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Influence of humans and climate on the fire history of a ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, California

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Abstract

Fire history of a ponderosa pine-mixed conifer forest was investigated in the Whiskeytown National Recreation Area, southeastern Klamath Mountains, California. Fire return intervals were found to be frequent and similar to other comparable forests in California. Median fire interval for the six sample plots (1.4–1.7 ha) ranged from 2 to 4 years (mean range, 4.8–7.4 years). Most fires (93%) occurred late in the growing season or after growth for the season had stopped. Early fire activity was frequent and heterogeneous; however, this trend dramatically changed ca. 1850 to a less frequent and more homogeneous fire pattern. Euro-American settlement, which was active in this area, most likely caused this change by the elimination of Native American ignitions and by introducing logging, gold mining, grazing, and early fire suppression. For the period of record (1750–2002), years when fires were widespread within the study area were not correlated with drought conditions represented by reconstructed climate indices: palmer drought severity index (PDSI) and southern oscillation index. After 1850 when Euro-American settlement began, widespread fire years were associated with wetter than average conditions 3 years preceding the fire year (PDSI, gridpoint #5). Although several recent fire history studies have identified fire–climate relationships with these indices in the Pacific Northwest, additional research is needed in the southern portion of the region. Possible future extensions from the fire–climate relationships identified include: anticipating wildfire extent for future fire seasons, understanding potential alterations in Klamath fire regimes forced by climate change or by cultural land use practices, as well as planning fire management activities (fuels reduction, prescribed fire, etc.).

Keywords: Climate indices; Dendrochronology; Fire return interval; Fire suppression; Seasonality; Settlement; Superposed epoch analysis; Whiskeytown National Recreation Area

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1. Introduction

Forests in western U.S. have been impacted by Euro-American land use practices and nearly a century of fire suppression resulting in the commonly referenced undesirable forest conditions (Leopold et al., 1963; Dodge, 1972; Franklin and Dyrness, 1973; U.S. Forest Service, 1992; Agee, 1993; Taylor, 2000; Stephens and Ruth, 2005). Fire is the predominant disturbance process in many ecosystems in California (Wright and Heinselman, 1973) affecting patterns of succession, community structure, and species diversity (Franklin and Dyrness, 1973; Agee, 1993; Taylor and Skinner, 1998).

More recently, resource managers and ecologists have attempted to restore ecosystem processes and structure in conifer forests with prescribed fire and mechanical thinning treatments (Agee, 1993; Hardy and Arno, 1996; Mast et al., 1999; Taylor, 2000). National Park Service policy mandates that managers incorporate natural disturbances into management plans to restore and perpetuate presettlement conditions (Bonnicksen and Stone, 1982; Kilgore and Nichols, 1995).

One obvious challenge to this mandate is the lack of reference information on forest structure and disturbance regimes prior to impacts from Euro-American settlement. Where feasible, fire history data (fire return intervals and seasonality obtained from fire scarred trees) provides some historical reference information in the context of the natural range of variability of the disturbance regime. Knowledge of historical reference conditions is important in guiding forest restoration goals (Swetnam, 1993; Swetnam et al., 1999).

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Variability in the disturbance parameters gives managers a range that may be simulated through treatments to maintain disturbance regimes sustaining ecosystem structure and function (Kaufmann et al., 1994; Morgan et al., 1994).

Several studies have provided fire history information in the Klamath Region of California and Oregon (Agee, 1991a; Wills and Stuart, 1994; Taylor and Skinner, 1998, 2003; Stuart and Salazar, 2000; Skinner, 2003a, 2003b). Whittaker (1961) identified the Klamath Ecoregion as an area of ''central significance'' with regards to its vegetation diversity. Due to the region's geologic age and complexity, climatic gradient from west to east, and topographic variation it supports a mosaic of vegetation patterns with rich and diverse flora unparalleled in other western forests (Skinner et al., in press).

Only one fire history study has been done in the southern portion of this mountain range (Taylor and Skinner, 2003). Most of the above-mentioned studies were conducted in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) dominated forests. There is limited fire history information available for ponderosa pine (*Pinus ponderosa* Laws) dominated mixed conifer forests in the Klamath Mountains. In Douglas-fir dominated forests, pre-Euro-American settlement fires occurred relatively frequently and strongly influenced patterns in forest structure (Wills and Stuart, 1994; Taylor and Skinner, 1998, 2003; Stuart and Salazar, 2000; Skinner, 2003b).

Despite the benefit of using historical information when managing ecosystems (Christensen et al., 1996), one caveat is that it represents a relatively small frame of reference of a spatio-temporally dynamic system (Swetnam et al., 1999). Considerable variation in climate has occurred over the past few centuries (Dettinger et al., 1998; Swetnam and Betancourt, 1998; Millar and Wolfenden, 1999), which have likely led to important changes in aspects of fire regimes (Swetnam, 1993). It is uncertain if similar prehistorical conditions would have existed today under different climatic regimes and in the absence of fire suppression (Stine, 1996; Donnegan et al., 2001; Stephens et al., 2003; Wright and Agee, 2004). Since current forest structure and species composition reflects past natural and human-caused disturbances, causes of the historical changes in fire regimes need to be understood in the context of human and climatic drivers before managers can apply reference information to future management plans (DellaSala et al., 2004; Odion et al., 2004).

