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RESEARCH ARTICLE

FIRE HISTORY OF A LOWER ELEVATION JEFFREY PINE-MIXED CONIFER FOREST IN THE EASTERN SIERRA NEVADA, CALIFORNIA, USA

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ABSTRACT

For thousands of years, fire has shaped coniferous forests of the western United States. In more recent time, land use practices have altered the role fire plays in the Sierra Nevada. By understanding the past, land managers can design better fuel treatments today. This research explores the fire regimes of Sagehen Experimental Forest in the eastern Sierra Nevada, California, through a fire scar reconstruction of lower elevation Jeffrey pine (*Pinus jeffreyi* Balf.) and Jeffrey pine-mixed conifer stands. Prehistoric and historic land use practices, fuel accumulation, and climate influenced the fire regime over three periods of time: pre-settlement (1700 to 1859), settlement (1860 to 1925), and suppression (1925 to 2006). Over the period of analysis, 293 fire scars were assigned calendar years. The mean composite fire return interval for all samples in the study area was two years. The mean composite fire return interval was significantly longer for the suppression period than both the pre-settlement and settlement periods. The lack of sufficient fire intervals for analysis using a filter that included fires that scarred at least three or more trees and 25% of the total sample indicates that fires in the study area are small in spatial extent. The proportion of dormant season fires increased from pre-settlement through the suppression period. No fires were recorded as middle and early earlywood during the suppression period. A superposed epoch analysis found significant correlation to warmer (Pacific Decadal Oscillation) and wetter (Palmer Drought Severity Index) conditions three years prior to large fire events during the pre-settlement period. During the post-settlement era, large fire years were correlated to El Niño conditions for two consecutive years prior. Little synchrony of fire events was recorded between fire scarred tree clusters. These findings suggest that small frequent prescribed burns would best mimic the pre-settlement fire regime if fire is reintroduced into the ecosystem.

Keywords: eastern Sierra Nevada, fire-climate interactions, fire history, land use, management

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INTRODUCTION

For thousands of years, fire shaped coniferous forests of the Sierra Nevada in California, USA. In more recent time, land use practices have altered the role fire plays in this system. In order to reintroduce fire into the ecosystem today, one needs to understand the role it played in the past. Fire atlases and fire scarred trees both aid in understanding past fire regimes (frequency, seasonality, and extent). When available, fire history data from fire scarred trees contain information about fire return intervals and seasonality of fire events that occurred before fire atlas records existed.

In the Truckee River Basin in the northern Sierra Nevada, the Washoe Indians and their prehistoric ancestors have been a part of the ecosystem for the past 8000 to 9000 years (Lindstom 2000). The intensity of their land use, however, was minimal until between 5000 and 1500 years before present (Lindstom 2000). The Washoe were known to use fire to clear brush, improve browse for wildlife, select for desirable plants, and hunt game (Anderson and Moratto 1996, Lindstom 2000). During the Euro-American settlement period (defined as 1860 to 1923 for this study), native populations started to dwindle for a variety of reasons such as disease and warfare (Johnston 1990, Anderson and Moratto 1996).

Throughout the settlement period, logging to support the extraction of silver for the Comstock Lode was the focus of activity in the Truckee River Basin. This era was a time of extensive timber harvesting to support silver mining, railroad construction, and construction of cities in the eastern Sierra Nevada and the Great Basin (Johnston 1990, Wilson 1992). Anthropogenic fires still occurred in this time; however, due to the dwindling Native American population, most of the fires were likely the result of settlement. Fires were common at mills and along railroads built for moving timber (Wilson 1992). In addition to timber-driven fires, sheep herders were known to set fires to improve grazing (Sudworth 1900, Leiberg 1902).

The forest reserves system was created in 1891 and the Forest Service was established in 1905 to administer the reserves (Pyne 1982). From the beginning, one of the main objectives of the Forest Service was timber production, and a policy of complete fire suppression was adopted (Stephens and Ruth 2005). It was not until 1924 when the Federal Clarke-McNary Act was created that national fire suppression became law (Stephens and Ruth 2005). With the onset of fire suppression and aggressive land use methods, forests started to change into what they are today. The absence of regular fire has lead to higher tree densities (Biswell 1959), changes in species composition (Weaver 1943), and higher fuel loads (Dodge 1972) in many coniferous forests in the Sierra Nevada, resulting in altered fire regimes (Taylor 2000, Beaty and Taylor 2001, Stephens and Collins 2004, Moody *et al.* 2006).

In addition to human influence, climatic variation may play a role in defining fire regimes. A common practice with dendrochronologically based fire history research is to complete a superposed epoch analysis (SEA) to explore fire-climate interactions. Through the use of an SEA, the temporal relationship between fire occurrence, drought, and large-scale climate anomalies can be better understood (Swetnam and Baisan 2003, Westerling *et al.* 2003, Schoennagel *et al.* 2005). Because of the proximity of the study location to the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) dipole, it has been found that the northern Sierra Nevada can exhibit fire-climate interactions similar to both the Pacific northwest and southwest (Dettinger *et al.* 1998, Taylor *et al.* 2008). The ENSO-PDO dipole shifts north and south at interannual to decadal time periods (Dettinger *et al.* 1998). Typically, during warm El Niño phases, the southwest experiences warmer and wetter conditions, whereas cool La Niña phases create cooler and drier conditions (Trouet *et al.* 2006*a*, Taylor *et al.* 2008). The opposite is seen in the Pacific northwest. Warm PDO phases create wetter than average conditions, and cool phases create drier than usual conditions in the southwest, while the opposite is true for the Pacific northwest (Nigam *et al.* 2000).

There are few fire history studies in the literature from the eastern Sierra Nevada that cite Jeffrey pine (*Pinus jeffreyi* Balf.) trees used for fire scar specimens. Two fire history studies that used Jeffrey pine occurred quite a bit south of the Truckee River Basin: one near Mammoth Lakes at the University of California Valentine Camp Natural Reserve (Stephens 2001), and the other in Yosemite National Park (Collins and Stephens 2007). Although these are useful studies for reference, the impacts of pre-settlement and settlement land use might vary from that of the Truckee River Basin. Four other studies occurred much closer to this research site. One was north on the Plumas National Forest and incorporated forest types from both sides of the Sierra Nevada crest (Moody *et al.* 2006). The other three studies took place in the Lake Tahoe Basin and are the most relevant to this work (Taylor and Beaty 2005, Trouet *et al.* 2006*b*, Beaty and Taylor 2007).

