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Regional synchroneity in fire regimes of western Oregon and Washington, USA

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Abstract

For much of the world's forested area, the history of fire has significant implications for understanding forest dynamics over stand to regional scales. We analyzed temporal patterns of area burned at 25-year intervals over a 600-year period, using 10 tree-ring-based fire history studies located west of the crest of the Cascade Range in the Pacific Northwest (PNW), USA, and related them to periods of possible influences of humans, climate, and stand development processes. An early period of widespread fire from the 1400s to ca. 1650 was followed by a period of reduced area burned from ca. 1650 to ca. 1800, possibly associated with cool climatic conditions. Fires were again widespread from ca. 1801 to ca. 1925, associated with European exploration and settlement and warm conditions. Fire suppression began ca. 1911, but appears to have been most effective in limiting the amount of area burned since ca. 1950. Anthropogenic change, climate, and the degree of stand/fuel development appear to have interacted in their influence upon temporal variation in fire regimes. Patterns of temporal variation in area burned were similar among the 10 studies, suggesting a regionally synchronous response.

The roughly synchronous nature of fire in the region has important implications for our understanding of landscape dynamics under pre-settlement conditions. Forest landscapes of the Pacific Northwest may have exhibited high spatio-temporal variability even when large areas are considered. Major shifts in the landscape age class distribution were likely associated with episodic, high-severity disturbance events. Over certain time intervals in the past, particular seral stages of forest were either dominant across the region, or relatively scarce.

Keywords: Climate and fire; Fire history; Fire regimes; Fire suppression; Indian burning; Landscape dynamics; Pacific Northwest

1. Introduction

Forest fire has been an important process in Pacific Northwest (PNW) forests (Agee, 1993), profoundly affecting forest age and species distributions, hence wildlife habitat, watershed processes (Swanson, 1981; Benda and Dunne, 1997), aquatic ecosystems (Reeves et al., 1995), carbon dynamics, and nutrient cycling (Grier, 1975). For these reasons, interpretations of historical fire regimes are used in plans for management of diverse forest landscapes in the western US (Swetnam et al., 1999), including the PNW (Cissel et al., 1998, 1999). Interpretations of fire regimes have also been invoked to explore probable historical

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structure and extent of old-growth forests (Wimberly et al., 2000) and the effects of climate change on forests of the region (Franklin et al., 1992).

Research on fire history and its applications has stimulated questions concerning the influences of climate variability and humans on fire occurrence. Such questions have been addressed convincingly in the high-frequency/low-severity fire regimes of forest and woodland sites in the southwest US. In that region, fires are strongly related to seasonal- to century-scale climate variability, especially extreme El Nino-Southern Oscillation events, and the conspicuous influence of anthropogenic fire suppression over the past several decades (Swetnam and Betancourt, 1998; Swetnam et al., 1999; Grissino-Mayer and Swetnam, 2000). Similar broad-scale analyses of fire regimes in the Pacific Northwest have been more limited. Prior to fire suppression, fire regimes of PNW forests varied from low to high frequency with related variation in severity across the broad range of forest types and climatic environments of the region (Agee, 1993). Landscape-scale studies (e.g. 10^1 to 10^3 km^2) suggest that fire occurrence declined during the Little Ice Age (ca. 1600–1800) and then increased during the 1800s, followed by greatly reduced fire extent in the 20th century (Morrison and Swanson, 1990; Weisberg, 1998). Influences of native people on fire occurrence have been documented in lowland ecosystems (Boyd, 1999), but the record of influence in more remote mountain areas is extremely limited.

The growing interest in fire regimes of the PNW has led to a series of tree-ring-based fire history studies in landscape samples of 2–1375 km^2 each (Fig. 1). This collection of studies employed similar techniques to sample mainly within the western hemlock (*Tsuga heterophylla*)-Douglas-fir (*Pseudotsuga menziesii*) forest type. The 10 sample sites are distributed north–south along the western Cascade Range and also along an east–west transect across the Coast and Cascade Ranges in Oregon (Fig. 1).

Collectively, this regional record can be examined for evidence of climatic and human influences on PNW fire regimes. To facilitate the integration of disparate fire history studies, we developed a common denominator, namely the area burned over broad (25-year) intervals. This measure of temporal fire trends is robust to dating errors inherent in the 10 studies, resulting from field counting of tree rings, rather than use of high-precision dendrochronological techniques (Weisberg and Swanson, 2001). Unfortunately, we were unable to consider fire severity because it is not consistently reported in the fire history studies comprising our sample.