The recent use of weather data, long term climate patterns, and indices reconstructed from tree-ring chronologies have proven beneficial in increasing the understanding of fire–climate relationships in conifer forests at various temporal and spatial scales. Among the commonly used indices include the palmer drought severity index (PDSI; Cook et al., 1999) and southern oscillation index (SOI, an index of the EL Niño-Southern Oscillation, ENSO; Stahle et al., 1998). In the American Southwest (SW), extensive research in dry ponderosa pine ecosystems have shown annual to interannual variability in local moisture availability associated with ENSO to be linked with fire regimes (Swetnam and Betancourt, 1998; Swetnam and Baisan, 2003). Variation in historical fire regimes and concomitant forest structure have also been documented to be influenced by human land use practices and climate patterns in the Pacific Northwest (PNW) and northern California (Taylor and Skinner, 1998, 2003; Heyerdahl et al., 2001; Taylor, 2000; Heyerdahl et al., 2002; Norman and Taylor, 2003; Hessl et al., 2004; Stephens and Collins, 2004; Wright and Agee, 2004; Taylor and Beaty, 2005). A better understanding of climatic influences on fire regimes enables managers to prepare resources in anticipation of potential severe wildfire seasons, tailor their management treatments to decrease fire hazard risk, and predict future changes in fire regimes (Swetnam and Betancourt, 1990; Heyerdahl et al., 2002; Hessl et al., 2004). The limited information on fire–climate relations for the Klamath Mountains suggests more areas tended to burn during drier years as measured by PDSI (Taylor and Skinner, 2003).

A particular case in which both wildlife habitat considerations and fire have complicated management options is with the northern spotted owl (*Strix occidentalis caurina* Merriam). In efforts to conserve this federally listed threatened species, managers have established large reserves of late-successional and old-growth forests in the Klamath Mountains (USDA–USDI, 1994). The use of prescribed fire in these areas is seen as both a risk and an important management tool for sustaining forest conditions (USDA–USDI, 1994).

The goal of this study was to describe the fire history in a ponderosa pine mixed-conifer forest in the southeastern Klamath Mountains using dendrochronology. The relationship between fire occurrence and climate was also examined. Specifically, our objectives were: (1) to describe the fire return intervals for six spatially segregated clusters, (2) to describe the season in which past fires occurred, (3) to describe the characteristics of these parameters for three periods: presettlement, settlement, and suppression, (4) to determine the relationship between spatially widespread fire occurrence within the study area and two reconstructed climate indices (PDSI and SOI), and (5) to compare acquired fire history information to other studies in similar forests in California.

2. Methods

2.1. Study area

Our study was conducted in ponderosa pine-mixed conifer forests at Whiskeytown National Recreational Area (WNRA) in the southeastern Klamath Mountains, located approximately 13 km west of Redding, California. In the Klamath Mountain physiographic province, WNRA is an area of significant biodiversity due to its proximity to the Cascade Range, Coast Range, and Sacramento Valley. The numerous vegetation types, rare ecological communities and rare plant species located in the Park illustrate this. WNRA manages approximately 181 km^2 (17,205 ha) of forest and brushland surrounding the 13 km^2 Whiskeytown Lake. Generally, the area has steep hillsides with steeply graded high velocity watercourses. Soils at WNRA are well-developed, well-drained haploxeralfs (alfisols), derived from either andesitic mudflow or granitic/granodiorite parent materials. Soils are deep, weathered, sandy loams overlain by an organic forest floor horizon. Common soil depths range from 85–115 cm (USDI, 2003).

Climate at WNRA is Mediterranean with a summer drought period that extends into the fall. Winter and spring receive the majority of precipitation that averages 150 cm, nearly all in the form of rain; however, snow often remains at the higher elevations well into June. Average annual temperature is 14.5 °C recorded at the weather station located at Whiskeytown headquarters (370 m elevation) but distinctly cooler temperatures are found at the higher elevations (USDI, 2003). Dry season thunderstorms are common and lightning is a common cause of fire in the Klamath Mountains (Schroeder and Buck, 1970).

Dominant conifer species in this forest include ponderosa pine, incense cedar (*Calocedrus decurrens* (Torr.) Floren.), Douglas-fir, sugar pine (*Pinus lambertiana* Dougl.), and white fir (*Abies concolor* (Gord. & Glend.) Lindl.). These species share dominance in stands depending on site conditions and stand history (Barbour, 1988; Taylor and Skinner, 2003). Hardwood tree and shrub species including California black oak (*Quercus kelloggii* Newb.), canyon live oak (*Q. chrysolepis* Liebm.), tan oak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehder), golden chinquapin (*Chrysolepis chrysophylla*), dogwood (*Cornus nuttallii* Audubon), greenleaf manzanita (*Arctostaphylos patula* E. Greene), pinemat manzanita (*A. nevadensis* A. Gray), and mahala mat (*Ceanothus protstratus* Benth.) are found in the understory.

