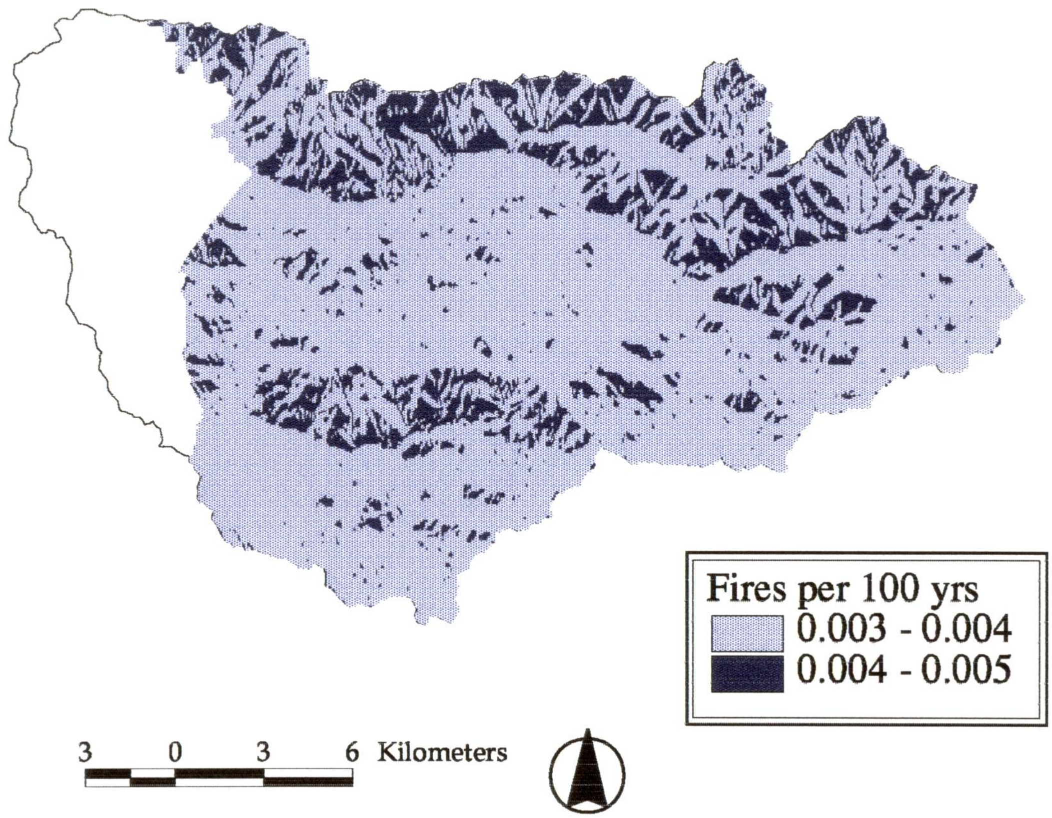


Fig. 34. Predicted number of fires per 100 years, 1570-1844.

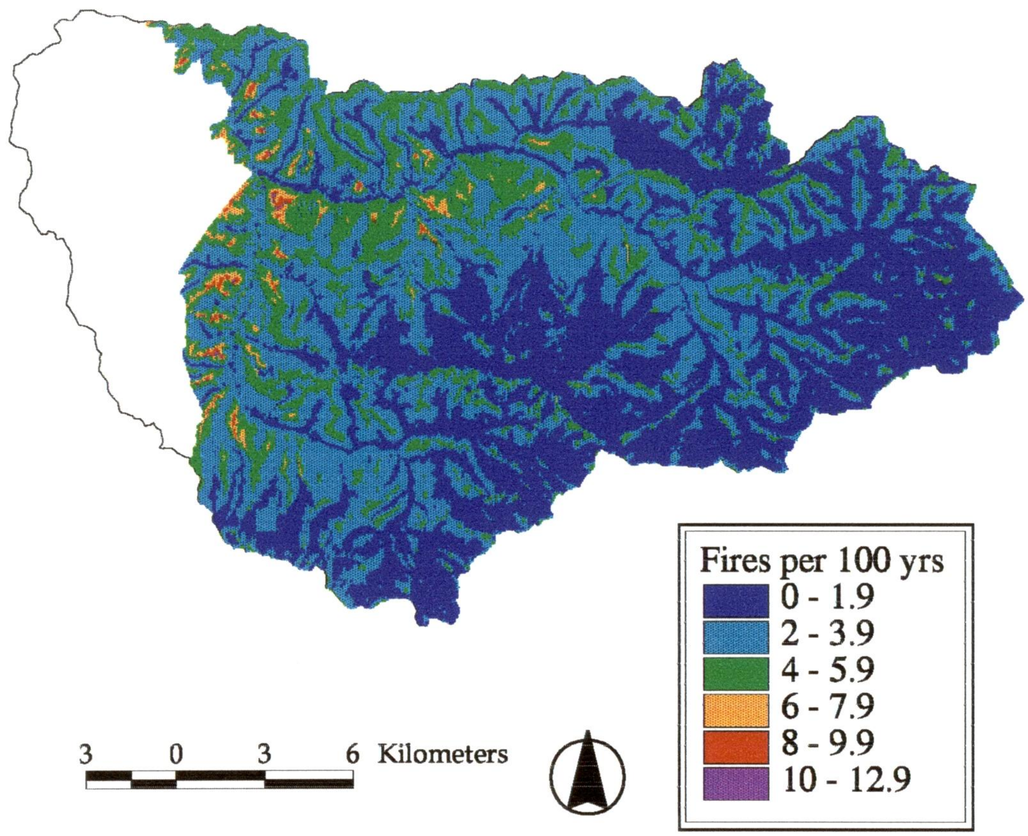


Fig. 35. Predicted number of fires per 100 years, 1845-1899.

in valley bottoms. Two to four predicted fires per 100 years occurred at mid-elevation, mid-slopes and low elevation, valleys. Four to six predicted fires per 100 years occurred along low elevation ridges, mid- to high elevation ridges, and south aspects. The highest predicted fire frequencies, six to thirteen fires per 100 years, occurred in small patches at low elevation, north aspects near the ridgetops.