The goal of this study was to describe the fire history of a Jeffrey pine mixed-conifer forest in the Truckee River Basin using dendrochronological methods. Specifically, the objectives were to: 1) describe the fire regime (fire return interval and seasonality); 2) describe the characteristics of fire regime for three periods, pre-settlement (1700 to 1859), settlement (1860 to 1923), and suppression eras (1924 to 2006); 3) explore the influences of climate on fire regime using a superposed epoch analysis for two time periods, pre-settlement (1700 to 1859) and post-settlement (1860 to 2006); and 4) consider management implications for Sagehen Experimental Forest today.

METHODS

Study Area

Sagehen Experimental Forest (Sagehen) is a 3642 ha watershed on the eastern slope of the Sierra Nevada about 32 km north of Lake Tahoe at approximately -120°14’ longitude and 39°26’ latitude. The watershed starts on the crest of the Sierra Nevada at 2670 m and proceeds east to Highway 89 at 1862 m. Slopes are typically mild, averaging 18 % but can reach 70 % in parts of the watershed. Soils are generally Andic and Ultic Haploxeralfs derived from volcanic parent material. Sagehen has a Mediterranean climate with warm, dry summers, and cold, wet winters. Average low and high winter (January) temperatures measured at 1943 m from 1953 to present are –10 °C and 4 °C; average summer (July) temperatures are 3 °C and 26 °C. Average annual precipitation is 85 cm with snowfall accounting for about 80 % of the precipitation (climate data available at http://www.wrcc.dri.edu/).

A reconnaissance of Sagehen was conducted to determine where clusters of trees and stumps with visible fire scars existed. Only clusters with a minimum of five samples (fire scarred trees and/or stumps) within a five-hectare area were considered for sampling. Fire scar sampling was limited to lower elevation Jeffrey pine and Jeffrey pine-mixed conifer stands within Sagehen. An attempt was made to select clusters with differing aspect, slope, and vegetation (Table 1, Figure 1). The study area occupied about 360 ha and was located north of Sagehen Creek. Tree species present in the study area include Jeffrey pine, lodgepole pine (*Pinus contorta* ex Louden), sugar pine (*P. lambertiana* Douglas), white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.), and red fir (*A. magnifica* A. Murray). Under-

Table 1. Sample size, area sampled, and topographic characteristics for each fire scar cluster and the study area.

Cluster	Area (ha)	No. samples	Elevation (m)	Slope (%)	Aspect
1	1.4	11	1922-1973	14-39	SE
2	1.0	5	2027-2040	11-14	E-SE
3	0.6	8	2003-2017	14-23	SE
4	3.5	8	2034-2063	7-23	SE
5	1.5	5	1965-1978	2-7	SE-SW
Study area	357.7	37	--	--	--

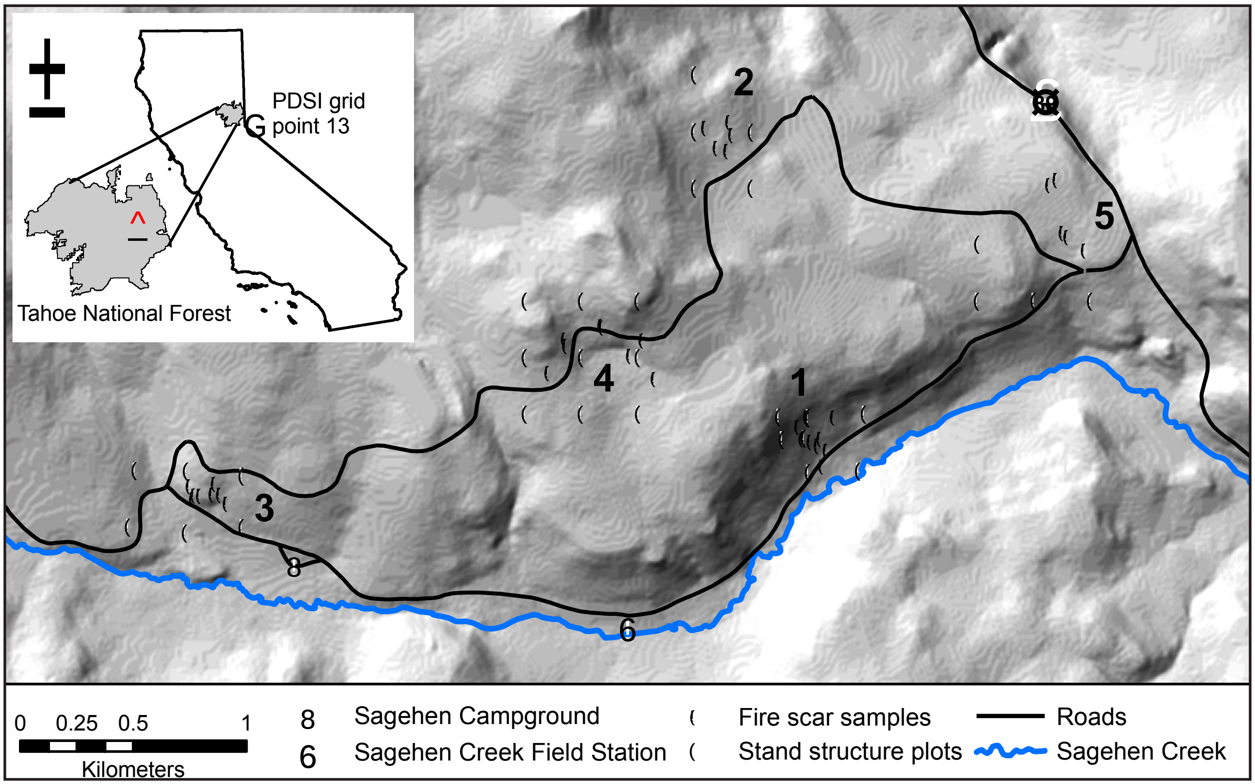

Figure 1. Fire scar samples (with cluster numbers) and vegetation plots for fire history study within Sagehen Experimental Forest, on the Tahoe National Forest in California.

story cover type is dominated by snowbrush ceanothus *(Ceanothus velutinus* Douglas ex Hook), prostrate ceanothus (*C. prostrates* Benth.), greenleaf manzanita (*Arctostaphylos patula* Greene), wax currant (*Ribes cereum* Douglas), and woolly mule-ears (*Wyethia mollis* A. Gray).

