Project Title: Multi-century reconstruction of chaparral fire history using fire-scarred bigcone Douglas-fir in three southern California National Forests

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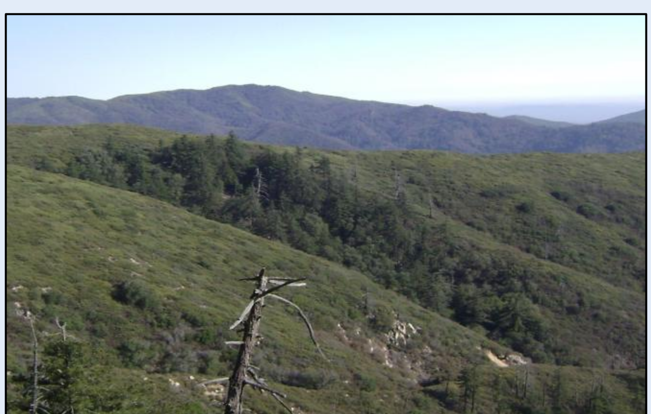


I. Abstract

It is generally accepted that stand-replacing fires are a natural phenomenon in southern California chaparral communities; however, there is vigorous debate regarding possible changes in the spatial and temporal attributes of chaparral fire regimes. Despite recent advances in chaparral fire ecology and reconstruction, most research lacked the temporal depth and spatial specificity to accurately understand the full range of natural variability of this ecosystem. Dendrochronology and fire-scar dating, which has been used extensively in other regions of the western United States to evaluate long-term changes in fire regimes is not directly suitable for many of the species found in the chaparral dominated southern California landscape. We proposed a set of novel dendrochronology approaches to reconstruct a multi-century record of chaparral fire history, and evaluated the effects of climate on these fire regimes, in particular inter-annual to decadal-scale climate variations.

We sampled and dated fire-scarred bigcone Douglas-fir (*Pseudotsuga macrocarpa*) that exist as scattered islands of forest in a chaparral matrix in the Los Padres, San Bernardino and Angeles National Forests. Replicated at the stand, watershed, and forest level, we have created local fire histories for each forest and a regional fire-scar network for the greater southern California area. We were highly successful in our corroboration of reconstructed fire event dates, derived from both direct and indirect tree-ring evidence, with an independently generated 20^{th} fire atlas maintained for the three forests. We then examined whether there were any relationships between the local and regional fire histories and indices of inter-annual to decadal-scale climate measurement, including PDSI, ENSO, precipitation and temperature.

The results of this research provide wildland fire managers and policy makers with significant spatial and temporal knowledge regarding the long-term natural range of fire regime variability for two communities, chaparral and bigcone Douglas-fir, of which little is currently known. Contemporary and future fire management plans require a full understanding of fire regime variability and the ability to assess current departures from "natural" conditions. Our findings provide assistance to managers who make those assessments for chaparral, the most abundant vegetation type in California, and bigcone Douglas-fir stands, a conservation priority in the Transverse Ranges.

II. Background & Purpose

At over 3.5 million ha, shrublands represent the most dominant vegetation type in the state of California. Unique synoptic climate patterns and geographic conditions, coupled with extreme weather events, create one of the most fire-prone landscapes in the United States (Barro & Conard 1991). In addition to natural factors that promote fire hazard, decades of fire suppression, increased human presence and the expanding wildland/urban interface greatly complicate the situation.

It is generally acknowledged that chaparral fire regimes are stand-replacing with multi-decade fire return intervals, however, there is substantial uncertainty about the "natural" range of variability of the fire frequency and extent in this type, especially over time scales of centuries (e.g., see Minnich and Keeley articles in Conservation Biology, vol. 15 [2001]). Minnich (2001) has argued that fire suppression in southern California has resulted in extensive even-aged patches of chaparral and has eliminated natural, fine-grained chaparral mosaics, such as those he has documented in northern Baja California, Mexico. Fire suppression is minimal in Baja California, and he argues that fires there are typically smaller, more frequent and spatially heterogeneous than in the U.S. Others (Mensing et al. 1999, Keeley & Fotheringham 2001, Moritz 2003, Westerling 2004) have countered this argument with data and analyses indicating that chaparral fire regimes in southern California have not changed substantially over time (with the exception of increased human-caused ignitions) and that fire suppression, stand age and fuel loads have played a minimal or secondary role in shaping the current state of fire occurrence and size distributions. They infer that weather, climate and geographic variables are of primary importance in driving large fires in Southern California, in particular the occurrence of "Santa Ana" (foëhn) winds and drought (Keeley 2004).