Historical human settlement and land use activities have impacted many areas of the WNRA Park. The Wintu, one of many Native American tribes that inhabited the Klamath Mountains, used fire for specific land management purposes. Fire was used to improve hunting conditions and promote growth of specific plants for food and cordage materials (Lewis, 1990, 1993). By the mid-19th century Euro-American settlement began in the area around what is now Whiskeytown Lake (Smith, 1964). Settlers mined gold in the foothills and produced lumber (Toogood, 1978; Norton and Short, 2002). Base metal and gold mining along with intense timber harvesting resulted in acid mine drainage in many areas, slowly revegetating eroded hillsides, sediment runoff, and impaired water quality in many watersheds in and around WNRA Park. Euro-American settlement into the Whiskeytown area coincided with the decline of the Wintu culture. Cultural documents recount fatal conflicts between Native Americans and early settlers (Lewis, 1990, 1993; Norton and Short, 2002).

The study area was Coggins IV prescribed burn unit (Coggins), located on the western boundary of WNRA. The 120 ha parcel is on a steep east slope at the headwaters of Crystal Creek below Buckhorn Summit with elevations ranging from 1150 to 1525 m above sea level. Coggins is dominated by ponderosa pine on the upper slopes while mixed conifer vegetation types occur on mesic slopes and drainages. The entire unit was burned in a manager-ignited prescribed fire in late September 1997. Pockets of high fire intensity resulted in high overstory tree mortality in several areas.

2.2. *Fire history*

A reconnaissance of Coggins was conducted to determine where clusters of trees with visible fire scars were located. Plots with a minimum of seven samples (fire-scarred trees) over an area less than 5 ha on a single aspect class were selected for sampling. Each sample collected was georeferenced and the area of each cluster was calculated by estimating the minimum area encompassing the sampled trees. The sampling strategy was intended to maximize the completeness of an inventory of fire dates within the unit, while also collecting samples that were spatially dispersed throughout the forest (Swetnam and Baisan, 2003).

Partial cross sections were cut with a chainsaw from all fire-scarred snags, downed logs, and live trees with visible fire scars. Live trees were sampled conservatively to reduce the probability of mechanical failure (Heyerdahl and McKay, 2001; Stephens, 2001).

Each fire-scarred sample was sanded to a high sheen so that tree rings and fire scars could be readily distinguished under a microscope. Fire scars were identified by the characteristic disruption and healing patterns of radial tree-ring growth (McBride, 1983). Calendar years were assigned to each fire scar by cross-dating tree rings using standard dendrochronological techniques (Dieterich, 1980; Swetnam et al., 1985).

Fire chronology information described at different scales allows a thorough examination of fire pattern across a site and facilitates comparisons with other fire history studies (Skinner and Chang, 1996; Falk and Swetnam, 2003). Therefore, we chose to develop fire return intervals (FRI) for individual trees as a point on the landscape (PFI) (Taylor, 2000) and for composites at several scales for each plot and the entire study area. First, a broad scale composite fire chronology where all fires were included was developed (C01). Two composites were developed using a minimum scar criterion, or filter, to include only years where fires scarred many trees over larger areas. An intermediate composite, C10, includes fires that scarred a minimum of two trees and at least 10% of available recording trees. Finally, a composite of fires scarring a minimum of three trees and at least 25% of available recording trees (C25) was developed. Composites of multiple trees will usually provide a more comprehensive record of past fires for the site in question (Dieterich, 1980; Agee, 1993) and the filters (C10 and C25) removed relatively small fires (“spot” fires; Swetnam and Baisan, 1996).

The position within the ring in which a scar occurred was noted as early earlywood (EE), middle earlywood (ME), late earlywood (LE), latewood (LW), dormant (D), or undetermined (U) to serve as an estimate of the season of fire occurrence (Ahlstrand, 1980; Dieterich and Swetnam, 1984).

2.3. *Data analysis*

Since the study area lacked older fire scarred trees, 1750 was selected as the initial date for analysis of composites based on visual inspection of the composite scar chronology to reduce interpretation errors that may occur from too few fire-scarred samples early in the record. The FHX2 software package (Grissino-Mayer, 2001) was utilized for analysis of fire interval data. Non-parametric Kruskal–Wallis test (Zar, 1999) was used to determine if significant differences ($p < 0.05$) in mean fire return intervals (MFI) existed between sample plots, aspect, periods, and vegetation types identified by Warner and Duriscoe (1998). If a significant difference was detected then a non-parametric Tukey multiple comparison test (Nemenyi test) was used to determine what significant differences existed (Zar, 1999).

It was apparent from the fire record that there were two dramatic changes in the fire pattern. First, fires became less frequent and more widespread in the study area following the substantial Euro-American settlement of the 1850s. Secondly, fires were generally eliminated from the study area after 1924 when fire suppression efforts were becoming more effective in accessible areas (Skinner et al., in press). To describe these differences, FRI's and season were divided into three periods: presettlement (1750–1849), settlement (1850–1924), and suppression (1925–2002).