Each sample was progressively sanded with finer sandpaper, ending with 400 grit, to distinguish tree rings and fire scars. Fire scars were identified by the disruption and healing pattern of tree ring growth associated with the injury (McBride 1983). Calendar years were assigned to each fire scar by cross-dating rings using common dendrochronological techniques (Dieterich 1980, Swetnam and Thompson 1985). Patterns of tree rings were compared to each other and to a nearby published master tree ring chronology from Lemon Canyon (Holmes 1980). When possible, the season of a fire scar was identified from the location of the scar within the growth ring (Caprio and Swetnam 1995). The position was noted as early earlywood, middle earlywood, late earlywood, latewood, dormant, or undetermined (Ahlstrand 1980, Dieterich and Swetnam 1984, Caprio and Swetnam 1995).

Data Analysis

Current forest structure was derived from an existing geo-referenced grid of plots (0.05 ha) installed in 2005 to assess vegetation and fuel characteristics within Sagehen. Those plots most closely located to the fire scar samples were used to further describe the sampled area (Table 2, Figure 1).

The FHX2 software package was used to analyze seasonality, fire return intervals (mean, median, range), and fire-climate interactions (Grissino-Mayer 2001). Fire return intervals were determined for composites of tree groups by cluster and for the entire study area (composite fire return interval; CFI). Seasonality of fire scars was determined using the whole study area for four time periods; the duration of the record (1700 to 2006), pre-settlement (1700 to 1859), settlement (1860 to 1923), and suppression (1924 to 2006).

Three different composite scales, or filters, were utilized in this study for each of the five clusters and the study area as a whole. The broadest composite (C01) included all samples experiencing a fire scar. The intermediate composite (C10) included fires that scarred a minimum of two trees and at least 10 % of the samples. The final composite (C25) included fires that scarred a minimum of three trees and at least 25 % of the recordable trees. Composites of multiple trees will often provide a more comprehensive record of fire events (Dieterich 1980, Agee 1993); the filters (C10 and C25) remove relatively small fires (Swetnam and Baisan 1996). A non-parametric Kruskal-Wallis test was used to determine if significant differences existed ($p < 0.05$) between clusters at each composite (C01, C10, and C25; Zar 1999). In addition, the Kruskal-Wallis test was used to determine if a significant difference existed between time periods (1700 to 1859, 1860 to 1923, and 1924 to 2006) for each composite (C01, C10, and C25) using all data from the study area (Zar 1999). If a significant difference was found between clusters or time periods, a Nemenyi test (non-parametric Tukey multiple comparisons test) was used to determine which clusters or time periods differed ($p < 0.05$, Zar 1999).

An SEA was used to investigate fire-climate interactions (Baisan and Swetnam 1995, Swetnam and Betancourt 1998). Fire years from the C01 and C10 composites for the entire study area were compared to three climate indices to determine if climate was significantly different five years before, the year of, and four years after the fire events ($p < 0.05$). Two time periods were used for this analysis, pre-settlement (1700 to 1859), and post-settlement (1860 to 2006). The climate indices include: the Palmer Drought Severity Index (PDSI re-

Table 2. Average (standard error) tree characteristics and small diameter fuel loads (sum of litter, 1 h, 10 h, and 100 h time lag fuels) for the reference study plots in and around the fire scar clusters sampled in 2005.

				Percent basal area by species				
Cluster	***n***	**Density (trees ha^{-1})**	**Basal area (m^2 ha^{-1})**	**White fir**	**Red fir**	**Lodgepole pine**	**Jeffrey pine**	**Small diameter fuel load (t ha^{-1})**
1	7	251 (32)	41.6 (8.4)	14	<1	16	70	23.3 (4.6)
2	5	340 (58)	35.4 (4.2)	65	0	0	35	33.2 (9.9)
3	6	273 (72)	31.9 (7.0)	26	0	25	49	12.5 (2.7)
4	9	384 (93)	35.6 (6.2)	37	1	0	62	23.3 (5.5)
5	4	190 (71)	13.6 (5.0)	0	0	6	94	14.3 (4.4)

construction, summer months, grid point 13; Figure 1; Cook *et al.* 1999), the Pacific Decadal Oscillation index (PDO reconstruction, Mantua *et al.* 1997), and the El Niño Southern Oscillation index (NINO3 reconstruction, Cook 2000).

RESULTS

Five fire scar clusters were located in Sagehen (Table 1, Figure 1). A total of 42 samples were collected and sanded; however, only 37 samples were used for the analysis because five samples were excessively rotten or non-datable. Of the 37 samples used, 13 (35%) were from living trees, with the remainder from stumps, snags, and downed trees. The duration of recorded years was from 1575 to 2006, with calendar years assigned to 300 fire scars. The average length of tree ring series was 224 yr (standard deviation 77 yr, range 76 yr to 344 yr). The earliest fire scar recorded was in 1605 and the most recent in 2001. The average number of scars per sample was 8 (standard deviation 4 scars, range 2 to 16 scars) (Figure 2).