This paper describes and evaluates the combined evidence for fire history in the PNW based on these 10 landscape-scale studies. Our objectives are to describe temporal changes in area burned over the past 600 years, and to evaluate the relative importance of human and climate factors for influencing the temporal patterns of area burned. By addressing these specific objectives, we hope to refine questions to be addressed in the next generation of forest history studies in the PNW region, while clarifying the distinctive temporal trends, human influences, and climate effects upon fire in the PNW.

2. Study area

This regional analysis considers results from 10 landscape-scale fire history studies within the Douglas-fir dominated forests west of the crest of the Cascade Range in Oregon and Washington (Fig. 1). The western hemlock/Douglas-fir forest type dominates lower elevations of the PNW region, from the foothills of the Willamette Valley and other interior valleys at 300–400 m, and extends upslope to elevations of 1100–1250 m. Pacific silver fir (*Abies amabilis*) and mountain hemlock (*T. mertensiana*) types dominate at higher elevations (Franklin and Dyrness, 1988). The region as a whole has a temperate, maritime climate with cool, wet winters and warm, dry summers. Precipitation increases from south to north, and toward the higher elevations of the Coast and Cascade Ranges. Despite abundant annual precipitation, periods of extended drought commonly occur during the summer months. The combination of summer drought, east wind events, and lightning storms leads to a favorable fire climate for the region during the late summer and early fall of certain years (Agee, 1993).

Human activities may have played important roles in the fire history of the study area. Throughout the region, native people based in the lowlands are believed to have made at least seasonal use of the middle and upper elevation forests, as exemplified by