DISCUSSION

Fire Regime Descriptors

Fire Return Intervals

Estimated fire return intervals in the Little River watershed study area were highly variable within sites and among sites (Figs. 11, 12). For example, fire return intervals ranged from 9 to 362 years at one site and only 3 to 55 years at another site. Average fire return intervals per site ranged from 24 to 520 years. The high variability may have been a result of low sampling density. However, it seems more likely that since high variability was evident both within and among sites, it probably was not an artifact of the study design, but a real property of the ecosystem and its environment.

Interpretation of measures of composite fire-return intervals must consider the method of calculation. For example, if a limited number of intervals per site are used, such as with the WMPI and Rule Sets 1 and 2 that use fewer sites (Tables 2, 6), then shorter intervals result. The higher composite fire return interval values result from including the longer TSLFI values. More reasonable MFRI estimates that include more of the sites ranged from 101 to 141 years (Table 6). MedFRI's were only slightly less, ranging from 90 to 123 years (Table 6). Perhaps the best composite fire return interval, accounting for the variability within and between sites, was Rule Set 5, which included all intervals and the TSLFI. The MFRI from Rule Set 5 was 136 years and the MedFRI was 123 years (Table 6).

When comparing fire return estimates among studies, the extent of area sampled at each study site is important. The larger the study site, the shorter the fire return interval because more ground is sampled and the greater the chance of sampling additional fires. Some studies calculated natural fire rotations (NFR), the time period divided by the proportion of the entire study area burned in that time (Agee 1993). The Oregon Caves study in the Klamath Mountains, for example, calculated a NFR for a 197 ha area (Agee 1991a). In the Little River watershed, where point frequencies were used, the sampled area for each site was 0.48 ha on average. This is much smaller than the approximately 4 ha sampled per site by Teensma (1987), Morrison and Swanson (1990), and Weisberg (1998). Therefore, the 101 to 136-year MFRI's calculated in this study may yield higher estimates of fire return intervals from the study site size factor alone.

Despite differences in calculation methods, MFRI's, medFRI's, WMPI's, and NFR's represent a small range around a landscape average of fire frequency (Agee 1993). Based on MFRI's and NFR's in other Pacific Northwest studies to the north and south of the Little River watershed, I had expected a composite MFRI for the study area between 50 and 85 years. However, the composite fire return interval in the Little River study area is more similar to Douglas-fir forests in the central western Cascade Range. The central western Cascade Range studies recorded MFRI's of 114 years (Teensma 1987), 96 years (Morrison and Swanson 1990), and 97 years (Weisberg 1998). Further north in Washington, wetter conditions result in lower fire frequency, from approximately 230 years calculated by Agee and Flewelling (1983) to a 434-year NFR observed in a field study (Hemstrom and Franklin 1982). To the south in the Klamath Mountains of southwestern Oregon, the NFR was 37 years in a Douglas-fir/oak zone (Agee 1991a).

Fire Extent

The majority of recorded fires in the study area were small. Of all sampled fires, 83% occurred at fewer than three sampled sites (Table 5). Even the large fires were not widespread, occurring among fewer than seven sites (Figs 14-17). The four largest fires were recorded in only six of the 2-km^2 sampling grid cells (Table 7), and so may have been roughly 2,000-3,000 ha in size if the entire area within the grid cells burned. More realistically, the maximum average distance between large fire sites (4.6 km) should be considered since fires tend to burn in irregular shapes. Also, designation of large fires was dependent on spatial and temporal adjacency. Some of these fires may actually be separate fire events that occurred near each other at the same time (Figs. 14-17).

The known extent of several recent fires offers useful information, although these were influenced to varying degrees by fire suppression efforts. The area in and near Little River watershed experienced several large fires in 1987 (Helgerson 1988). The Clover Fire, a moderately large fire for the study area, burned approximately 600 ha with little fire suppression, the Fall Creek Fire in the Little River watershed west of the study area burned 1,300 ha, and the Apple Fire just north of the Little River watershed burned 1,000 ha (Helgerson 1988).

The small extent of fires observed in this study mirrors nearby findings. Fires in two relatively small study areas (1940-ha) to the north in the Oregon western Cascade Range burned approximately 300 to 2,000 ha, although there was strong evidence that events extended beyond study area boundaries (Morrison and Swanson 1990). To the south in the Klamath Mountains, estimated fire sizes ranged from 86 to 576 ha (Agee 1991a). For comparison, in the Bull Run watershed of the northern Oregon Cascade Range, the largest fire may have been 26,000 ha, although several fires were much smaller (ca. 2,800 ha) (Krusemark *et al.* 1996). In the southern Cascade Range of Washington, evidence of small, patchy fires was found, but some fires have been large and stand-replacing, such as the 1902 Yacolt Fire (app. 97,000-243,000 ha) (Gray and Franklin 1997). Further north near Mt. Rainier, several fires were believed to have been large and widespread (ca. 13,000-25,000 ha), but evidence of more recent fires reveals smaller extents (ca. 500-4,000 ha) (Hemstrom and Franklin 1982). The largest fires in the PNW Douglas-fir zones have occurred in the Oregon Coast Range burning as much as 200,000 or even 330,000 ha (Morris 1934; Means *et al.* 1996; Impara 1997). Compared to fire extents in the Oregon Coast Range and in the Washington Cascade Range, fires in the study area have been small, perhaps due to patchy surface fuels resulting from more frequent, low to moderate severity fires over time and space.