Superposed epoch analysis (SEA) (Baisan and Swetnam, 1995; Swetnam and Betancourt, 1998) was used to investigate fire–climate relationships. Years when fires were widespread within the study area (identified by percentage of samples scarred) were compared to two proxy climate indices to determine if climate was significantly different ($p < 0.05$) from average before, during, and after fire years (±3 years). We analyzed the fire scar record separately by two periods (1750–1849 and 1850–2002), the approximate time when substantial Euro-American settlement began. This was done to determine if fire occurrence responded differently to climate after the land use changes altered the fire regime.

PDSI was used to capture interannual moisture availability. PDSI incorporates precipitation, temperature, evapotranspiration, and soil moisture conditions to indicate relative levels of drought (Palmer, 1965). Tree-ring based reconstructions of PDSI exist for grid points throughout the Western U.S. (PDSI-5; Cook et al., 1999). PDSI-5 is the nearest grid point to our study area, located in the Trinity Mountains approximately 80 km northeast of Whiskeytown at 41°N and 122.5°W. A tree-ring reconstruction of winter SOI, an index of ENSO, was also used and is based on averaged tree-ring data from Mexico and Oklahoma (Stahle et al., 1998). In the PNW (SW), positive (negative) phases of SOI are associated with cooler, wetter conditions and negative (positive) phases are associated with warmer, drier conditions. This study area is located in the transition area between these two dipoles and does not have a clear relationship to SOI (Cayan et al., 1999).

We chose these two commonly used indices because they facilitate comparisons with other studies in western U.S. and aid in extending our understanding of fire–climate relationships to regional scales. All recorded fires that met or exceeded the 25% minimum scar class (C25) were used in the SEA. C25 was selected to represent only fires that were relatively widespread in the study area.

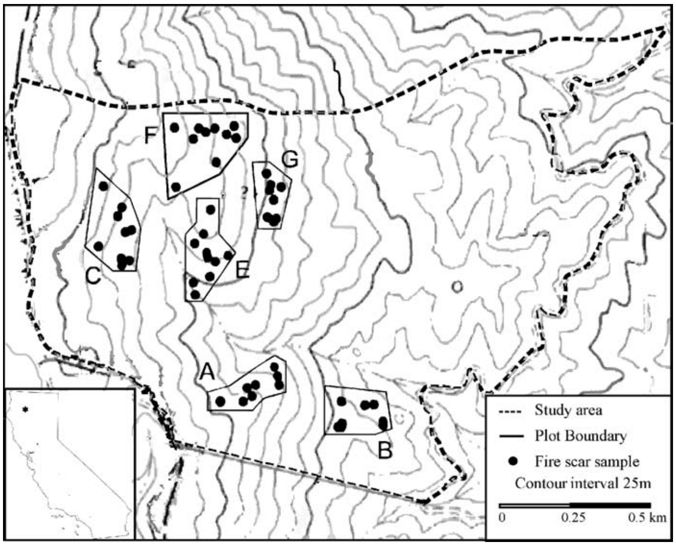

Fig. 1. Fire history plots and sample locations in Coggins IV burn unit, Whiskeytown NRA, southeastern Klamath Mountains, California.

3. Results

Six fire scar plots were located in Coggins, primarily on the upper slopes of the unit (Fig. 1). The terrain on the bottom third of the unit increases in complexity making it difficult to traverse and locate fire scarred trees. Additionally, approximately 5.5 ha on the northeast corner of Coggins was logged in the 1960s and contained very few mature trees. Plots were approximately 80–660 m apart. A total of 56 fire scarred logs, snags, and live trees were sampled. Ninety-three percent of the collected samples were crossdated; the remaining samples were not useable because of excessive rot. A total of 570 fire scars were assigned a calendar year.

Ponderosa pine accounted for 85% of all samples and the majority of samples in each plot (Table 1). Plots were located in three vegetation types identified by Warner and Duriscoe (1998), ranging from relatively pure stands of ponderosa pine on the upper slopes to mesic mixed conifer in drainages and north slopes. The remaining samples were from sugar pine (10%) and incense cedar (5%). Nine samples were collected from live trees (17%) and two-thirds of the live samples

Table 1
Forest characteristics of fire scar sample plots in a ponderosa pine-mixed conifer forest at Whiskeytown National Recreation Area, southeastern Klamath Mountains, California

Plot	Vegetation type	Aspect	Percentage of fire scar samples ponderosa pine	Mean tree density (>61 cm dbh/ha) (1S.E.)
A	Xeric mixed conifer	NE	91	35.6 (7.4)
B	Mesic mixed conifer	N	91	29.2 (6.4)
C	Ponderosa pine	E	60	40.5 (12.1)
E	Xeric mixed conifer	S	71	35.6 (7.4)
F	Xeric mixed conifer	E	92	35.6 (7.4)
G	Ponderosa pine	E	100	40.5 (12.1)

Forest classification from Warner and Duriscoe (1998) (S.E., standard error of the mean).

recorded the 1997 prescribed fire. Forty-six percent of the total samples died the same year or the year after the 1997 prescribed fire. The mean number of fire scars on a tree was 10.2 (range, 2–25 scars; S.D., 4.7). The mean age of available trees sampled was 280 years ($n = 21$; range, 176–424 years; S.D., 63.7).