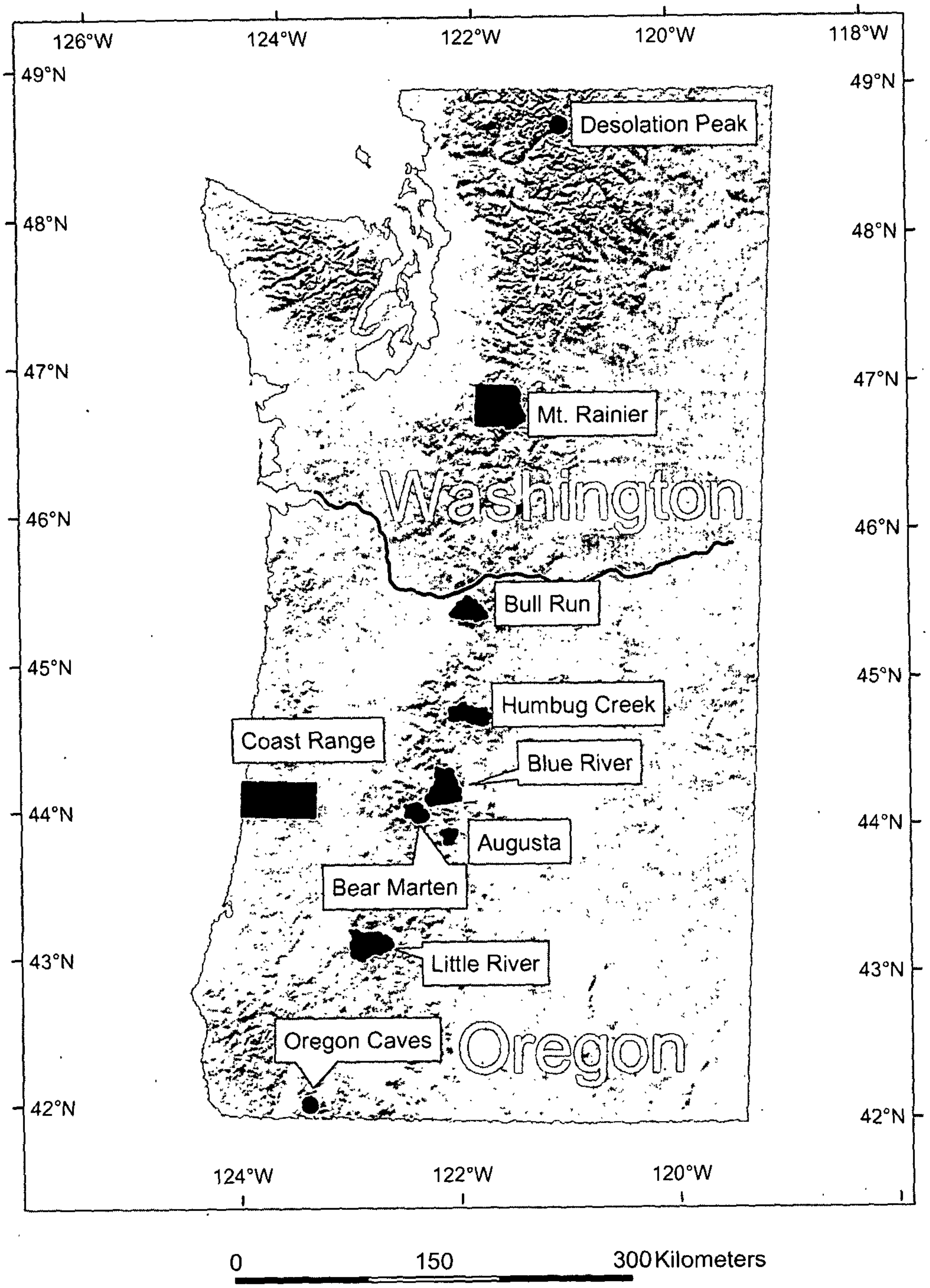

Fig. 1. Map of the 10 fire history study sites, showing their locations and boundaries within the states of Oregon and Washington.

intensive studies on individual tribes and areas (Minor and Pecor, 1977; Boyd, 1986; Mierendorf, 1999). Prior to Euro-American settlement, the Molala and other tribes occupied much of the central western Cascades, wintering along lower-elevation rivers and streams, and moving into upland areas during the summer to hunt, fish, and gather vegetable foods (Minor and Pecor, 1977). There is also evidence that Salish-speaking people utilized the mountain forests, including subalpine and alpine zones of the northern Washington Cascades for at least 4500 years prior to settlement (Mierendorf, 1999). The Kalapuya people were associated primarily with the Willamette Valley and its major tributaries, but may have utilized the uplands of the Cascades for summer food-gathering activities as well (Minor and Pecor, 1977). The specific role of native people in influencing the pre-settlement fire regime of major river valleys in the western Cascades is not well known and is debated (Burke, 1979; Teensma, 1987), although it is likely that they had significant influences on forests in major river valley and foothill environments of both the Coast and Cascade Ranges (Boyd, 1986; Ripple, 1994).

3. Methods

We conducted a review of literature and databases (Heyerdahl et al., 1995) concerning tree-ring-based, fire history studies for the western Cascades of Washington and Oregon and the Coast Range of Oregon, and selected for further analysis the studies that either reported sizes for historical fires or provided sufficient information from which estimates of fire size could be derived (Hemstrom and Franklin, 1982; Agee et al., 1990; Agee, 1991; Garza, 1995; Impara, 1997; Weisberg, 1997; Cissel et al., 1998; Van Norman, 1998; Weisberg, 1998; Agee and Krusemark, 2001).

Interpretation of tree-ring-based fire history results is conditioned by important limitations of the record (Lertzman et al., 1998). Because each of these 10 studies was based on field-counted fire scar and tree origin year estimates, and none was based on cross-dated fire chronologies, fire year estimates are imprecise. A study comparing field-counted with cross-dated fire history results for an area centrally located among these study sites found that field-counted scar years were within 10 years of cross-dated values for about 75%, and within 20 years for about 87%, of observed cases (Weisberg and Swanson, 2001). We used the area burned within 25-year increments as an appropriate level of resolution for comparing fire history among time periods and sites. We believe that this temporally aggregated record can reveal broad inter-century patterns in fire occurrence, while remaining robust to likely inaccuracies in fire dating.

The area burned in each 25-year interval was calculated for each study, using three approaches. Seven of the studies reported estimates of area burned for historical fires that could directly be aggregated to area burned over 25-year intervals (Hemstrom and Franklin, 1982; Garza, 1995; Weisberg, 1997; Cissel et al., 1998; Impara, 1997; Weisberg, 1998; Agee and Krusemark, 2001). For two studies (Agee et al., 1990; Agee, 1991) fire size was estimated by superimposing published maps of historical fires on high-resolution graph paper, counting the number of squares within each fire boundary, and then multiplying the study area size by the proportion of area burned. These area estimates were then grouped into 25-year intervals. For one study, neither estimates of fire size nor published maps of fire boundaries were available (Van Norman, 1998). Therefore, the area burned by each fire was estimated from the proportion of study sites that had a record of a fire, compared to the number of study sites that could have recorded the fire, following Morrison and Swanson (1990):

$$A_i = A\left(\frac{n_i}{n - k_i}\right) \tag{1}$$

where A_i is the estimated area burned in time period i ($1 \leq i \leq 24$), A the study area size, n_i the number of sites with a record of fire in time period i, n the total number of sites in the study area, and k_i is the number of sites where the tree age is less than $i \times 25$ years, i.e. evidence of fire in period i has been subsequently erased.

For all the 10 studies, the area burned in 25-year increments was compared graphically among studies and between time periods by plotting: (1) sites and time periods in which fires had burned more than 20, 30, or 50% of the study sites; (2) the mean proportion of area burned for each 25-year increment, including only those sites with trees old enough to have recorded fire during that period.