Fire Severity

My limited assessment of fire severity suggests that fires in the Little River watershed spanned a range of severity. Severity varied among sites (Figs. 12, 18) and between fires within individual sites, evidenced by regeneration and scarring data (Figs. 19-22). Classification of a variable severity fire regime with variable fire frequency is difficult because it does not readily fit into the common classification schemes (Table 3; Fig. 12). The 136-year MFRI suggests a classification of long return interval, crown fires and severe surface fires (Table 3), although it is apparent that light surface fires also occurred (Fig. 21).

Stand-replacement fires did occasionally occur, but more often it appeared that fires had been less intense. I found old growth Douglas-fir trees generally widespread and mixed among younger cohorts (Figs. 20-21). A predominance of old growth was also noted by an aerial photograph/GIS analysis of western Oregon pre-logging old growth (Ripple 1994). The highest proportion of large-size class conifers was found in the Umpqua River area (78%) and can be attributed to the lack of stand-replacement fires and historically low human population (Ripple 1994).

Interpretation of aerial photos from 1946 show that stands in the study area were composed of trees of differing sizes and age classes mixed together making stand boundaries difficult to identify. Moreover, it was difficult to interpret if a distinguishable stand edge represented specific fire boundaries, variation in the severity of one fire, or perhaps other factors (e.g., soils). The result of variable severity is a patchy mosaic of tree ages and species in a complex, fine-grained spatial pattern.

Fine-scale variation in fire severity in the Little River watershed study area seems to have created small and irregular patches. Examples of varying severities were observed among historic fires at the study sites. A general pattern I found was trees scarred from a particular event in one part of the transect adjacent to a mix of scarred trees and regeneration, adjacent to an area with only regeneration from that fire event all within a single transect. Spatial variation within transects was not recorded, however, so I could not characterize the fine-scale spatial patterns of fire severity expressed in stand age, structure, and composition.

Although I did not analyze fire-mortality patches, other analyses and observations of recent fires in and near the study area provide supporting information and show a large proportion of low severity burns. In the approximately 6700-ha 1996 Spring Fire, located northeast of the Little River watershed, 24% of the burned area was high severity (100% mortality), 13% was moderate severity (40-60% mortality), and 63% was low severity (<40% mortality) (R. Davis, North Umpqua Ranger District, 1998). In the 1987 Clover fire, stand-replacement burns were adjacent to stands that experienced light surface burns. One fire behavior characteristic of the study area is for surface fires to creep around and occasionally flare into crown fires that run and spread. Similar fire behavior was noted by Morris (1934) when he compared the slow nature of fire spread in southern Oregon versus the fast, wind-driven fires in the Oregon Coast Range.

There is much potential for error in interpreting severity of early fires in landscape fire history studies. Even so, several studies have mapped historical fire severities for more recent fire events. In the central western Oregon Cascade Range, a 351-ha fire in 1893 was estimated to have been 18% high severity (70-100% mortality), 53% medium severity (30-70% mortality), and 29% low severity (<30% mortality) (Morrison and Swanson 1990). This and other fires were complex mosaics of numerous small and irregular fire severity patches. A similar pattern of patchiness and irregularity was found in the same study area for all fire-mortality patches from 1800-1900. Different from this were the high severity, stand-replacement fires that dominated in the northern Oregon Cascade Range where low and moderate severity burns were found mostly near fire edges (Krusemark *et al.* 1996).

Temporal Patterns of Fire Regime

The five distinctive time periods of fire frequency (Table 8; Fig. 24) revealed in this study likely relate to climate and human land-use change. During the earliest time period from 1490-1569, fires occurred at a relatively high rate (11.7 fires per decade). Other studies in western Oregon Douglas-fir zones also found frequent fires during this period (Connelly and Kertis 1992), in addition to widespread fire events (Krusemark *et al.* 1996; Impara 1997), and evidence of extensive fires (Morrison and Swanson 1990).

During the 1570-1844 time period, fire occurrence was less (7.5 fires per decade) (Table 8), and may have been influenced by cooling during the Little Ice Age. Paleoclimatic records from around the world have recorded cooler conditions from approximately 1560 to 1850 (Bradley 1985). Dendrochronological records from the

Pacific Northwest have shown temperatures 1°C lower between 1590 to 1900 than during the 20th Century (Graumlich and Brubaker 1986).

The early portion of the 1570-1844 period is when Native American populations were stable and burning would likely have been apparent. There may have been a small amount of Native American burning, but most accounts of their burning in western Oregon are anecdotal (Burke 1979). The frequency and extent of Native American burning could not be verified in this study.

Fire frequency increased to 19.8 fires per decade between 1845-1899 (Table 8). During the 1840's in the Pacific Northwest, the Little Ice Age ended evidenced by increasing summer temperatures (Graumlich and Brubaker 1986). The 1849-1850 interval exhibited a record number of fires at 19 sampled sites; 3 of these fires were relatively large, occurring among 3 and 4 sites (Fig. 16). Elsewhere, eastern Oregon ponderosa pine experienced below normal growth from 1839-1853 with 1849 being a particularly dry year (Keen 1937). Published accounts tell of large fires in the Oregon Coast Range in the late 1840's, and especially during 1849 in the Cascade Mountains (Morris 1934). Other fire history studies also found evidence for high fire activity around 1849 (Teensma 1987; Morrison and Swanson 1990; Impara 1997).