Current stand structure was assessed using 31 reference plots in and around the fire scar clusters (Figure 1, Table 2). All calculations were completed using live overstory trees (defined as trees greater than 19.4 cm diameter at breast height, dbh). Average tree density ranged from 190 trees ha^{-1} to 384 trees ha^{-1}. Average basal area was between 13.6 m^2 ha^{-1} and 41.6 m^2 ha^{-1}. Overstory tree species present included white fir, red fir, lodgepole pine, and Jeffrey pine. Jeffrey pine had the highest percentage of basal area in all clusters except in Cluster 2 where white fir represented the highest percentage (Table 2). Total mean small

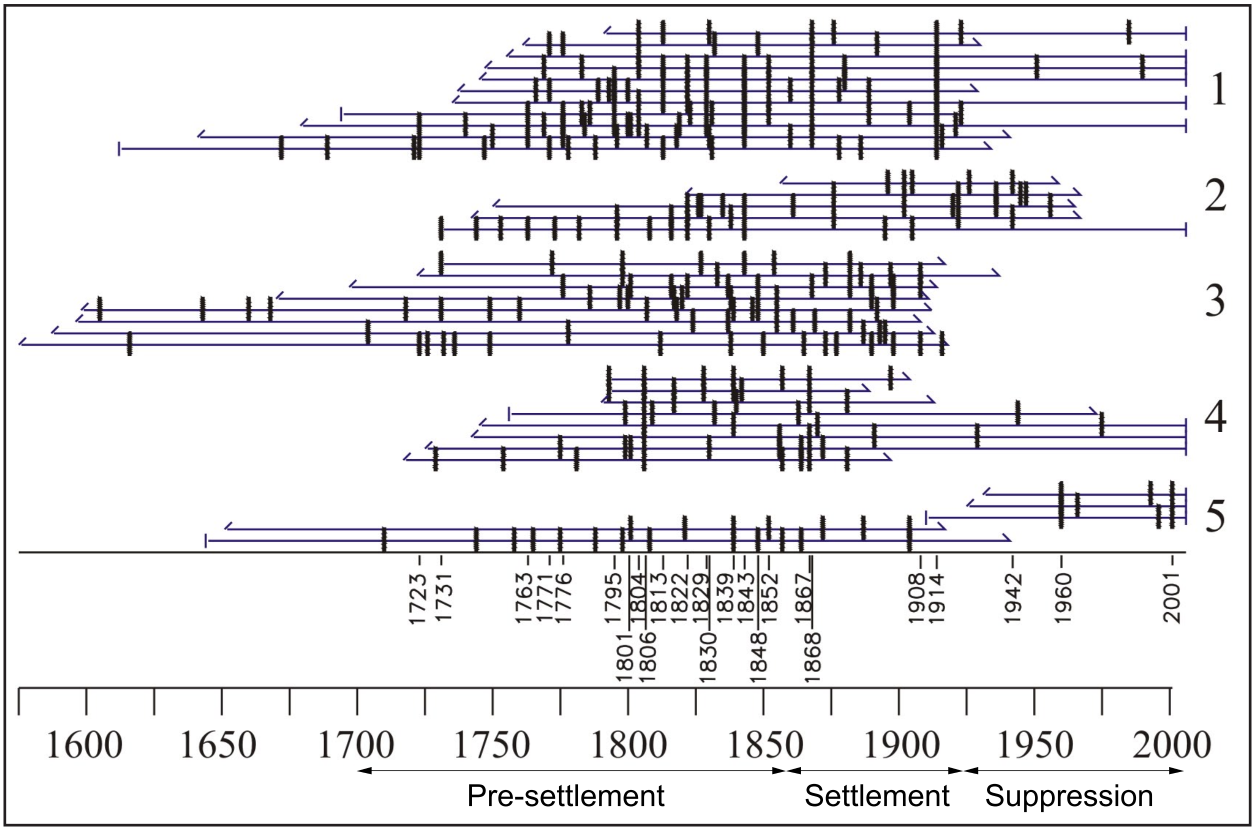

Figure 2. Composite fire activity of five sample tree clusters. Horizontal lines represents the crossdated age of each fire scar sample, with the vertical lines representing fire events. The list of years at the bottom represents the C10 composite (scarring more than 10% and at least two trees) for all samples.

diameter fuel load (defined as litter, 1 h, 10 h, and 100 h time lag fuel classes) was also assessed from the reference plots for each fire scar cluster (Table 2). Mean fuel load ranged from 12.5 t ha^{-1} to 33.5 t ha^{-1}, with Cluster 3 having the lowest loading and Cluster 2 the highest loading.

Fire Return Intervals

The initial year for fire return interval analysis was chosen as 1700 based on visual inspection of the composite scar chronology and lack of samples prior to that date (Figure 2). The mean CFI for the entire study area (358 ha) for C01 was 2 yr (median 2 yr, range 1 yr to 10 yr) with 293 fires recorded and 137 fire intervals from 1700 to 2006 (Table 3). The CFI for C10 (study area) was 12 yr (median 7 yr, range 1 yr to 41 yr). There was insufficient data to complete the analysis for C25.

Mean CFIs were also compared between each of the five clusters for the three composite levels when enough data existed. A significant difference ($p < 0.05$) between CFIs was found for C01 and C10 with the Kruskal-Wallis test ($p < 0.05$). For C01 Clusters 1 and 5, Clusters 2 and 3, and Clusters 3 and 5, the CFI remained significantly different using the Nemenyi test ($p < 0.05$). Only Clusters 1 and 5 had significantly different fire return intervals for C10. Clusters 1 and 3 were the only clusters with enough data to complete the analysis for C25, and the means were not significantly different (Table 3).

For the entire study area, an analysis was completed to determine if differences existed between periods of pre-settlement, settlement, and suppression. We found a significant difference between the CFIs for the three time periods for C01; the mean fire return interval for the suppression period was significantly longer than both the pre-settlement and settlement periods (Table 4). However, at C10, the three time periods were not significantly different with the Kruskal-Wallis test.

Table 3. Composite fire return interval data for the duration of the record (1700 to 2006). C01 includes all fire scars, C10 includes fires scarring two or more trees and at least 10 % of the sample, C25 at least three or more trees and 25 % of the sample scarred. The dash indicates that there were not enough data to complete analysis. Means followed by the same letter in the column are significantly different ($p < 0.05$).