We were interested in looking for patterns and relationships between climate history, human history, and the timing of widespread fire periods, over the broad regional scale. The Pearson χ^2-test for association (Ramsey and Schafer, 1997) was used to determine if the frequency of study sites with burned areas of at least 20% in 25-year periods was associated with time periods reflecting possible human effects on fire, climate effects on fire, and combined human and climate effects.

The delineation of time periods representing climate effects was based on published tree-ring chronologies from timberline in the Washington Cascades (Graumlich and Brubaker, 1986). These chronologies show: (1) a period of warm summers and low snow accumulation from 1650 to 1690; (2) a period of very cool temperatures from 1690 to 1760; (3) a transition period toward warmer temperatures from 1760 to 1840; (4) a period of warm summers, but cool, snowy winters from 1840 to 1900; (5) a period of warm summers and low snow accumulation from 1920 to the present.

The period spanning decline of native people and development of Euro-American settlement involved dramatic changes in human populations, settlement, and resource use over the study period that may have influenced fire regimes (Mackey, 1974; Burke, 1979; Boyd, 1986). Prior to the late 1700s, burning by native people may have been an important ignition source for fires in the region, particularly at lower elevations (Boyd, 1986, 1999). During the late 1700s and early 1800s, native people were decimated by smallpox and malaria. Settlement by Euro-Americans was well underway by the mid-1800s. From the 1850s to the 1890s the lower elevations of the region were heavily utilized by a succession of ranchers, farmers, homesteaders, and travelers, while the upper elevations were locally utilized by herders, miners, and loggers. All of these activities have been associated with a high incidence of anthropogenic fire (Burke, 1979). Fire suppression activities were initiated ca. 1910, although it is likely that the efficacy of fire suppression was limited for some years, prior to development of an extensive road system and modern fire-fighting technology.

On the basis of these historical data, we selected three sets of time periods to test for association with the frequency of large-fire events. The "human effects" set consists of four periods: 1551–1775 (native influences), 1776–1850 (low human population), 1851–1925 (Euro-American settlement), and 1926–1996 (fire suppression). The "climate effects" set consists of four different periods: 1551–1700 (warm and dry), 1701–1775 (very cool), 1776–1850 (transition to warm), and 1851–1996 (warm). The "human × climate effects" set consists of five periods reflecting a direct overlay of the above two classifications: 1551–1700 (native × warm), 1701–1775 (native × cool), 1776–1850 (few people × transitional climate), 1851–1925 (settlement × warm), and 1926–1996 (fire suppression × warm). We used the χ^2-statistic to assess the degree of association between the number of sites with widespread fire ($\geq$20% area burned) and each of the three time classifications. Expected values for cells in the contingency table were calculated assuming the 35 occurrences of widespread fire since 1550, at a given site and in a given 25-year period, were evenly distributed among 25-year periods.

4. Results

Patterns of temporal variation in fire regime exhibit striking similarities among 10 tree-ring-based fire history studies from west of the crest of the Cascade Range in Oregon and Washington (Fig. 2). An early period of widespread fire extends from the 1400s to ca. 1650. Most old-growth forests in the western Cascades date from this period, making it difficult to use tree-ring-based methods to reconstruct forest history for earlier periods. Fires in this period may have been much larger than individual study sites, particularly for study sites that are small relative to the sizes of their largest reconstructed fires, such as Bull Run, Bear-Marten, and Oregon Caves (Fig. 2). Other study sites, such as Blue River, appear to have experienced multiple large fires within a century or more.

Although the period of widespread fire ended at different times in different parts of the region, it was followed consistently by a period of reduced area burned from ca. 1650 to ca. 1800 (Fig. 2). Only the Oregon Caves (Agee, 1991) experienced fires that burned large portions of the study site during this period.

A second period of widespread fire occurred from ca. 1801 to ca. 1925 (Fig. 2). Eight of the ten studies recorded at least 20% of their areas burned during this time interval. This period is rather variable, appearing