Our project directly responded to the Joint Fire Science Program AFP 2006-3, Task 1 by supplying wildland fire managers and policy makers with extensive spatial and temporal information regarding the long-term natural range of variability of chaparral fire regime, a characteristic of which little is currently known. Under federal programs such as the Healthy Forest Initiative and the Fire Regime Condition Class, managers need accurate historical information for assessing current departures from "natural" or historical conditions. In addition to providing managers with baseline information for chaparral ecosystems, this proposed research also delivers locally needed fire history knowledge for, bigcone Douglas-fir, which is an important vegetation and wildlife habitat type in the Transverse Ranges of southern and central California.

The broad goals of this project were to determine the long-term historical fire regime characteristics of bigcone Douglas-fir (PSMA) stands in southern California chaparral and to assess the effect of climate on the fire regime. To achieve these goals we addressed these specific objectives:

(i) Determine the historical fire regime characteristics of chaparral stands over the past three or more centuries by dating fire-scarred PSMA trees found within extensive chaparral stands,

(ii) Corroborate the modern tree-ring record with the highly accurate 20th century fire atlas database to determine the strength of our interpretations,

(iii) Evaluate the role fire has played in patches of PSMA as they occur within chaparral stands and

(iv) Investigate the historical and contemporary influence of weather and climatic variations on chaparral and PSMA fire regimes.

III. Study Description & Location

Our research took place on Los Padres (LPF), San Bernardino (SNF) and Angeles (ANF) National Forests located in the Transverse ranges of southern California. LPF is the northern most site in the project and is approximately 1.6 million acres in size. A vast majority (68%) of the vegetation on LPF is classified as chaparral, with most occurring below 5,000' in elevation. ANF and SNF, located to the south and east of LPF, cover over 650,000 and 670,000 acres respectively. Like LPF, the predominant vegetation type of both forests below 5000' is chaparral. Fire atlases are available for all three of these National Forests. This database contains fire names, dates and perimeter boundaries for all fires greater than 100 acres that have occurred within the three national forest boundaries since 1910.

A total of 37 sites were sampled, 15 in LPF, 14 in ANF and 8 in SNF. When accessible stands were identified, sites were selected in consultation with forest personnel to maximize information needs and to meet our requirements of having PSMA stands whose fire history would be reflective of the surrounding chaparral environment. This last condition is critical to achieving our objectives as the stands we selected must accurately capture the fire and climate characteristics of the surrounding chaparral stands at regional, landscape and local scales. All sampled stands, which ranged in size from roughly 10 to 20 acres (with a few stands closer to 100 acres), were completely encircled by chaparral and relatively homogenous in topography and cover.

Individual trees were chosen using a sampling criterion similar to that of stand selection (accessible, well distributed and maximum information possibilities). Open cat faces on PSMA trees are an uncommon occurrence and, when present, are relatively poor recorders due to decay and burning out by subsequent fires. However, trial and error sampling of full bark trees revealed that buried scars were very common on most trees within stands. We subsequently targeted our sampling toward obviously older trees (as indicated by bole size, branch characteristics, etc.,) and those with characteristic furrows in the boles, which indicated healed over scars. Using a chainsaw, a skilled sawyer made plunge cuts to extract partial sections on upslope sides of living and standing dead trees as well as on downed snags.

The samples were taken back to the Laboratory of Tree Ring Research (LTRR) where we prepared and dated all fire-scarred specimens according to standard procedures (Baisan and Swetnam 1990). A belt sander, using progressively finer abrasive belts, was used to surface the samples. A binocular microscope (x7-30 variable power) was used to examine and date the samples. Ring-width skeleton plots from the fire-scarred samples were cross-dated using a master chronology from the region. We then determined and recorded all fire scar dates (Baisan and Swetnam 1990).