3.1. Fire return intervals

Fires were found to have been frequent during the early period of record (Fig. 2). Although the earliest recorded fire was 1663, there were limited fire scars available before 1750 in most of the plots. The most recent recorded fire was the prescribed fire in 1997 but there was a general cessation of fire after 1925. There were no significant differences in MFI's between plots for all scar classes (C01, C10, and C25; Table 2).

The number of small fires decreased dramatically around 1850 (Fig. 2). After this time fires were less frequent but more widespread in the study area. Years when at least 50% of the available samples were scarred in all plots occurred during the settlement period (1887, 1915, and 1924).

For the all inclusive fire scar class (C01), the MFI's for the presettlement and settlement periods were significantly smaller ($p < 0.05$) than the suppression period (Table 3). For the larger scar classes (C10 and C25), MFI's from the presettlement

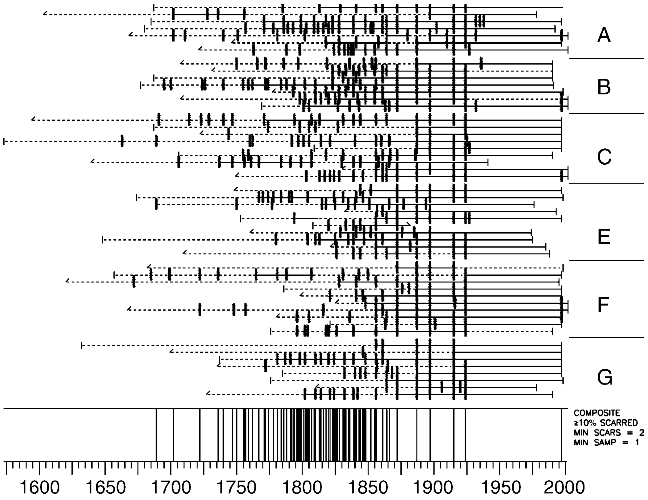

Fig. 2. Composite fire activity of six fire scar plots in a ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, California. Each horizontal line is an individual tree scar record and each vertical tick is a dated fire scar. Horizontal continuous lines indicate recorder years and dashed lines refer to null (non-recorder) years.

Table 2
Fire return interval data (1750–2002) from a ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, northern California

Plot	No. samples	Area sampled (ha)	No. intervals	Mean (years)	Median (years)	Range (years)	No. (fire scars)
A	7	1.6					
C01			51	4.9	3.0	1–62	90
C10			19	12.1	9.0	2–68	58
C25			10	17.2	10.5	3–76	40
B	7	1.4					
C01			52	4.8	3.0	1–61	95
C10			18	12.7	7.5	1–76	62
C25			12	15.8	10.5	5–76	51
C	9	1.6					
C01			50	4.9	2.0	1–73	92
C10			16	12.2	8.0	2–76	58
C25			10	19.3	12.5	3–76	46
E	10	1.7					
C01			48	5.2	3.0	1–73	94
C10			17	11.5	5.0	1–76	63
C25			8	20.1	13.5	5–76	45
F	11	1.7					
C01			38	6.4	3.5	1–73	76
C10			10	20.4	15.0	5–76	59
C25			8	19.9	13.0	5–76	55
G	8	1.6					
C01			31	7.4	4.0	1–76	74
C10			15	13.2	8.0	3–76	58
C25			9	18.7	10.0	3–76	46
Study area	52	120					
C01			120	2.1	1.0	1–59	529
C10			68	3.7	2.0	1–73	467
C25			34	6.7	3.0	1–76	380

Data excludes scar information from 1997 prescribed fire (C01, composite of all fire scars; C10, composite of fires scarring two or more trees and at least 10% of available recording trees; C25, composite of fires scarring three or more trees and at least 25% of available recording trees).

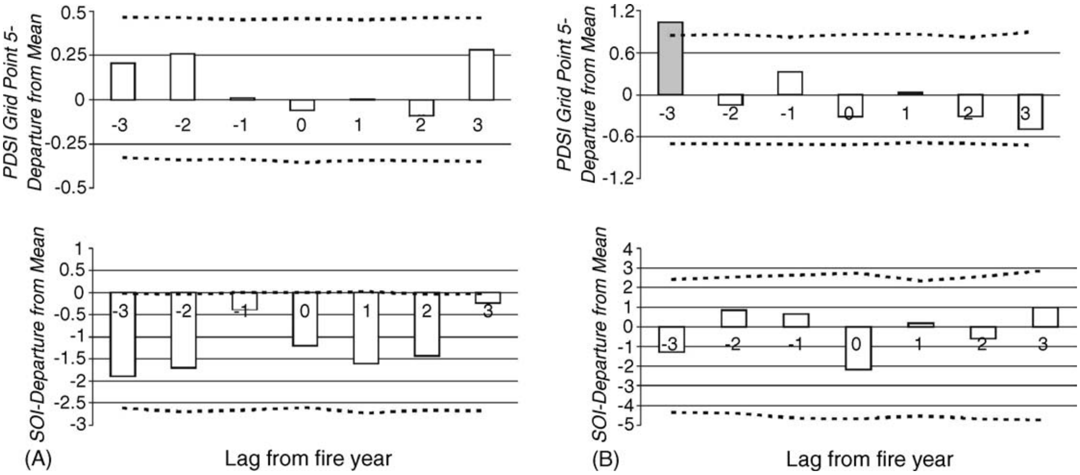

Fig. 3. Superposed epoch analysis of fires scarring more than 25% of the trees (minimum of three trees scarred per fire) compared to two reconstructed climate indices. Fire–climate relationship was analyzed by two periods (A, 1750–1849; B, 1850–2002). PDSI, summer palmer drought severity index (gridpoint #5); SOI, winter southern oscillation index (- - -, 95% CI).