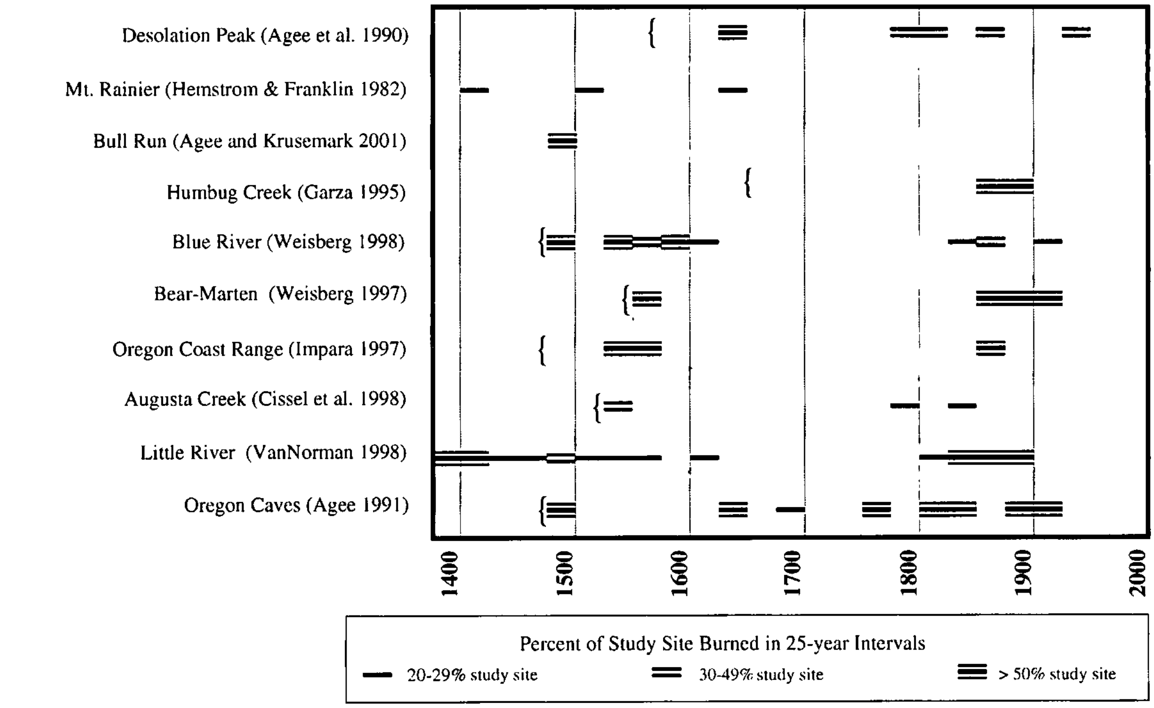

Fig. 2. The percentage of each study site that has burned over time, shown for three classes of area burned (20–30%, 31–50%, 51–100% of study site). The 10 fire history studies are listed from north to south. Each horizontal bar symbol represents the area burned at a site over a 25-year interval. Absence of a horizontal bar indicates that less than 20% of the site has burned in that interval. Each vertical line demarcates a period of 100 years, or four 25-year intervals over which fire history has been summarized. The bracket at left marks the start of the period of record adequate to estimate area burned.

to range from no extensive burning in 25-year intervals at two study sites, to a single 25-year period of extensive burning (e.g. the Coast Range site (Impara, 1997) which actually had several very extensive fires) to a century-long period of extensive burning in the case of Little River. The start of this period at all but the southern-most site ranges from the late 1700s to 1850; in four cases, this period extends into the 1900s. Nearly all studies recorded limited fire occurrence since ca. 1926, although starting dates for the period of low-fire extent are quite variable.

A weak north–south gradient is apparent in the temporal pattern of areas burned (Fig. 2). Two of the four northern-most study sites did not exhibit the most recent period of widespread fire, experienced by all other study sites. Also, the temporal pattern of fire in the southern-most Oregon Caves study site (Agee, 1991), differed from that of the other study areas analyzed in that relatively extensive burning occurred during the 1651–1800 period. The four sites in the Oregon Coast Range and central Oregon Cascades (Impara, 1997; Weisberg, 1997; Cissel et al., 1998; Weisberg, 1998) experienced very similar patterns of fire (Fig. 2).

From plotting the mean percentage of area burned for each 25-year increment (Fig. 3), it is apparent that relatively large areas burned (i.e. mean percentage $\geq 20\%$) during the 1376–1425, 1476–1500, 1526–1575, 1626–1650, and 1801–1925 periods. Periods of limited area burned (i.e. mean percentage $\leq 10\%$) included 1426–1450, 1501–1525, 1576–1625, 1651–1675, 1701–1725, and 1951 to the end of record (1996). Results for earlier periods are suspect because few sites (only two sites prior to 1475) included surviving trees old enough to have recorded evidence for such early fires (Fig. 3a). A 75-year running mean shows periods of widespread fire may be generalized as ca. 1475 (or earlier) to ca. 1575, and ca. 1801 to ca. 1925 (Fig. 3b).