Both climate change and Euro-American settlement occurred in the 1840's and 1850's, making it difficult to determine which had a greater influence on the shift in fire frequency. The change cannot be attributed to Native Americans as their populations had already begun decreasing as early as 1782 from disease epidemics (Honey and Hogg 1980; Abdill 1982). The original Indian population of the upper Umpqua basin, where the Little River watershed is located, was estimated between 3,000 and 4,000, but by 1846 the population had dropped to near 400 (Honey and Hogg 1980). Trappers entered the Umpqua region in 1819-1821, and settlers began to arrive in 1846 (Beckham 1986). The first settler arrived near Glide in 1851, after which the area valleys filled rapidly (Bakken 1970). Few people resided near the study area at the time of the fire frequency change. Also, fires were spatially dispersed between 1845-1850, not aggregated along transportation routes or near valley floors where settlement may have occurred. Based on these observations, it was likely that the change in fire frequency in the study area that began around 1845, and the 1849-1850 fires, were more related to climatic factors than humans.

The high fire frequency throughout the 1845-1899 period was probably not sustained by climate. The 1850-1895 period in the Southern Valleys of the Pacific Northwest is characterized as uniformly wet with the exception of severe drought in 1889 (Graumlich 1987). Consequently, it was unlikely that natural ignitions were that numerous. Instead this portion of the fire regime was more likely influenced by Euro-Americans. Generally, during the mid 1800's the common attitude was that forests were not a valuable resource, and fires were not unusual nor perilous (Burke 1979). Sheepherders believed that burning the forest had a positive benefit for sheepgrazing by improving forage, and the Little River watershed may have been a travel route to take livestock to higher summer pasturage (Bakken 1970).

The 1900-1925 and 1926-1996 periods correspond to the time of fire suppression. However, the rate of fire occurrence during the 1900-1925 and 1926-1996 periods may be undersampled in this study. All sites that burned from approximately 1900 to 1984 would not qualify as a study site because (1) post fire/salvage tree regrowth would be too young to be selected as a timber sale, and (2) I only sampled areas cut during the last 12 years (prior to the 1996 field season).

Aside from undersampling concerns, human actions have influenced fire frequency since 1900. The 1900-1925 period, when 6.2 fires per decade were sampled (Table 8), was distinctly a transition period when people set fewer fires, but did not necessarily exercise suppression. Attitudes toward wildfires had begun to change by the end of the 19th Century in the Pacific Northwest as timber became recognized as a valuable commodity. A number of actions, including the establishment of the Federal Cascade Range Forest Reserve, grazing restrictions, and fines for setting fires, were established at the turn of the century (Honey and Hogg 1980; Beckham 1986; Bakken 1970). The rate of fire occurrence dropped to 1 fire per decade beginning around 1926 (Table 8). This is likely due to increased road and trail access, cooperation between the federal, state, and county governments for fire protection, and the development of more effective fire detection and suppression techniques (Beckham 1986; Pyne 1982).

Spatial Patterns of Fires

The spatial dispersion of historical fires (Fig. 25) fits the variable fire frequencies found among sites (Fig. 12) and with the patterns of recent fires. The dispersion of fires is probably due to a combination of dispersed lightning strikes, fuel properties including discontinuous fuels, and the interaction between fire frequency and severity over the landscape. In western Oregon, where the number of lightning-caused ignitions varies greatly from year-to-year, a few lightning storms dominate each decade (Burke 1979). During the summers of 1987 and 1996, lightning ignited dozens of fires throughout the study area illustrating how dispersed fires can be within a single year.

Spatio-temporal Patterns of Fires

The most apparent spatial pattern is that of the spatially random dispersion of fires throughout the length of the record. In general, fires occur from both human and lightning ignitions. Lightning-caused fires are generally unevenly distributed, whereas human-caused fires tend to occur along travel routes and accessible areas (Burke 1979). The common belief is that human-caused fires may have been locally important, but lightning-caused fires explain the greater number of fires observed in fire history studies (Burke 1979; Agee 1991b; Swetnam and Baisan 1996). That was mostly true in the Little River watershed, except during the 1845-1899 period when humans were probably a significant source of ignitions in the study area and apparently in the more accessible low elevations. Several studies found influences of Euro-American burning by settlers, stockmen, and miners, in the late 1800's (Burke 1979; Hemstrom and Franklin 1982; Taylor 1993). Other studies found no influence on fire frequency (Teensma 1987; Agee 1991a; Wills and Stuart 1994), suggesting human influence could be profound or weak depending on local circumstances.

Because of the spatial randomness of historic fire locations in the study area, relations between fire frequency and topography were not expected and seemingly did not occur for the length of the record (Table 9; Fig. 26). The regression analysis of topographic variables explained only 20% (adjusted R^2) of the variation in total fire frequency of the study area (Table 15).

The relationship between fire frequency and topography from 1845-1899 was strikingly similar to that for the full length of the record (Tables 15 and 16). The interaction terms for the 1313-1996 and the 1845-1899 period were also similar (Fig. 32). Like the 1845-1899 period, a large number of fires occurred from 1570-1844, but the presettlement period had almost no correlation between fire frequency and topography (Table 16; Fig. 34). Apparently, the large numbers of fires from 1845-1899 heavily influenced the 1313-1996 regression results, and except from 1845-1899, there was very little correlation between fire frequency and topography because the fires were dispersed across all elevations, slope positions, slope gradients, and aspects.

Even though the 1845-1899 regression analysis correlation was fairly weak, it revealed a positive association between fires occurring at low elevation north aspects near the ridgetops. These results paralleled those found in a study in the central western Cascade Range of Oregon (Morrison and Swanson 1990), except for the higher fire frequency on north aspects. North aspects are typically moist, have lower temperatures, and are less likely to burn (Agee 1993). Yet from 1845-1899, many sampled sites at low elevations on north aspects near Little River and its main tributary, Cavitt Creek, burned more frequently than other sampled sites (Fig. 29). During the same time, higher elevations had higher fire frequencies on south aspects as expected (Fig. 35). The anomalous fire frequencies at low elevation, north aspects suggested that human-based ignitions from 1845-1899 may have been a factor. These particular north aspect sites were between the river corridor and plateaus where grazing may have been important. Also, having less solar exposure and more moisture, north aspects were likely to have had continuous fuels contributing to fire spread.