Cluster	Composite	Intervals (count)	Mean (yr)	Median (yr)	Range (yr)	Fire scars (count)
1	C01	50	5.4a	3.0	1-34	108
	C10	22	9.1d	8.0	1-40	80
	C25	10	14.3	9.0	5-46	56
2	C01	29	7.8b	6.0	1-19	41
	C10	9	16.2	17.0	3-33	21
	C25	0	--	--	--	3
3	C01	52	4.1bc	3.5	1-36	69
	C10	11	16.1	10.0	1-49	28
	C25	3	8.7	8.0	8-10	12
4	C01	28	8.8	6.0	1-32	47
	C10	10	8.8	9.0	1-17	29
	C25	2	30.5	--	28-33	13
5	C01	22	13.2ac	9.5	3-56	28
	C10	3	54.0d	56.0	41-65	9
	C25	0	--	--	--	3
Study area	C01	137	2.2	2.0	1-10	293
	C10	23	12.1	7.0	1-41	113
	C25	1	71.0	--	--	19

Table 4. Fire return interval by time period where C01 includes all fire scares and C10 represents fires that burned two or more trees and 10 % of the sample. Means followed by the same letter are significantly different ($p < 0.05$)

Composite	Period	Intervals (count)	Mean (years)	Median (years)	Range (years)	Fire scars (count)
C01	1700 to 1859	82	2.9a	1.0	1-8	183
	1860 to 1923	37	1.7b	1.0	1-6	88
	1924 to 2006	16	4.7ab	4.5	1-10	22
C10	1700 to 1859	16	8.1	6.5	1-32	82
	1860 to 1923	3	15.7	6.0	1-40	24
	1924 to 2006	2	38.5	--	--	7

Fire Season

It was possible to determine the location within the annual ring and therefore infer fire season for 78 % of the scars. For the analysis period, the majority of fires occurred at the ring boundary (58 % dormant). Fires were not as prevalent in the latewood portion of the ring (10 %) as the earlywood portion of the ring (early 1 %, middle 10 %, late 21 %; Figure 3). Seasonality varied for the different time periods (Figure 3). The proportion of fires occurring during the dormant period increased from pre-settlement to settlement, and again from settlement to suppression. Early earlywood fires do not occur after settlement, and middle earlywood fires are no longer present during the suppression period.

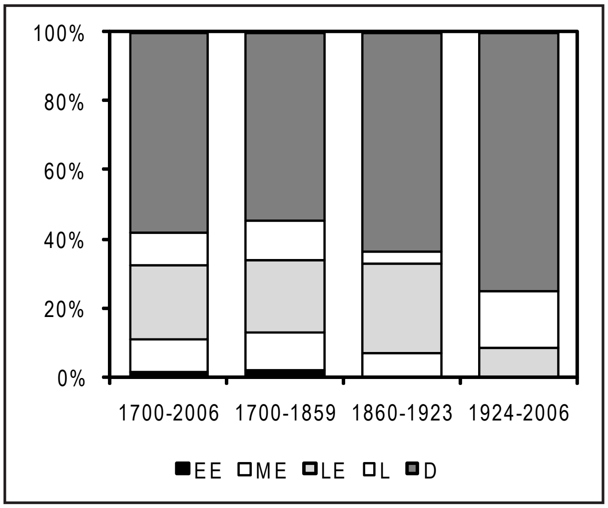

Figure 3. Seasonality of fire scars for the duration of the analysis (1700 to 2006), pre-settlement (1700 to 1859), settlement (1860 to 1923), and suppression (1924 to 2006) periods. D-dormant; EE-early earlywood; ME-middle earlywood; LE-late earlywood; L-latewood.

Fire-Climate Interactions

Pre-settlement fire years (including the fire events, five years prior, and four years after) were associated with warmer PDO conditions and an El Niño phase when all fire years were analyzed (Figure 4). During the pre-settlement period, the periods two to four years prior to fire events were significantly correlated to wetter conditions. During post-settlement, the period four years prior to the fire event was significant, and the lag before fire years was significantly associated with positive PDO and El Niño conditions (Figure 4). For C10, pre-settlement fire years were significantly associated with wetter PDSI and warmer PDO conditions three years prior to the fire year ($p < 0.05$, Figure 5). During post-settlement, the period four years prior to fire events was associated with La Niña conditions, and the two consecutive years prior to fire events were correlated to El Niño conditions according to the SEA with the NINO3 reconstruction (Figure 5). Fire years were not associated with PDSI, PDO or NINO3 for either time period for the C10 composite.