On the basis of a Pearson χ^2-test (Table 1), there was no association between the frequency of widespread

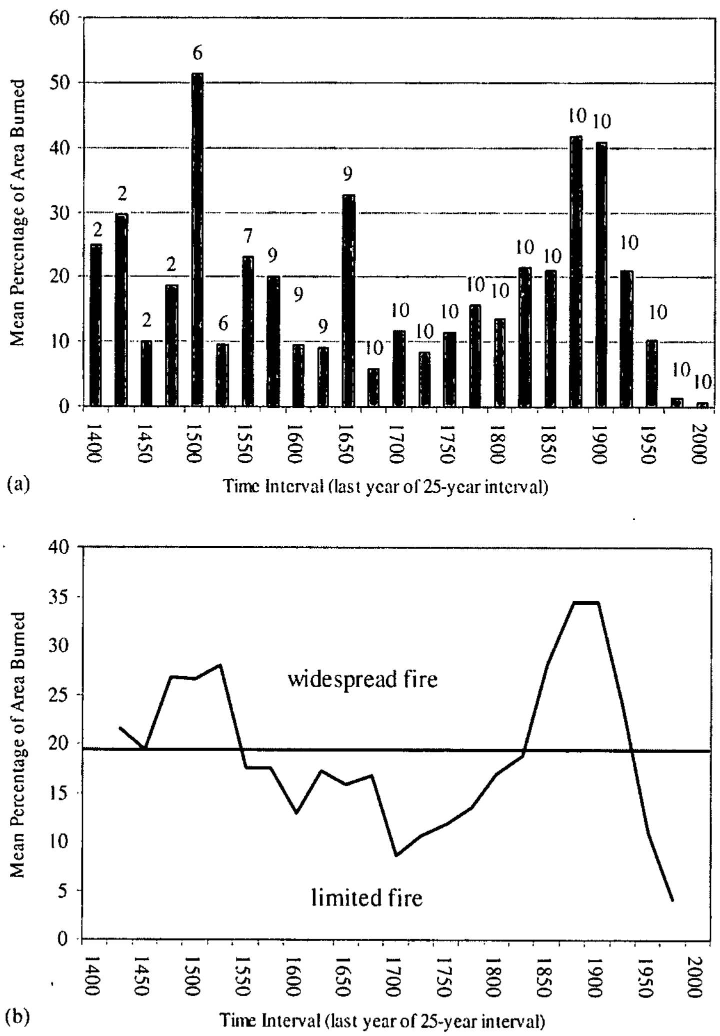

Fig. 3. The mean percentage of area burned for each 25-year increment, averaged over all sites with trees old enough to have recorded fire during that time period. Years labeled on the x-axis refer to the more recent endpoint of each 25-year interval. (a) The mean percentage of area burned is shown for each time interval, and the number of sites included in the estimated mean is shown above each bar. (b) Departures from the 20% cut-off criterion for "widespread fire", based on a 75-year running mean of values in (a).

fire and time periods based solely on climate effects ($P < 0.11$), but the association was significant for time periods based on human effects ($P < 0.002$). The periods selected to delineate possible climate effects combined the 1851–1925 settlement period with the 1926–2000 fire suppression period. Periods based on combined possible human and climate effects were the most strongly associated with the prevalence of widespread fire ($P < 0.0004$, Table 1). The difference between the human effects and human × climate effects periods was that the human × climate effects split separated the 1701–1775 period, a period of low fire activity, from the 1551–1700 period.

5. Discussion

Changing fire patterns over time may be related to: (a) climate variability, (b) changing anthropogenic

Table 1
Pearson χ^2-test for association between the frequency of studies with burned areas of at least 20% of study site in 25-year periods, with time periods potentially representing human effects on fire, climate effects on fire, and combined human and climate effects

Time period Hypothesized effects	1551–1700 Native × warm	1701–1775 Native × cool	1776–1850 Few people × transition	1851–1925 Settlement × warm	1926–2000 Suppression × warm	Test Statistic
Human effects	←——12——→ (17)		9 (6)	13 (6)	1 (6)	$\chi^2 = 15.49$, 3 d.f. $P < 0.002$
Climate effects	11 (11)	1 (6)	9 (6)	←——14——→ (12)		$\chi^2 = 6.04$, 3 d.f. $P < 0.11$
Human × climate effects	11 (11)	1 (6)	9 (6)	13 (6)	1 (6)	$\chi^2 = 20.44$, 4 d.f. $P < 0.0004$

Columns refer to the sequence of five time periods, described both in terms of human effects (native people, low human population, Euro-American settlement, and fire suppression) and climate effects (warm, cool, transition). Rows refer to hypothesized effects (human, climate, or the interaction of both) defining over which of the five time periods widespread fire events were tallied. Expected values were calculated assuming the 35 occasions when sites recorded widespread fires were equally likely to occur in any 25-year period.