Ecological Implications

Forest stand structure is an important key to understanding small-scale fire effects on vegetation (McNeil and Zobel 1980; Means 1982; Stewart 1986), and to larger landscape patterns. A key structural ingredient of Pacific Northwest old-growth, Douglas-fir forests is large, individual, old trees (Franklin and Spies 1991). Morrison and Swanson (1990) and Agee (1993) have suggested that low and moderate severity fires can sustain old-growth, Douglas-fir forests. Eighty-two percent of the sampled sites had evidence of more than one fire, which is a good indicator of moderate severity fire. Also, 95% of the sampled sites had trees older than 200 years, the majority of which were Douglas-fir. Thus, it appears that the study area prior to Euro-American settlement was forest dominated by old-growth Douglas-fir.

However, the complex, heterogeneous patterns of age classes, species, and canopy layers within the forest landscape seem to have developed in part because of the high variability in fire frequency and severity. Today's forest structure and composition in the Little River watershed study area represents the cumulative effects of past disturbance processes, climatic variability, and human intervention. From 1570-1844, much of today's old-growth forest became established and was affected by the Little Ice Age climate and a moderate fire frequency. Increased fire frequency during the 1845-1899 period interacted with this existing older forest, changing its composition, patterns, and stand and landscape structure. These settlement period fires may have reduced fuel loads and were probably small and of low severity, creating small openings at low elevations. Such openings are generally short lived, but their presence can change forest age classes, structure, density, and composition (Skinner 1995). During the fire suppression period (1845-1899), the gaps created by increased fire occurrence may have promoted regeneration of shade-tolerant species, and led to development of a more structurally diverse forest.

The forest that we see today is a legacy of the past. The increased fuel loads and the shade-tolerant and fire-intolerant species of today's forests are a legacy of fire suppression (Mutch *et al.* 1993; Agee 1993). The patchy, heterogeneous forest that we see at lower elevations in the study area is a legacy of late 19th Century human fire-ignitions. Perhaps stands at the mid- and upper elevations in the study area may approximate more closely the conditions prior to Euro-American settlement.

Trying to capture elements of a repeating cycle such as a fire regime can be difficult and somewhat misleading because forest landscapes and climate are dynamic systems in which there is probably no repeating cycle. The 103-141-year MFRI observed in the study area is a general description of fire frequency for the last 500 years, but, as this study noted, it has changed during that time, and with it the forest patterns, structure, and composition have changed. It is likely that future natural and human-induced climate shifts may further change the fire regime, including fire extent and severity. The extents of historical fires seems to have been small in the Little River watershed study area, mostly in the 10's to several 100 ha. Fire suppression has greatly reduced the extent and frequency of wildfires.

If the time since the last fire continues to increase, the Little River watershed study area, like many other western forests, will accumulate fuels and be at higher risk for large, severe fires, especially if the climate warms and dries. Because the Little River watershed study area has traditionally been a fire-prone forest, future management plans should consider re-introducing fire at nearer to historical levels into the forest where the reference conditions suggest a history of frequent fires.

CONCLUSIONS

(1) Fire frequency in the Little River watershed study area was highly variable within and among sampled sites. There were 0.1 to 4.2 fires per 100 years per site, but at 51% of the sites, less than 1 fire occurred per 100 years per site. Individual fire return intervals at sites ranged from 2 to 520 years. The composite mean fire return interval (MFRI) for all sites over the length of the record (1313-1996) was 101 to 141 years with a median fire return interval (medFRI) of 90 to 123 years, which is within the range of fire return intervals determined for other nearby Douglas-fir forests.

(2) Historical fires in the study area tended to be relatively small. Eighty-two percent of fires occurred at one to two sites and 18% of fires occurred at $\geq$3 sites, but the largest fire detected was recorded at only 7 sampled sites with a 5.9 km maximum distance between sites.

(3) Fires appeared to be of variable severity, showing low to high mortality rates within and among sampled sites, and within individual fires as well. Low to moderate severity surface fire appeared to have been more common than high severity, stand-replacement events. Old-growth Douglas-fir trees were common throughout the study area and perhaps were sustained by the moderate severity fire regime.

(4) The study area had a temporally varying fire regime most likely associated with changes in climate and human fire ignition and fire suppression. Five distinct changes in the rate of fire occurrence were identified as 1490-1569 with 11.7 fires per decade, 1570-1844 with 7.5 fires per decade, 1845-1899 with 19.8 fires per decade, 1900-1925 with 6.2 fires per decade, and 1926-1996 with 1 fire per decade. The fire rates during the last two time periods (1900-1925 and 1926-1996), however, may be underestimated because sites that burned from 1900 to 1984 were unlikely to qualify as study sites.

(5) The period 1849-50 had the most fires events recorded in the historical record. Fire was observed at 19 of the 117 sampled sites. These fires occurred at the end of the Little Ice Age period. The first settler did not arrive near the Glide area until 1851. Also, fires were spatially dispersed between 1845-50, not aggregated along transportation routes or near valley floors where settlement may have occurred. Based on these observations, it was likely that the change in fire frequency in the study area that began around 1845, and the 1849-50 fires, were more related to climatic factors than humans.

(6) Historical fires in the study area were randomly dispersed, which correlates with the variable fire frequency found among sites. The pattern of fires was probably most strongly influenced by dispersed lightning ignitions, as well as fuel properties and feedback between fire frequency and severity. Thus, the spatial component of fire frequency did not differ much among temporal periods.