period were significantly smaller than MFI's from the settlement period. Insufficient data for the suppression period prohibited analysis of C10 and C25.

The overall mean PFI for single trees (point) was 13.2 years (median, 13.5 years; range of means, 11.3–15.3 years; S.D., 1.5). Summarized PFI for Coggins was similar to C10 at the plot scale (Table 2).

3.2. Fire season

The location of the scar within the annual ring indicating the season in which the fire occurred was determined for 59.5% of the fire scars. Scars occurred most frequently in the latewood (56.8%) position or at the ring boundary (36%). Early growing season (earlywood) fires were relatively rare (7.1%) and no fire scars were found in the early or middle portion of the earlywood. One wide spread fire year (1887) was recorded in the late earlywood.

Fire season varied by period. The proportion of presettlement fire scars occurred similarly in the latewood (48%) and at the ring boundary (52%). During the settlement period the percentage of latewood scars increased to 61% and dormant period scars decreased to 27.5%, in addition to the late earlywood fire scars recorded (11.5%). The suppression period record was similar to the presettlement (latewood, 45.5%; dormant period, 54.5%).

Table 3
Fire return intervals (in years) by period from a ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, northern California

Scar class	Period	No. intervals	Mean (CV)	Median
C01	1750–1849	77	1.3 (0.5) a	1.0
	1850–1924	35	2.1 (0.8) a	1.0
	1925–2002	7	11.0 (1.9) b	3.0
C10	1750–1849	56	1.8 (0.6) a	1.0
	1850–1924	10	7.2 (0.8) b	5.5
	1925–2002	–	–	–
C25	1750–1849	26	3.0 (0.7) a	2.5
	1850–1924	7	9.7 (0.5) b	9.0
	1925–2002	–	–	–

Summarized interval data for the suppression period (1925–2002) could not be calculated for the larger scar classes due to insufficient data. Within scar classes mean values in a column followed by the same letter were not significant different ($p < 0.05$). CV, coefficient of variation.

3.3. Fire–climate relations

SEA of PDSI and SOI indicated that widespread fire years within the study area (C25) were not correlated with low moisture conditions during the presettlement period ($p > 0.05$, Fig. 3A). After 1850, widespread fire years were associated with wetter than average conditions 3 years prior to the fire year using PDSI ($p < 0.05$, Fig. 3B). Fire years were not associated with SOI during the settlement period.

4. Discussion

Fire return intervals recorded in this study were relatively frequent at all spatial scales and analogous to other studies of mixed conifer forests in Northern California and Oregon (Wills and Stuart, 1994; Taylor and Skinner, 1998, 2003; Stuart and Salazar, 2000; Beaty and Taylor, 2001; Stephens and Collins, 2004). These results indicate that fire was a common ecosystem process in the ponderosa pine-mixed conifer forests in the southeastern Klamath Mountains.

Variation in fire return intervals are influenced by geographic variables such as slope steepness, slope position, aspect, and physical barriers (streams, rock outcrops, mountain ridges) in the Klamath Mountains (Taylor and Skinner, 1998, 2003). There were no differences in mean FRI's between sample plots, aspect, or forest types in the study area. Although the mean FRI was lowest in the plot with a southern exposure (Table 2), the difference was not significant. This study area was comparatively small and lacked contrast in site variables contributing to the minimal differences found. In forests with similar species composition, spatial controls such as aspect limited fire spread influencing burn area and frequency in strongly contrasting terrain in the Klamath Mountains (Taylor and Skinner, 1998, 2003), Cascade Range (Beaty and Taylor, 2001), and Blue Mountains (Heyerdahl et al., 2001).

Due to decay and successive fires removing woody tissue from samples, the season for many scars could not be determined. For the fire scars in which the season was determined, most of the fires in the study area occurred late in the growing season and dormant period, primarily the midsummer through fall period when lightning ignited fires are most common (Schroeder and Buck, 1970). Most of the scars occurring in the earlywood portion of the annual ring were from a widespread fire that burned the entire study area in 1887. Numerous articles in *The Shasta Courier* reported large fires burning throughout the Whiskeytown area and these accounts were dated in the last half of July (Norton and Short, 2002). However, we do not know if these fires burned in the Coggins study area. Generally, fires burning during this time of the summer in California may correspond to scar formation in the latewood (Caprio and Swetnam, 1995; Skinner, 2002), though cambial phenology varies on an annual basis (Wright and Agee, 2004). While the timing and ignition source of this fire is unknown, the season in which fires occur has strong effects on woody debris accumulation (Kaufmann and Martin, 1989) and vegetation response (Agee, 1993; Kauffman, 1990).