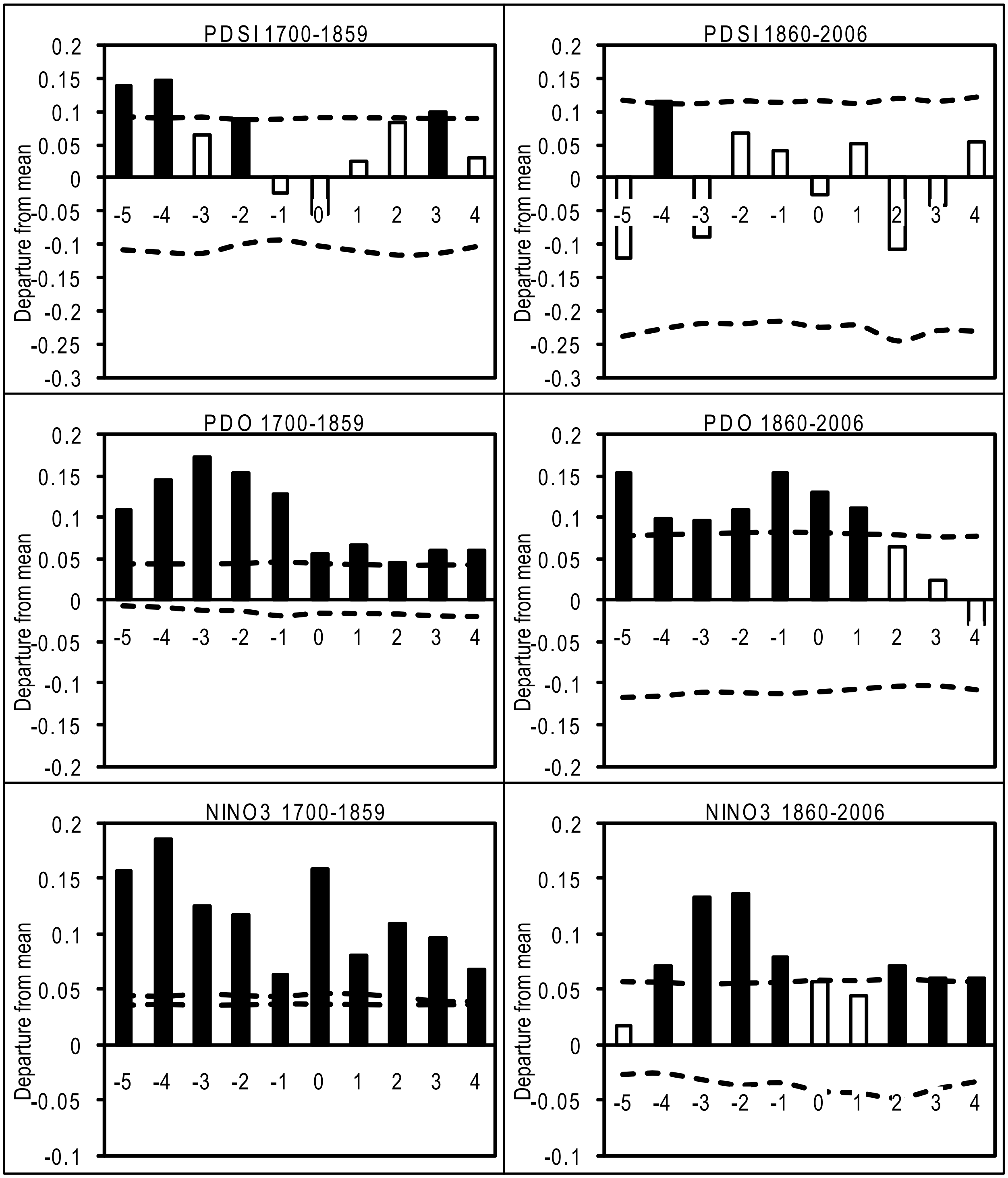

Figure 4. Superposed epoch analysis of all fire years for the Palmer Drought Severity Index (PDSI), Pacific Decadal Oscillation (PDO), and El Niño Southern Oscillation (NIÑO3) for two time periods: pre-settlement (1700 to 1859) and post-settlement (1860 to 2006). Black bars are statistically significant and the dashed lines represent the upper and lower 95 % confidence intervals.

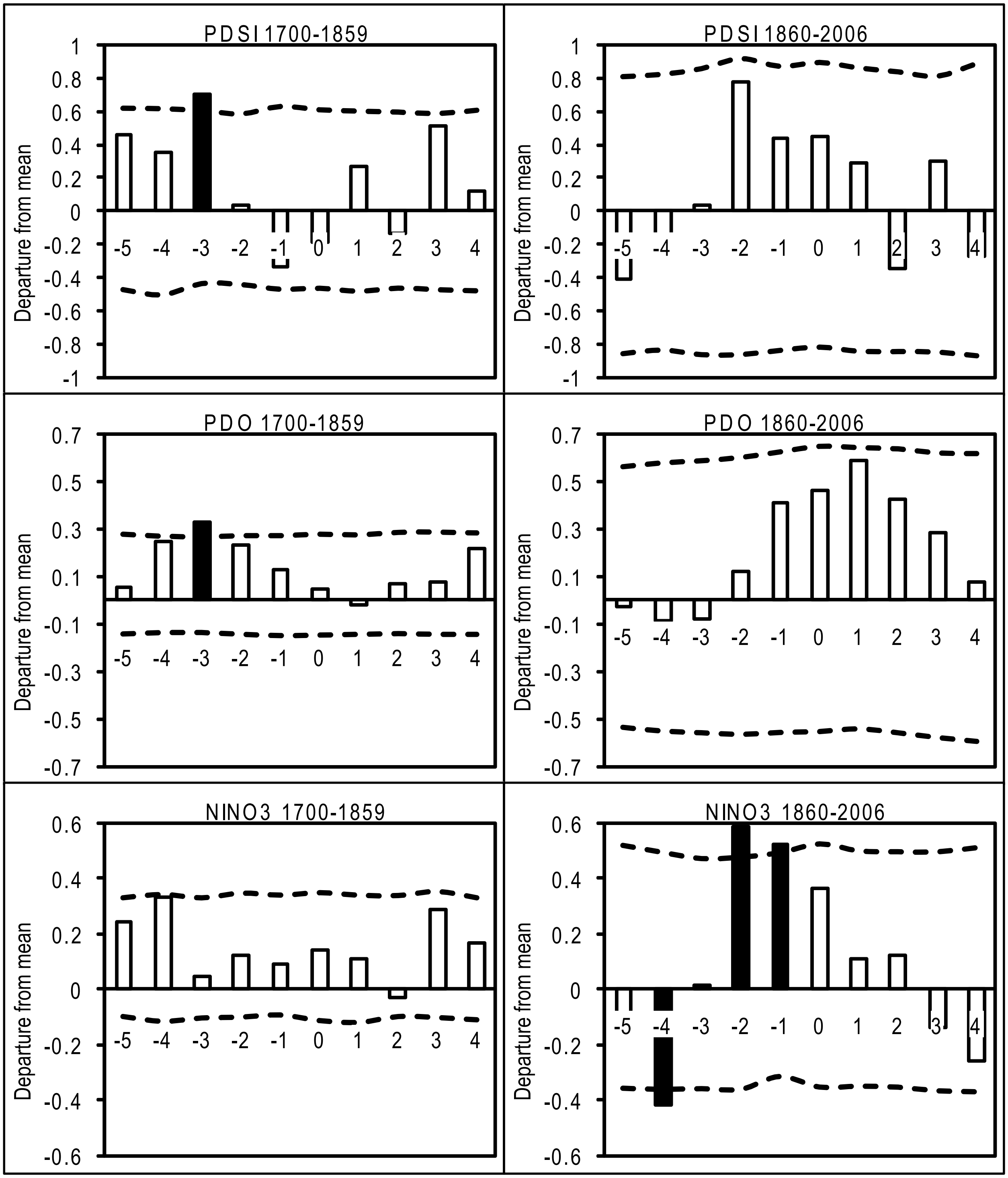

Figure 5. Superposed epoch analysis of fire years scarring more than 10 % with a minimum of two trees scarred by fire for the Palmer Drought Severity Index (PDSI), Pacific Decadal Oscillation index (PDO), and the El Niño Southern Oscillation index (NIÑO3) for two time periods, pre-settlement (1700 to 1859) and post-settlement (1860 to 2006). Black bars are statistically significant and the dashed lines represent the upper and lower 95 % confidence intervals.