influences, (c) long-term patterns of fuel accumulation related to disturbance and stand development (Agee and Huff, 1987; Mann et al., 1994), or (d) combinations of these influences. The degree of regional synchroneity in fire regimes may provide useful clues to understanding the relative importance of these factors. Using similar reasoning, Carcaillet (1998) concluded that from 6000 BP to the present, fire regimes have not been strongly influenced by climate variability in the French Alps, where two sites only 10 km apart had burned asynchronously, presumably due to local anthropogenic influences. If regional climate variability is a major influence, temporal changes in fire regimes should be significantly synchronous over regional scales. Wetter, cooler periods should be associated with reduced fire frequency and extent. Anthropogenic influences of Euro-American settlement should be roughly synchronous, but may differ somewhat according to different timing and rates of settlement, travel, and other land uses. If changing fire patterns over time result solely from fuel succession processes at the stand level, changes should occur at different times in different parts of the region. Interactions among these three factors may confound interpretation of the importance of any one factor. For example, a major drought might render a whole region prone to high-severity fire, causing the timing of stand development influences to coincide over a large area for an extended period. Subsequent droughts might not lead to widespread fires due to lags in fuel accumulation, as stands develop following the earlier fire.

Our results suggest that all three of the factors hypothesized to influence fire patterns over time (i.e. climate, human influences, fuel accumulation) likely had important effects on the temporal patterns of area burned over the PNW region west of the Cascade Range, during the periods considered. Evidence for the role of climate includes the prevalence of widespread fire during relatively warm periods from ca. 1400 to ca. 1575, and from ca. 1800 to ca. 1925. Only one site recorded widespread fire during the cool period from ca. 1700 to ca. 1775. Cooler climate associated with the Little Ice Age also has been linked with reduced fire frequency and burned area in northwestern Minnesota (Clark, 1990), and the southern Canadian Rockies (Johnson and Larsen, 1991). The relatively low amount of area burned in the Desolation Peak study area during the 1700s was attributed to the Little Ice Age cool period (Agee et al., 1990).

The time required for fuel accumulation following high-severity fires has been reported to modulate the effects of climate on fire frequency (Clark, 1989; Mann et al., 1994) and severity (McNeil and Zobel, 1980). Relatively low fuel loads associated with the earlier stages of stand development may help explain why the relatively warm period, from ca. 1650 to ca. 1700, experienced limited fire over the region. Extensive, widespread fires during the 1500s and early 1600s would have resulted in young and mature stands with low fuel loadings (Agee and Huff, 1987), potentially limiting the possibility of an ignition becoming a widespread fire during subsequent decades. Observed rates of post-fire fuel succession in the region suggest that surface fire intensity is the lowest for stands 110–180 years old (Agee and Huff, 1987).

The most recent period of regional, widespread fire (Figs. 2, 3b) is associated with warmer, drier climate beginning ca. 1840 (Graumlich and Brubaker, 1986). However, dramatic changes in human influences on forest patterns and fire regimes were also underway. If native burning had been an important influence on fire regime, fire frequency and burned area would be expected to have been reduced following the series of deadly epidemics from 1782 (smallpox) to 1833 (malaria), and the 1855 relocation of nearly all Kalapuya in the central part of our regional study area to the Grand Ronde reservation, far removed from these study sites (Mackey, 1974). Because most of the major river valleys within the Cascade Range were not utilized by Euro-Americans substantially until the mid-1850s (Burke, 1979), the early 1800s would be expected to have experienced relatively few fires, if humans were an important ignition source. These 10 fire history studies show the onset of a widespread fire period beginning as early as ca. 1800 (Figs. 2, 3), following the decimation of native populations, but preceding significant Euro-American settlement. However, the mean percent of area burned among the sites doubled during the 1850–1875 period, as Euro-Americans greatly expanded their influence in the region (Fig. 3). These results suggest that climatic factors may have been important in initiating the 19th century period of widespread fire, but that changing human influences intensified it.

Limited fire occurrence in these study sites since ca. 1925 has coincided with warm, dry conditions (Graumlich and Brubaker, 1986) and the onset of effective fire suppression activities. Clearly, the dramatic trend toward smaller, lower-severity fires during this recent period is due to anthropogenic influences. Our results suggest relatively ineffective fire suppression during the ca. 1900–1925 period, but a dramatic reduction in widespread fire following ca. 1950, corresponding with the development of forest road systems and effective fire-fighting technology. Overall, ignitions may have increased in the suppression period. Burke (1979), for example, summarized documentation of suppression efforts on 816 lightning-caused fires and 621 human-ignited fires for the central Cascades of Oregon in the period 1910–1977, suggesting a 75% increase in ignitions due to human influence.