During the dating process, we observed abrupt growth changes evident in the ring-width patterns of our specimens that appeared to be associated with fire scars or occurred following known fire dates. While changes in growth can be caused by various means (e.g., stand opening and reduced competition from wind-throw and other mortality agents), we believe these changes frequently result from a shift in resource availability due to fire mediated mortality (Mutch and Swetnam 1995). Unlike fire scars, fire related growth changes usually do not begin the same year as the fire event because cambial growth often ceases prior to most fire events in southern California. Because it can take several years for trees to recover from fire damage and take advantage of the decreased competition for resources, growth changes typically begin in the years following the fire. These growth anomaly events were recorded and a separate chronology was derived from them. Growth change magnitude and duration were visually estimated and began when ring widths became substantially larger or smaller than the preceding 5 to 10 rings and were at least three years in duration. The event was considered completed when ring widths returned to pre-fire sizes. We recorded release events when ring widths increased by more than 150 %. Suppression events were identified when ring widths decreased by more than 50 %.

Replication at the local, stand and forest level allowed us to build both local and regional fire-scar networks, using both fire scars and growth anomalies, upon which to determine fire characteristics at numerous spatial scales and to examine the influence of large-scale climatic factors. This design also allows us to assess the degree of synchrony of fire dates from the watershed level to the regional level.

Synchrony of events is a key component to dendrochronological crossdating, network building and identification of broad-scale climatic patterns (Swetnam & Baisan 2003). Composites of numerous ring-width chronologies, and numerous fire-scar chronologies, from broad areas allows for site-specific variations to be averaged out, and identification of regional climatic and fire patterns to emerge (e.g., Swetnam 1993, Veblen et al. 1999, Kitzberger et al. 2001). Differences in climate, especially extreme wind events, and fire regimes across the study region have been observed in other related research (Moritz 2003, Keeley 2004). The comparative analyses across these gradients allowed us to interpret the influence of climatic patterns and events, like the Santa Ana winds, across this region.

Finally, to test the fidelity of the tree-ring record, we examined the California Fire History Database (CFHD) and selected modern-era, chaparral-driven fires that have occurred in at least one sampling location within each National Forest. SBNF had 23 such events, while ANF had 11 and LPF had 8. The number of actively recording stands within each mapped modern fire perimeters was documented and a cumulative total of possible outcomes were determined. Assessments were made on a point-by-point basis. At each point, a tree-ring based fire record was created by describing when and how each fire event was recorded (i.e., via fire scar or growth change) within the stand. Based on error typology work described in Falk (2004), Farris et al. (in press) and Lombardo et al. (2009), we assessed total accuracy and potential errors of fire event detection using fire scars, growth changes and a combination of both indicators. Type I errors occur when a tree-ring based fire year is detected in a stand despite that location being outside the document-based fire perimeter in that year, while Type II errors occur when tree-ring samples from a stand within a document-based fire perimeter fail to show a fire in that year.

All data obtained from the samples was entered into FHX2 (Grissino-Mayer 2001). FHX2 is a fire history program capable of data compilation, sorting, statistical analysis and graphical presentation. Changes in fire frequency and extent, over time and space, were analyzed using data derived from both fire-scar and growth change information. Fire interval statistics such as mean fire interval, median fire interval and composite filter return intervals were determined for individual trees, sites and for each forest. We compared the reconstructed fire dates and synchrony patterns from the fire scars and growth change events with 20th century fire atlas data (past fire dates, locations and perimeters). This comparison enabled us to determine how well and the manner in which the fire scars and growth changes in the PSMA stands reflected the spatial and temporal patterns of fire in the surrounding chaparral stands.

Fire interval statistics can be assessed on several levels using "filtering" methods, which assist in identifying fires that were probably more or less extensive within sites (Swetnam & Baisan 2003).

We conducted a variety of graphical and statistical time series analyses of climate and fire records. These included graphical overlays of time series, correlation and superposed epoch analyses (e.g., Swetnam 1993, Grissino-Mayer & Swetnam 2001, Kitzberger et al. 2001). Our general goals were to evaluate the relationships between regional fire events (high and low fire occurrence years), and seasonal, inter-annual, decadal to centennial trends and variations identified in our reconstructed fire chronologies with a broad suite of climate parameters, including mean seasonal temperatures, total precipitation, seasonal Palmer Drought Severity Index, and the Southern Oscillation Index.