Our results on seasonality were generally similar to other fire history studies with comparable forests conducted in the Klamath Mountains (Taylor and Skinner, 1998, 2003) southern Cascades (Norman and Taylor, 1997; Taylor, 2000; Beaty and Taylor, 2001), and northern Sierra Nevada (Stephens and Collins, 2004). Fire season information for the southern Klamath Mountains (this work; Taylor and Skinner, 2003) indicates 90–93% of the fire scars occurred in the latewood and dormant portion of the annual ring, late in the growing season and after growth had ceased for the year. However, in this study less than half the proportion of fires occurred during the dormant season.

Variation in burn season noted here can be attributed to differences in species composition, local site variables and possibly the timing of Native American ignitions (Martin and Sapsis, 1992). Taylor and Skinner's (2003) study was conducted in forests dominated by Douglas-fir while ponderosa pine was the dominant conifer in this study. The intraring fire scar position may vary between species (Caprio and Swetnam, 1995; Stephens, 2001). Furthermore, studies conducted at larger spatial scales with more variation in site variables such as aspect, topographic position, and elevation captures more variation in burn season. Fires tend to burn earlier in the season in forests at lower elevations and slopes with southern and western exposures because fuels dry earlier (Beaty and Taylor, 2001; Skinner, 2002).

The significant increase in MFI circa 1850 may be attributed to impacts from Euro-American settlement and/or climate change. The timing coincides with dramatic increases in the Whiskeytown population. Common land use practices associated with human settlement (mining, livestock grazing, and timber harvesting) likely had profound effects on the landscape.

Gold miners began settling in the area in 1849 after gold was discovered in Clear Creek in 1848. The town population peaked in 1855 with about 1000 miners (Smith, 1964). In addition, by 1853 three sawmills in Whiskeytown were producing lumber (Smith, 1964; Toogood, 1978). Both miners and loggers used lumber and water in their operations and water was also diverted from streams to generate power (Norton and Short, 2002). Altering stream hydrology through diversion and intensive logging likely influenced soil and fuel moisture, fuel loads, and vegetation patterns.

Cultural documents indicate residents and volunteer fire companies also suppressed fires as early as the 1880s (Norton and Short, 2002). It is unknown to what extent fire suppression was successful in changing fire patterns across the landscape but reports often praised people's efforts in protecting the town.

Another impact of Euro-American settlement that ultimately altered the fire regime was the decline of the Wintu population. There are numerous reports of conflicts between Euro-American settlers and Native Americans that often resulted in fatalities (Jackson, 1964; Norton and Short, 2002). The utilization of fire by local tribes was extensive (Lewis, 1990, 1993) and their displacement likely decreased fire frequency in the Whiskeytown area.

The observed initial temporal change we saw in fire frequency occurred much earlier than in Taylor and Skinner's (2003) Hayfork study area 50 km to the west. Fire frequency in their study area did not decline until 1905 when fire suppression was implemented on National Forest lands and dramatically decreased in the 1920s after fire suppression was more effective. Suppression period (early to mid-1900s) declines in fire frequency have been documented elsewhere in conifer forests in the Klamath Region (Agee, 1991a; Wills and Stuart, 1994; Taylor and Skinner, 1998; Stuart and Salazar, 2000). The earlier decline documented in this study is similar to a few fire history studies in the Sierra Nevada (Swetnam, 1993; Caprio and Swetnam, 1995; Stephens and Collins, 2004), which has been attributed to the introduction of livestock grazing and decline in Native American ignitions (Skinner and Chang, 1996). This work marks the earliest recorded decline in fire frequency in the Klamath Mountains. In conjunction with cultural information on settlement in the Whiskeytown area it suggests Native American ignitions were likely to have been an important component to the fire regime and vegetation dynamics.

The initial impacts on fire regimes in the late 18th to early 19th century associated with Euro-American settlement activities vary regionally. When using reference conditions to restore forest structure managers may need to identify when and to what degree the vegetation changed from the altered fire regime, subsequently developing appropriate management techniques to meet restoration goals.

This study investigated fire–climate relationships using fire scar information collected within the study area. Other studies have examined these relationships at much larger spatial scales. The authors acknowledge that the spatially limited fire scar record may be inadequate to reflect significant relationships with regional influences of climate on fire regimes (Lertzman et al., 1998; Heyerdahl et al., 2001).

Fire–climate relationships were analyzed by period because the fire pattern that changed ca. 1850 to a less frequent, more homogeneous pattern may respond differently to climate. For both periods, annual to seasonal time scale drought conditions were not related to years when fires were widespread within the study area. Characteristic annual summer drought at WNRA may facilitate conditions for large fire years once fuels have accumulated regardless of immediate, regional climatic fluctuations. Local factors overriding the influence of regional-scale climate have been suggested in other studies (e.g., Swetnam and Baisan, 1996; Heyerdahl et al., 2002). Conversely, widespread fires considered at spatial scale of our study area (120 ha) may not reflect true landscape scale fires. In northern California and the PNW, widespread fire years have been associated with warmer and drier than normal years using site specific precipitation and temperature data (Heyerdahl et al., 2002; Hessl et al., 2004) as well as PDSI (Hessl et al., 2004; Stephens and Collins, 2004; Wright and Agee, 2004; Taylor and Beaty, 2005) and SOI (Heyerdahl et al., 2002; Wright and Agee, 2004; Taylor and Beaty, 2005).