DISCUSSION

The mean CFI for all fire scar samples was similar to other studies of various dry forests in the Sierra Nevada, Cascades, and northern Baja Mexico (Stephens 2001, Stephens *et al.* 2003, Taylor and Beaty 2005, Moody *et al.* 2006, Beaty and Taylor 2007, Collins and Stephens 2007). As filtering increased, the composite fire return interval became longer, which is to be expected because smaller isolated events are no longer considered. The lack of fire intervals for the C25 filter was also seen by Moody *et al.* (2006) in the eastern Sierra Nevada. The lack of fire intervals for this filter level is probably due to the nature of fire spread in this ecosystem. Sagehen is located in the eastern Sierra Nevada, which falls in the rain shadow, lowering the productivity of the forest. Therefore, fuels are typically less abundant and continuous than in the western Sierra Nevada, which can result in fires of smaller spatial extent. Beaty and Taylor (2007) found stands in the Lake Tahoe Basin to burn with equal frequency, although not necessarily with the same fire events. Trouet *et al.* (2006*b*) also found a strong temporal frequency among fires in the Lake Tahoe Basin. The smaller spatial extent but high fire frequency seen at Sagehen is exemplified by considering the synchrony, or lack thereof, for fire events between clusters. Of the 136 fire event years recorded in this study, only 39 fire years were recorded in more than one cluster and all were before the suppression period (Figure 2). Of those 39 fires, none were recorded by all five clusters, 33 burned two clusters, five burned three clusters and only one burned four clusters. Fire atlases are another means of understanding the spatial extent and synchrony of fire events (Figure 6). Fires were typically smaller in extent for the area surrounding the study area. Those that grew larger seem to have been influenced by more extreme wind, as can be seen by the shape of the fires. However, it must be pointed out that in California, the fire atlas only dates back to the turn of the century, which represents the period after settlement.

The mean CFI for the study area was significantly shorter for both the pre-settlement period and the settlement period than for the suppression period for C01. For the C10 filter level, there was no difference between time periods. Shorter CFIs for both the pre-settlement and settlement periods as compared to the suppression era is not unexpected. Pre-settlement fires can be attributed to lightning and possibly burning by Native Americans. Settlement fires were likely due to lightning, timber harvesting, and sheep herding. Five fires occurred at a larger spatial scale (C10) in Sagehen after 1900, which differs from the smaller scale found in many other studies in the Sierra Nevada (Stephens 2001, Stephens and Collins 2004, Moody *et al.* 2006, Beaty and Taylor 2007, Collins and Stephens 2007). Two of the fires are known to be human caused; the Donner Ridge Fire of 1960 was started during the construction of Interstate 80 and burned over 16 000 ha, and the fire in 2001 was a prescribed burn. With logging in Sagehen active until 1936, and lightning caused fires still possible, it is not surprising that fires occurred despite a policy of suppression.

The existence of fires after the turn of the century is unique for fire history reconstructions in the Sierra Nevada and allows for comparison with the fire atlas (Figure 6). Although samples were not specifically collected to calibrate the fire atlas, Clusters 1, 2, and 5 were within the boundaries of mapped fires. Cluster 1 was within the perimeter of two fires; the first fire occurred in 1914 and then was subsequently re-burned in 1960. Nine out of the 11 samples recorded the 1914 fire but none recorded the 1960 fire. Cluster 2 was within the boundary of a 1926 fire with two samples recording the event. Cluster 5 was also within the 1960 fire, and three out of the five samples recorded this event. The fact that not all sam-