It is difficult to separate anthropogenic, climatic, and stand development influences on the observed temporal patterns of the regional fire regime, as they have varied at nearly the same times. All have clearly played roles. However, humans have succeeded in greatly limiting the extent of wildfire during the period since ca. 1950, despite generally warm temperatures. There is also the possibility that suppression success during this period has been influenced in part by temporal patterns of fuel accumulation. Since fire was extensive in the study landscapes during the early Euro-American settlement period, though not necessarily with stand-replacing severity, these areas may be in a period of "fuel recovery", thus reducing potential for widespread, severe fire.

The history of fire has significant implications for understanding old-growth forests in the PNW, which have been the topic of heated debate. Many contemporary old-growth forest stands in the region have their origin in the fires of the ca. 1500s and also may reflect other aspects of temporal variation in fire history (Weisberg, 1998). While we have an emerging understanding of the full spectrum of successional development of forests leading to old-growth states (Spies and Franklin, 1996; Acker et al., 1998), mental images of old growth are strongly conditioned by this particular, widespread age class dating from extensive fires 400–500 years ago. Furthermore, the roughly synchronous nature of fire in the region has important implications for our understanding of landscape dynamics under pre-settlement conditions. The PNW may never have been equilibrial in the sense that all seral stages of forest would be represented in consistent proportions if a large enough area were considered (Turner et al., 1993). Rather, as has been suggested for crown-fire-driven landscapes in general on the basis of modeling (Boychuk and Perera, 1997; Wimberly et al., 2000) and observational (Baker, 1989) studies, the PNW may have exhibited high spatio-temporal variability at any spatial scale. Over certain intervals in the past, particular seral stages of forest may have been either dominant across the region, or extremely scarce. This finding has important implications for understanding past population dynamics of species associated with particular forest seral stages. For example, species associated with late-seral forests survived a period of high fire occurrence from the 1400s to ca. 1650, during which time their preferred habitat was likely to have been scarce or isolated. Such effects were likely mitigated since, for many parts of the PNW, old trees and other old-growth forest attributes can be sustained in stands and landscapes through many fires (Morrison and Swanson, 1990; Weisberg, 1998). Since low and moderate severity fires were common over much of the study area (Morrison and Swanson, 1990; Teensma, 1987; Garza, 1995; Impara, 1997; Van Norman, 1998; Weisberg, 1998), it is inappropriate to think of these fire events as being entirely stand replacing.

Some contemporary approaches to forest management utilize historical information on landscape conditions and disturbance regimes as a significant input for landscape-level forest planning. This "coarse-filter approach" attempts to maintain landscape patterns and ecological processes within a historic range of variability (HRV) with the objective of sustaining native species (Hunter et al., 1989; Attiwill, 1994; Holling and Meffe, 1996; Landres et al., 1999). Use of the HRV approach for guiding forest landscape management in the PNW may be complicated by the observed tendency toward regionally synchronous burning and extended periods of little burning. The temporal variability of landscape structure resulting from either traditional forestry practices or HRV-based forest management approaches may be greatly reduced relative to that of the past 500 years, when the metric of disturbance regime used to quantify the HRV is based only on the central tendency of the distribution of disturbance-free intervals, and not on the whole distribution (Cissel et al., 1999). While it would not be feasible (nor desirable) for HRV-based management to go too far in the direction of replicating regionally synchronous disturbance processes, it is important that such management plans consider as complete a knowledge of historical spatio-temporal dynamics as possible, preferably over a range of spatial scales from individual forest landscapes to broad regions.

Findings from this regional analysis of fire history studies suggest higher resolution fire dating could be used to refine the interpretation of fire history over this period. For example, improved dating might permit better distinction of human and climate influences for the 1775–1850 period when fewer native people are believed to have been present to ignite fires. However, a warming climate may have counteracted this effect by contributing to a greater frequency of fire. As it turns out, the frequency of widespread fire during this period was just slightly greater than what one would expect had fire been evenly distributed from 1550 to 2000 (Table 1). Precise fire dates for specific locations where human and climate history are well known may allow better distinction between possible effects of changing land use patterns and changing climatic regimes, in contributing to the onset of the ca. 1800 to ca. 1925 period of widespread fire. It would also be interesting to have higher resolution dates on fires in the 1400s to ca. 1650 period in order to better distinguish fire frequency and extent at that time. However, improved spatial coverage and temporal resolution for both climate history and patterns of pre-settlement human land use would be needed to describe human and climate influences on fire with greater detail.

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