For the settlement period, higher than average moisture conditions 3 years prior to large fire years suggests a period of site conditioning is required. Fine fuel production (grass and forb growth) is particularly sensitive to variation in seasonal and annual moisture availability (Bond and van Wilgen, 1996; Taylor and Beaty, 2005). Antecedent conditions favorable for fine fuel growth are an important factor in years when large fires occur in Northern California (Norman and Taylor, 2003; Stephens and Collins, 2004; Taylor and Beaty, 2005). The 3 year time lag for the settlement period may have been due to the impacts of livestock grazing on fine fuel accumulation because grazing reduces herbaceous fuels that carry fires. Although, we do not have any direct evidence that livestock grazed within the study area, Whiskeytown residents utilized areas at lower elevations for livestock grazing (Norton and Short, 2002). The post-1850 fire pattern may have created more uniform fuel conditions allowing fires to burn larger areas under suitable fire–weather conditions (Miller and Urban, 2000).

Interannual variation in climate depicted by SOI was not correlated to widespread fire years. ENSO affects the variation in cool season weather in the PNW by causing shallower than normal snow packs (Cayan et al., 1999; Mantua et al., 1997). Warm winters during El Niño conditions result in lower mountain snow packs and consequently early spring snowmelt leading to longer, drier summers increasing the fire season duration (Wright and Agee, 2004). Despite the linkage between weather in the PNW and SOI, similarly weak climate signals were also noted in a number of studies in the PNW (Heyerdahl et al., 2002; Hessl et al., 2004; Wright and Agee, 2004).

Our results from SEA may also reflect the varying degree of influence of climatic patterns across geographic regions. Numerous studies investigating fire occurrence with climate patterns have been undertaken in regions (PNW and Southwestern U.S.) identified as being the "centers of action" (Dettinger et al., 1998; Cayan et al., 1999) where atmospheric patterns related to ENSO are most pronounced. Effects on precipitation patterns in regions in between may be less evident. Dettinger et al. (1998) analyzed precipitation patterns across western North America over the last 110 years and suggested a contrast in north–south precipitation patterns that pivot around 40°N latitude. Additionally, variation in precipitation, which is positively correlated with SOI in the PNW, also pivots near 40°N latitude and is related to offshore atmospheric conditions that steer storms north and south of the pivot point. Other studies located near this north–south pivot have reported similar findings using SOI (Norman and Taylor, 2003; Taylor and Beaty, 2005).

For managers at WNRA Park, implementation of prescribed fire treatments requires consultation with the U.S. Fish and Wildlife Service (USFWS) because the Northern Spotted Owl is a federally listed threatened subspecies (USFWS, 1990). Since 1994, a nesting pair of spotted owls has been monitored within a few kilometers of Coggins. This and the surrounding area of high elevation unlogged ponderosa pine and mixed conifer old-growth forests are considered ecologically important, both for its uniqueness and suitable spotted owl habitat.

Management plans for forests occupied by spotted owls recommend reducing the risk of catastrophic fire (Thomas et al., 1990) as well as maintaining ecosystem processes for sustaining late-successional old-growth forest conditions and wildlife habitat (FEMAT, 1993; USDA–USDI, 1994). Spotted owl habitat requirements in the Klamath Mountains are thought to include interior mature and old-growth forests, fragmented to a degree with other vegetation types in various seral stages (Thomas et al., 1990; Zabel et al., 1995; Franklin et al., 2000). Given historical fire regimes within their home ranges in the PNW, this species may prefer habitat that was historically subject to wildfires of various sizes and low to moderate severities (Agee, 1993).

Natural disturbances (e.g., fire, insect attacks, windstorms) varying in frequency, size, and severity generally create a landscape mosaic of forests in different seral stages with irregular shaped patches and convoluted edges (Agee, 1991b; Taylor and Skinner, 1998, 2003; Taylor, 2000). Conversely, more recent human-caused disturbances (e.g., thinning, prescribed fire, and logging) are often limited in scale and tend to create uniform patches with more regular, discrete edges due to economic, social, and environmental constraints.

Although managing forests scaled to treatable units utilizing landscape features as boundaries may be feasible and within prefire suppression burn patterns (Taylor and Skinner, 1998, 2003), it is unclear what consequences result from this type of landscape control on forest structure and development (Baker, 1994; Taylor, 2000). Utilizing landscape features consistent with pre-suppression patterns will aid in restoring aspects of the fire regime. Restoring other aspects in forests under current conditions (i.e., forest structure and climate) will be a challenge for managers with the uncertainty of what future forest conditions will result from using different management techniques (White and Walker, 1997).

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