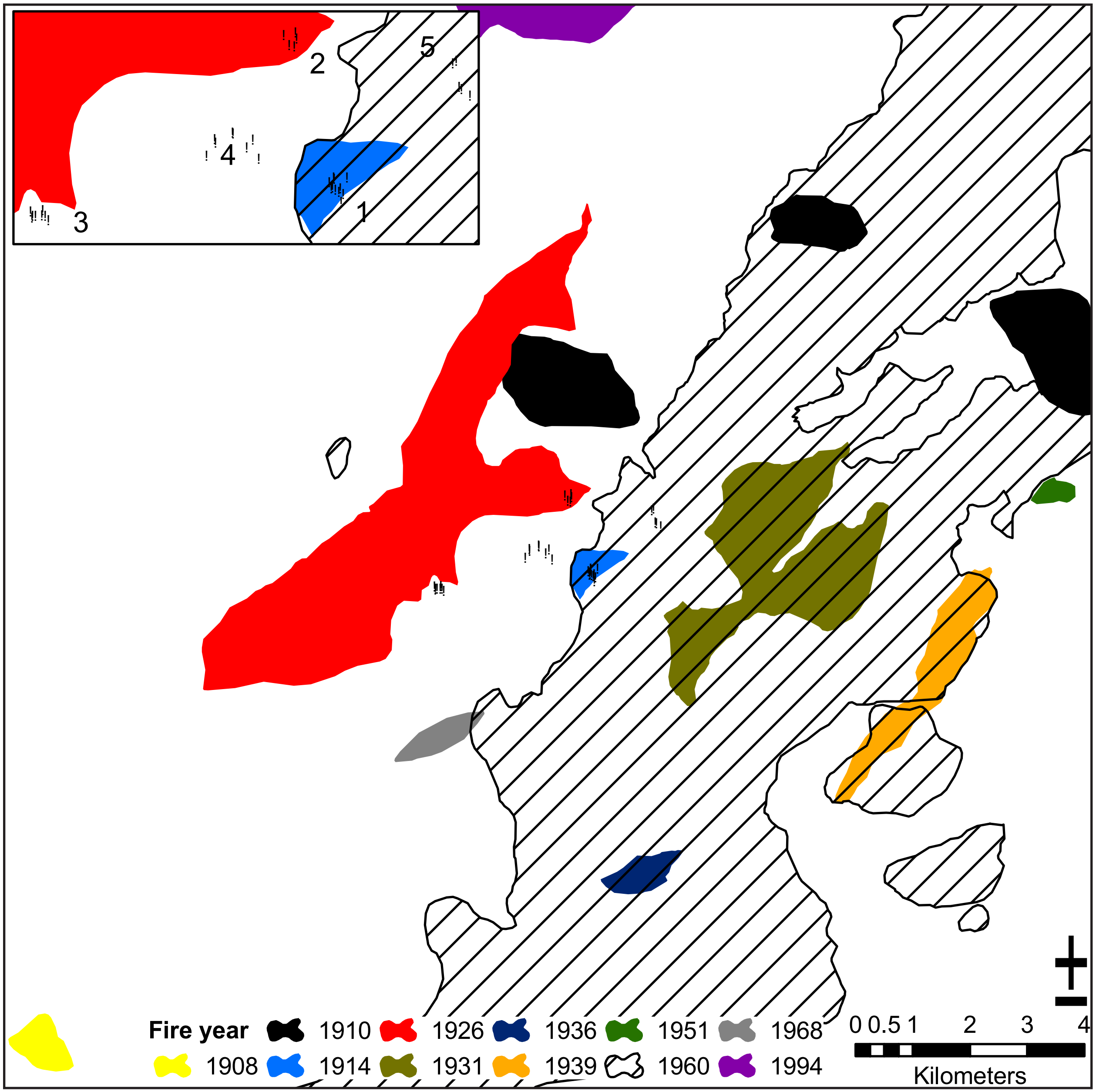

Figure 6. Fire atlas for the area around the fire scar study area. The insert is a zoomed view of the fire scar clusters. The fire atlas represents mapped fires from ca. 1900 to 2006 (data available at: http://www.fs.fed.us/r5/rsl/clearinghouse/data.shtml).

ples recorded the fires in the atlas can be testament to the patchy mosaic of fire in this ecosystem. Beaty and Taylor (2007) found that fire propagation and spread in the Lake Tahoe Basin was dictated more by the spatial pattern of fuels (abundance, pattern, and forest structure) rather than strictly by forest structure.

Fires were probably most prevalent during the late summer and fall months at Sagehen as inferred from the location of fire scars in the tree rings. The majority of fires where seasonality could be determined occurred during the latewood and dormant portions of the tree ring. The proportion of fires occurring during the earlywood section of the tree ring is higher than other study in the eastern Sierra Nevada during the pre-settlement and settlement periods (Taylor and Beaty 2005, Moody *et al.*

2006, Beaty and Taylor 2007). The higher proportion of growing season fires could have been caused by Native American burning, logging accidents, or opportunistic burning by sheep herders. Latewood and dormant season fire occurrence was dominant through the pre-settlement and settlement periods and suppression period fires mainly occurred during this season. The lack of early earlywood fires during both the settlement and suppression periods is possibly due to the loss of Native American burning in Sagehen. The effectiveness of suppression most likely eliminated fires burning during middle earlywood formation after 1923.

Fire-climate interactions were explored using both the C01 and C10 composites for the entire study area over two distinct time periods: pre-settlement and post-settlement. Although smaller in scale, the results of this study can be most closely compared with existing studies in the Lake Tahoe Basin (Taylor and Beaty 2005, Trouet *et al.* 2006*b*), northern Sierra Nevada (Trouet *et al.* 2006*a*), and the Plumas National Forest (Moody *et al.* 2006). We found correlations to wetter conditions (PDSI) and a warm phase for PDO prior to fire events for the C10 composite pre-settlement. These findings for PDSI are similar to those found by Taylor and Beaty (2005) for the period from 1650 to 1850 in the Lake Tahoe Basin. Trouet *et al.* (2006*b*) also found large fire years to occur during drought years preceded by wet periods in the Lake Tahoe Basin. In contrast, Moody *et al.* (2006) did not find a correlation to PDSI or PDO prior to fire events on the Plumas National Forest, but did find a significant correlation to dry conditions during the fire event years. Based on an SEA of the Southern Oscillation Index, Moody *et al.* (2006) found a correlation to El Niño conditions two years prior to fire events. Using the NINO3 reconstruction, we found a similar correlation to El Niño conditions one and two years prior to fire events post-settlement. Trouet *et al.* (2006*a*) found a correlation to PDO phases for fire events in the northern Sierra Nevada for the time period of 1929 to 2004; our findings support this when all fire events are incorporated.

The varying fire-climate interactions over the two time periods show these relationships to be unstable. The 1900s signify a time of more frequent climate swings (between El Niño and La Niña periods) compared to the 1600s through the 1800s (Biondi *et al.* 2001). This fluctuation in climate might account for the differing fire-climate interactions during the two time periods. In addition, the location of Sagehen likely plays a role in the fire-climate interactions. The northern Sierra Nevada is located at the ENSO-PDO dipole, where El Niño and La Niña influences are not clearly defined like in the Pacific northwest and southwest (Trouet *et al.* 2006*a*). As the pivot point shifts north and south, the associated fire-climate interactions mimic those of the Pacific northwest or southwest depending on the time period in question (Westerling and Swetnam 2003).

With the alteration of fire regimes in many conifer forests in the west, an understanding of historic fire regimes is important for land managers today. In addition to altering fire behavior and effects, fuel treatments can be used to complete a number of objectives such as the reintroduction of fire into the ecosystem. Fire history research can help determine both the historical fire return interval and seasonality of past fires. This information can be used to plan future prescribed burns. Although the study area was located in less than 10% of Sagehen, it can be utilized for other stands with similar forest composition. It would not be safe to assume that all vegetation types within Sagehen experienced similar fire regimes. Based on the findings in this study, small frequent prescribed burns would best mimic the pre-settlement fire regime if reintroducing fire to the ecosystem is an objective. Although the majority of fire occurred during the dormant and latewood seasons, growing season fires also occurred and could be prescribed.

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