(7) Although the correlation of fire frequency with topography in the regression analysis was relatively weak (adjusted $R^2 = 20\%$), an odd interaction between elevation and aspect was found for both the settlement period (1845-1899) and the length of the record (1300-1996). As aspect shifted from south to north at mid- to high elevations, fire frequency decreased; as aspect shifted from south to north at low elevations, fire frequency increased. Usually fires are less frequent on north compared to south aspects. The similarity between the settlement period and the length of the record suggested that the high number of fires during the settlement period influenced the regression analysis for the length of the record. The anomalous fire frequencies at low elevation, north aspects during the 1845-1899 time period was interpreted as being influenced by Euro-American settler fire ignitions.

BIBLIOGRAPHY

Abdill, J. R. 1982. Historic Douglas County, Oregon. Douglas County Historical Society. Taylor Publishing Company, Dallas, Texas.

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

Agee, J. K. 1991b. Fire history of Douglas-fir forests in the Pacific Northwest. *In* Wildlife and vegetation of unmanaged Douglas-fir forests. pp 25-33. Edited by L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff. USDA Forest Service General Technical Report PNW-285.

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington D.C.

Agee, J. K. and R. Flewelling. 1983. A fire cycle model based on climate for the Olympic Mountains, Washington. Fire and Forest Meteorology Conference 7: 32-37.

Arno, S. F. and K. M. Sneck. 1977. A method for determining fire history in coniferous forests of the Mountain West. USDA Forest Service General Technical Report INT-301.

Bakken, L. J. 1970. Lone Rock free state: A collection of historical adventures and incidents in Oregon's North Umpqua Valley 1850 to 1910. The Mail Printers, Myrtle Creek, Oregon.

Beckham, S. D. 1986. Land of the Umpqua: A history of Douglas County, Oregon. Douglas County Commissioners, Roseburg, Oregon.

Beers, T. W., P. E. Dress and L. C. Wensel. 1966. Aspect transformation in site productivity research. Journal of Forestry 64: 691-692.

Bradley, R. S. 1985. Quaternary paleoclimate: Methods of paleoclimate reconstruction. Unwin Hyman Ltd., Cambridge, Massachusetts.

Brown, P. M. and T. W. Swetnam. 1994. A cross-dated fire history from coast redwood near Redwood National Park, California. Canadian Journal of Forest Research 24: 21-31.

Burke, C. J. 1979. Historic fires in the central western Cascades, Oregon. M.S. thesis, Oregon State University, Corvallis, Oregon.

Connelly, K. P. and J. A. Kertis. 1992. Report on Augusta fire history. Administrative Report. USDA Forest Service, Blue River Ranger District, Willamette National Forest.

ESRI. 1997. ARC Version 7.1.2. Environmental Systems Research Institute, Inc., Redlands, California, USA.

FEMAT. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Federal Ecosystem Management Assessment Team (FEMAT). USDA Forest Service 1993-793-071. Washington, D. C.

Franklin, J. F. and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA Forest Service General Technical Report PNW-8.

Franklin, J. F. and T. A. Spies. 1991. Composition, function, and structure of old-growth Douglas-fir forests. *In* Wildlife and vegetation of unmanaged Douglas-fir forests. pp. 71-80. Edited by L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff. USDA Forest Service General Technical Report PNW-285.

Graumlich, L. J. 1987. Precipitation variation in the Pacific Northwest (1675-1975) as reconstructed from tree rings. Annals of the Association of American Geographers 77: 19-29.

Graumlich, L. J. and L. B. Brubaker. 1986. Reconstruction of annual temperature (1590-1979) for Longmire, Washington, derived from tree rings. Quaternary Research 25: 223-234.

Gray, A. N., and J. F. Franklin. 1997. Effects of multiple fires on the structure of southwestern Washington forests. Northwest Science 71: 174-185.

Grissino-Mayer, H. D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Ph.D. dissertation, University of Arizona, Tucson, Arizona.

Grissino-Mayer, H. D. 1997. FHX2: Software for the analysis of fire history from tree rings. Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8: 27-38.

Hatfield, D. 1996. Slopeposition AML, version 08/12/96; ArcInfo 7.0.3. USDA Forest Service Pacific Northwest Research Station, Portland, Oregon.

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research 3: 329-382.

Helgerson, O. 1988. Historic fire year for Oregon and California. Fir Report 9(4): 2-4.

Hemstrom, M. A. and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quaternary Research 18: 32-51.

Heyerdahl, E. K., D. Berry and J. K. Agee. 1995. Fire history database of the western United States. Interagency Agreement DW 12934530. University of Washington: US Environmental Protection Agency/ USDA Forest Service.

Hickman, J. C. (ed.) 1993. The Jepson manual: Higher plants of California. University of California Press, Berkeley.

Honey, W. D. and T. C. Hogg. 1980. Cultural resource overview: Umpqua National Forest and Bureau of Land Management, Roseburg District. USDA Umpqua National Forest and USDI Bureau of Land Management, Roseburg District, Roseburg, Oregon.

Impara, P. C. 1997. Spatial and temporal patterns of fire in the forests of the central Oregon Coast Range. Ph.D. dissertation, Oregon State University, Corvallis, Oregon.

Johnson, E. A. and S. L. Gutsell. 1994. Fire frequency models, methods, and interpretations. Advances in Ecological Research 25:239-287.

Keen, F. P. 1937. Climatic cycles in eastern Oregon as indicated by tree rings. Monthly Weather Review 65: 175-188.

Krebs, C. J. 1989. Ecological methodology. Harper Collins Publishers, New York.

Krusemark, F., J. K. Agee and D. Berry. 1996. The history of fire in the Bull Run watershed, Oregon. USDA Forest Service Mt. Hood National Forest final report PNW-92-0025.

Madany, M. H., T. W. Swetnam and N. E. West. 1982. Comparison of two approaches for determining fire dates from tree scars. Forest Science 28: 856-861.