IV. **Key Findings**

A. Fire atlas corroboration

		All Indicators			Scars only			Growth Change only		
		Overall	Error		Overall	Error		Overall	Error	
Forest	Total outcomes	Accuracy	Type 1	Type 2	Accuracy	Type 1	Type 2	Accuracy	Type 1	Type 2
LPF	120	86%	9%	5%	91%	2%	7%	80%	9%	11%
ANF	154	90%	6%	4%	88%	2%	10%	88%	5%	7%
SBF	184	92%	7%	1%	97%	2%	1%	92%	6%	2%

The results of our corroboration of the tree-ring record with the modern fire atlas database yielded two significant findings. First, the tree-ring record of bigcone Douglas-fir is a highly accurate tool that can be used to capture the fire regime characteristics of the surrounding chaparral vegetation. Overall accuracy of the methodology, using all available indicators, ranged from 86 to 92%. Here, type I errors (false detection of an event) are generally higher as a result of the inclusion of growth change data. The indication of fire evidence outside of the mapped perimeter may imply that some growth events are not evidence of fire and instead reflect other environmental changes. However, given that the fire atlas itself is incomplete in that it does not account for events smaller than 100 ha, it may well be that these" false" detections are simply a more sensitive recorder of small events that are missed in the fire mapping process.

A second significant finding of this test is the discovery and value of growth change information, which when coupled with fire-scar data, substantially augments the fire history record with only minimal negative impact upon the overall accuracy of the corroboration. Using just fire scars provides the highest overall accuracy but limits the ability of the tree-ring record to capture the spatial and temporal dynamics of past and present chaparral regimes. In addition to providing a more robust reconstruction, using all available indicators allows us to reconstruct fire events with 90% accuracy, on average, while limiting type II errors (failure to detect an event within a known perimeter).

B. *Mean fire return intervals*

		SCAR		EVENT			SCAR		EVENT		
		LOCAL		**LOCAL**			**LANDSCAPE**		**LANDSCAPE**		
Forest	**Time**	**MFI**	**n**	**MFI**	**n**	**p**	**MFI**	**n**	**MFI**	**n**	**p**
LPF	1600-2005	13.0	28	11.7	31	0.49	52.5	7	27.0	14	0.06
ANF	1695-2005	19.8	13	14.2	20	0.66	61.0	4	17.7	16	*0.004*
SBF	1695-2005	16.1	14	9.5	29	0.23	34.5	2	17.1	15	0.09

Reconstructed mean fire return intervals for each forest using just fire scars (SCAR) and all indicators (EVENT) are illustrated in the table above. No significant differences, using the non-parametric Mann-Whitney U test, between the two methodologies were observed under the LOCAL composite (2-3 stands recording an event) MFI. Absolute differences between the two techniques were also minimal with a maximum of 6 years difference between mean values. However, under the LANDSCAPE composite (events burning 4 or more stands), there were substantial differences in the reconstructed mean values. While only one forest (ANF) showed a statistically significant difference (but note that LPF is nearly significant at the 0.05 level), we believe there is considerable evidence that suggests the EVENT MFIs are more reflective of actual fire regime characteristics than those developed using only fire-scar data, particularly when considering large-scale events.

First, our corroboration of the bigcone Douglas-fir tree-ring record with modern chaparral fire atlas data illustrates the power of using both fire-scar and growth change data to accurately depict the temporal and, to a lesser extent the spatial, dynamics of southern California chaparral fire regimes with minimal impact on overall accuracy. Second, the LANDSCAPE composite values derived from the EVENT methodology fall within a range that is far more consistent with the Mensing et al. (1999) dataset, which is the only other long-term fire history compiled for the region. We elaborate further regarding this connection in the “relevant findings” section. Finally, averaged MFIs at the point (28.25 years) and stand level (21.17), derived using both fire scars and growth anomalies, also imply that multi-decadal fire events are common place in this landscape. When return intervals remain relatively constant across vast spatial scales, as we have observed here in southern California, it is generally an indication of a fire regime that is driven by large-scale fire events.