McNeil, R. C. and D. B. Zobel. 1980. Vegetation and fire history of a ponderosa pine-white fire forest in Crater Lake National Park. Northwest Science 54: 30-46.

Means, J. E. 1982. Developmental history of dry coniferous forests in the central western Cascade Range of Oregon. *In* Forest succession and stand development research in the Northwest: Proceedings of a symposium. March 26, 1981; Corvallis, Oregon. pp. 142-158. Edited by J. E. Means.

Means, J. E., T. Spies, S. Chen, J. Kertis, and P. Teensma. 1996. Forests of the Oregon Coast Range: Considerations for ecological restoration. *In* The use of fire in forest restoration. pp 68-71. Edited by C. C. Hardy and S. F. Arno. USDA Forest Service General Technical Report INT-341.

Morgan, P., G. H. Aplet, J. B. Haufler, H. C. Humphries, M. M. Moore, W. D. Wilson. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry 2: 87-111.

Morris, W. G. 1934. Forest fires in western Oregon and western Washington. The Oregon Historical Quarterly 35: 313-339.

Morrison, P. H. and F. J. Swanson. 1990. Fire history and pattern in a Cascade Range landscape. USDA Forest Service General Technical Report PNW-254.

Mutch, R. W., S. F. Arno, J. K. Brown, C. E. Carlson, R. D. Ottmar and J. L. Peterson. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. *In* Forest health in the Blue Mountains: Science perspectives. Edited by T. M. Quigley. USDA Forest Service General Technical Report PNW-310.

Peck, D. L., A. B. Griggs, H. G. Schlicker, F. G. Wells and H. M. Dole. 1964. Geology of the central and northern parts of the Western Cascade Range in Oregon, 1:250,000. US Geological Survey Professional Paper No. 449.

Pickett, S. T. A. and R. S. Ostfeld. 1995. The shifting paradigm in ecology. *In* A new century for natural resources management. pp. 261-278. Edited by R. L. Knight and S. F. Bates. Island Press, Washington D. C.

Pyne, S. J. 1982. Fire in America: A cultural history of wildland and rural fire. Princeton University Press, New Jersey.

Ramsey, F. L. and D. W. Schafer. 1997. The statistical sleuth: A course in methods of data analysis. Duxbury Press, New York.

Ripple, W. J. 1994. Historic spatial patterns of old forests in western Oregon. Journal of Forestry 92: 45-49.

SAS. 1997. SAS/STAT Software: Changes and enhancemnts through release 6.12. SAS Institute Inc., Cary, North Carolina, USA.

SAS. 1990. SAS/STAT User's Guide, Version 6, Fourth edition, Vol. 2. SAS Institute Inc., Cary, North Carolina, USA.

Skinner, C. N. 1995. Change in spatial characteristics of forest openings in the Klamath Mountains of northwestern California, USA. Landscape Ecology 10: 219-228.

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. Tree-ring dating. University of Chicago Press, Chicago, IL.

Swanson, F. J., T. K. Kratz, N. Caine, and R. G. Woodmansee. 1988. Landform effect on ecosystem patterns and processes. BioScience 38: 92-98.

Swanson, F. J., J. A. Jones, D. O. Wallin and J. Cissel. 1994. Natural variability: implications for ecosystem management. *In* Eastside forest ecosystem health assessment, Vol. II: Ecosystem management: principles and applications. pp. 89-103. Edited by M. E. Jensen and P. S. Bourgeron. USDA Forest Service Pacific Northwest Research Station, Portland, OR.

Swetnam, T. W. and C. H. Baisan. 1996. Historical fire regime patterns in the Southwestern United States since AD 1700. *In* Fire effects in Southwestern forests: Proceedings of the second La Mesa fire symposium. pp. 11-32. USDA Forest Service General Technical Report RM-286.

Taylor, A. H. 1993. Fire history and structure of red fir (*Abies magnifica*) forests, Swain Mountain Experimental Forest, Cascade Range, northeastern California. Canadian Journal of Forest Research 21: 626-634.

Teensma, P. 1987. Fire history and fire regimes of the central western Cascades of Oregon. Ph.D. dissertation, Department of Geography, University of Oregon, Eugene.

USDA-USDI. 1995. Little River watershed analysis. USDA Umpqua National Forest North Umpqua Ranger District and USDI Bureau of Land Management Mt. Scott Resource Area. Roseburg, Oregon.

Weisberg, P. 1998. Fire history, fire regimes, and development of forest structure in the central western Oregon Cascades. Ph.D. dissertation, Department of Forest Science, Oregon State University, Corvallis, Oregon.

White, P. S. and Pickett, S. T. A. 1985. The ecology of natural disturbance and patch dynamics. Academic Press, Inc. Orlando, Florida.

Wills, R. D. and J. D. Stuart. 1994. Fire history and stand development of a Douglas-fir/hardwood forest in northern California. Northwest Science 68: 205-212.

APPENDICES

Appendix A

Data

The data collected in the field, the site-level fire events, and the among site unique fire events were entered into the Forest Science Data Bank (FSDB) at the Forestry Sciences Laboratory in Corvallis, Oregon. The data code is DF08. There are six formats containing (1) site-level data, (2) transect stump tallies, (3) tree ages, (4) injury ages (5) site-level fire events, and (6) unique fire events. Another file, not included here, lists the variable codes. For more information, contact:

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Forestry Sciences Laboratory
3200 Jefferson Way
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The computer program developed to determine site-level fires is also available, although incomplete. For more information, contact:

Steve Garman
Forestry Sciences Laboratory
3200 Jefferson Way
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****