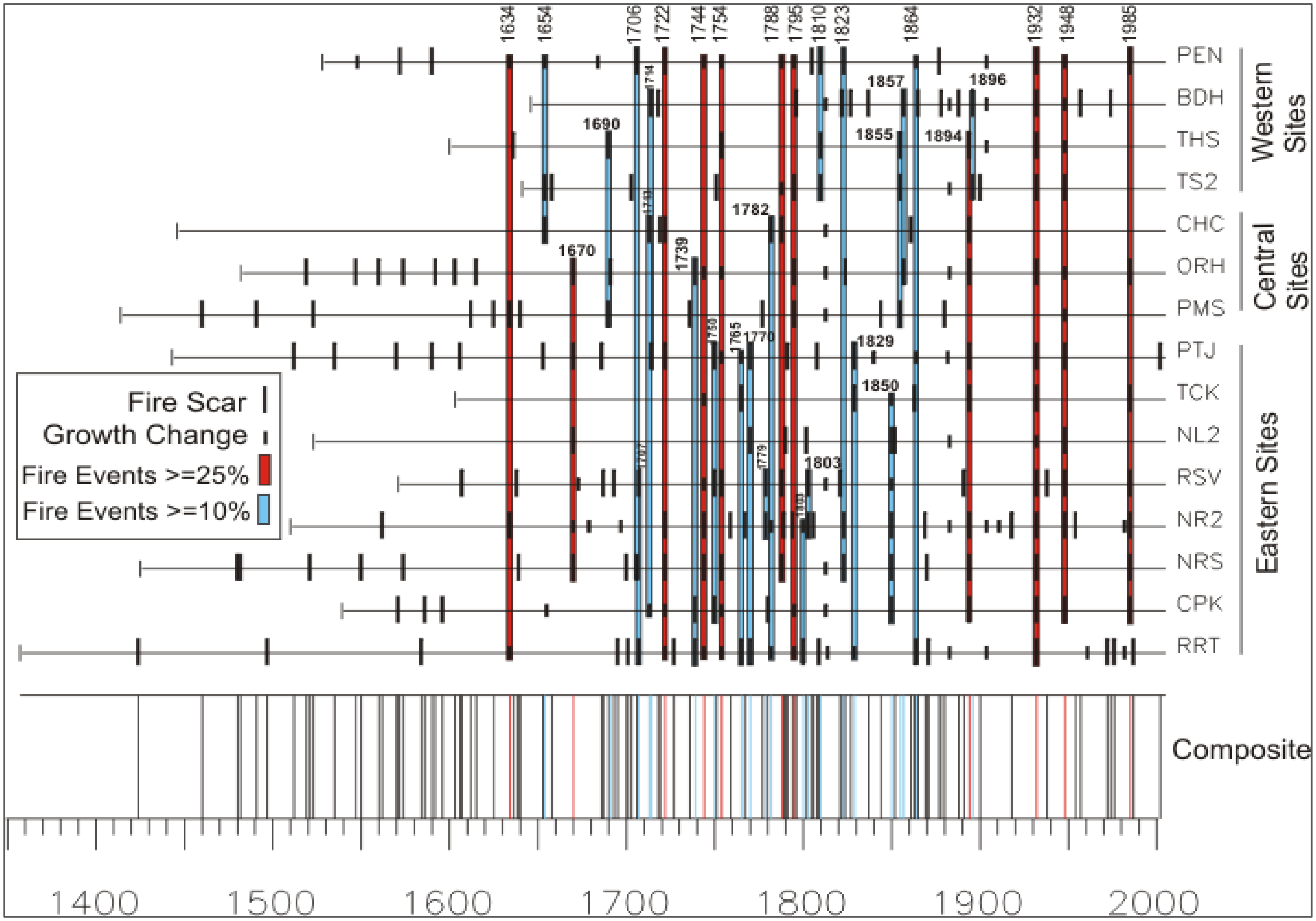
C. Fire return intervals pre- and post 1904

	LOCAL					LANDSCAPE				
Forest	**Pre-1904 MFI**	**n**	**Post-1904 MFI**	**n**	**p**	**Pre-1904 MFI**	**n**	**Post-1904 MFI**	**n**	**p**
LPF	9.7	27	29.7	3	*0.02*	26	10	29.7	3	0.55
ANF	13.0	16	18.8	4	0.51	14.9	14	37.5	2	0.15
SBF	8.1	24	16.2	5	0.10	12.8	13	45	2	*0.03*