FSDB Variables and Definitions DF08

****

Format: 1

Site Data at Unit Level

Coded Variable	Unit	Definition
DATACODE		FSDB Database Code
FORMAT		Format Number
WATERSHED		Name of Watershed
UNITNO		Harvest Unit Number
YEAR		Year of Data Collection
HARVYEAR		Year of Harvest
ELEVATION	Feet	Average Transect Elevation
ASPECT	Degrees	Average Slope Aspect
SLOPE	Percent	Average Percent Slope
MICROSLOPE		Micro Slope Position
MICROVERT Micro		Vertical Slope Description
MICROHORIZ		Micro Horizontal Slope Description
TRAN_AZ	Degrees	Sampling Transect Azimuth
TRAN_DIST	Feet	Approximate Length of the Sampling Transect
LEGAL		Township, Range, and Section Describing the Location of the Clearcut Unit
DIRECTIONS		Directions for Locating the Site
FIELDNOTES		Observations Written about the Site in the Field

****

FSDB Variables and Definitions DF08

****

Format: 2

Stump Tally, Species, and Diameters

Coded Variable	Unit	Definition
DATACODE		FSDB Database Code
FORMAT		Format Number
WATERSHED		Name of Watershed
UNITNO		Unit Number
YEAR		Year of Data Collection
SPECIES		Tree Species
SIZE_CLASS		Diameter Size Classes
COUNT		Tallied Count of Species per Size Class

****

FSDB Variables and Definitions DF08

****

Format: 3

Tree Ages

Coded Variable	Unit	Definition
DATACODE		FSDB Database Code
FORMAT		Format Number
WATERSHED		Name of Watershed
UNITNO		Unit Number
YEAR		Number Assigned to Each Counted Stump at a Site
SPECIES		Tree Species
STUMP_HT	cm	Average Stump Height
DIAM	cm	Average Stump Surface Diameter
RING_CNT	Years	Total Number of Tree Rings
INCH_CNT	Years	Number of Tree Rings in the First Inch of the Tree near the Pith
TAG		Tag Indicating if the Stump is Located Inside or Outside of the Transect
STUMP_ADJ	Years	Age adjusted for height up the stump (derived field; see abstract for formulae)
RW	mm	Width of the innermost 3 Rings of the Sample
CALYAGE	Years	Calender Year Age (Birth Year)

****

FSDB Variables and Definitions DF08

****

Format: 4

Injury Ages and other Injury Information		
Coded Variable	Unit	Definition
DATACODE		FSDB Database Code
FORMAT		Format Number
WATERSHED		Name of Watershed
UNITNO		Unit Number
YEAR		Year of Data Collection
TREENO		Tree Number
SPECIES		Tree Species
INJ_TYPE		Type of Tree Injury
INJ_POS		Injury Position on the Stump
INJ_CNT	Years	Number of Tree Rings from the Bark in to the Injury
CIRCUMF	Percent	Percent of the Stump Surface Circumference of the Injury
S_R_CNT	Years	Number of Tree Rings from the Bark in to the Growth Release/Suppression
S_R_TYPE		Growth Release or Suppression Indicator
TAG		Tag Indicating if the Stump is Located Inside or Outside of the Transect
INJ_YEAR	Years	Calendar Year of the Tree Injury

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FSDB Variables and Definitions DF08

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Format: 5

Site-level Fire Events

Coded Variable	Unit	Definition
DATACODE		FSDB Database Code
FORMAT		Format Number
UNITNO		Unit Number
FE_START	Years	Fire Event Start Year
FE_END	Years	Fire Event End Year
MAJ_FE_YR	Years	Majority Year of the Site-level Fire Event
UNIQUE_FE		Number Assigned to Each Unique Fire Event

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FSDB Variables and Definitions DF08

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Format: 6

Among Site Unique Fire Events		
Coded Variable	Unit	Definition
DATACODE		FSDB Database Code
FORMAT		Format Number
UNITNO		Unit Number
FE_START	Years	Unique Fire Event Start Year
FE_END	Years	Unique Fire Event End Year
MAJ_FE_YR	Years	Majority Year of the Unique Fire Event
UNIQUE_FE		Number Assigned to Each Unique Fire Event
ASSOC_SITE		Unit Number of Sites Sharing a Unique Fire Event

Appendix B

GIS Data

The following are spatial data coverages in a Geographical Information System (GIS). These coverages are archived at the Forestry Sciences Laboratory in Corvallis, Oregon in accordance with federal digital geospatial metadata standards. For more information, write to the following:

Don Henshaw
Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, OR 97331

A brief description of the archived coverages follows. Other coverages of the Little River watershed and vicinity, such as streams, roads, and vegetation, can be obtained from the Roseburg Bureau of Land Management or the USDA Umpqua National Forest Supervisor's Office, also located in Roseburg, Oregon.

Name	Type	Description
watershedbndy	vector	Boundary of the Little River watershed.
studyareabndy	vector	Boundary of the fire history study area within the Little River watershed.
fishnet2km	vector	2x2-km sampling grid.
sites_1984	vector	The Bureau of Land Management and Forest Service units harvested between 1984 and 1996 from which fire history sample sites were chosen.
sample_site	vector	The 117 sites sampled for fire history during 1996.
transect	vector	The 117 transects sampled for fire history during 1996. Locations and boundaries are approximate.
latdem	raster	Digital elevation model (DEM) of the Little River watershed and vicinity (30-meter resolution).
latcosaspect	raster	Cosine of aspect for Little River watershed and vicinity.
latslpos	raster	Slope positions for Little River watershed and vicinity calculated from Hatfield (1996).
latslope	raster	Coarse-scale landscape slope for Little River watershed and vicinity.
f1313_1996	raster	Predicted fire frequency per 100 years from 1313-1996 calculated with a regression equation (Fig. 33).
f1570_1844	raster	Predicted fire frequency per 100 years from 1570-1844 calculated with a regression equation (Fig. 34).
f1845-1899	raster	Predicted fire frequency per 100 years from 1845-1899 calculated with a regression equation (Fig. 35).