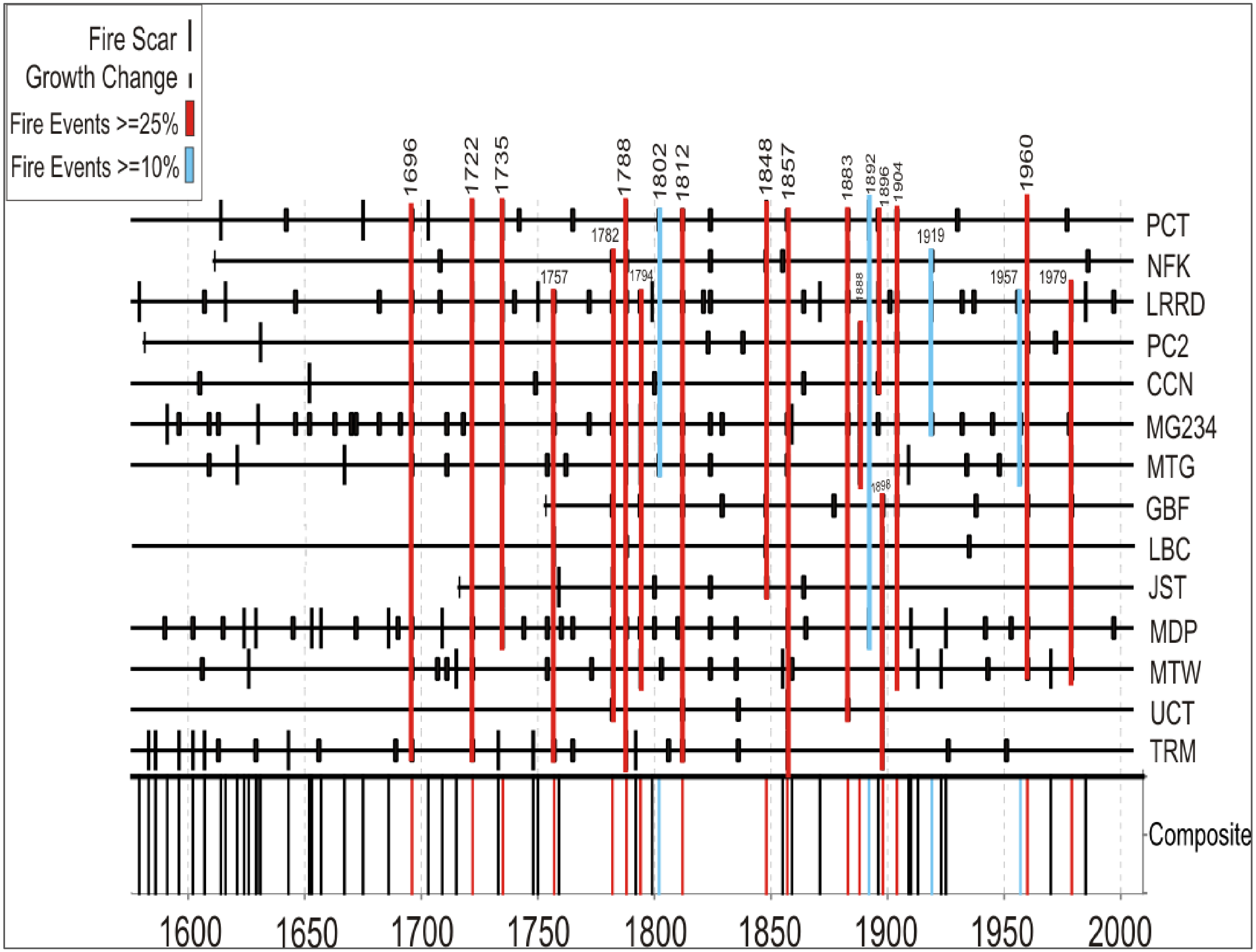
We compared reconstructed mean fire return intervals between two periods of time (pre- and post- 1904) for both local- and landscape-scale fire events across all three forests. The date 1904 was chosen for two reasons. One, all three forests have a fire event evident in the tree-ring record during this year. Two, it is representative of a time when fire suppression tactics are known to have influenced many of the arid ecosystems of the western United States. Though suppression tactics are not believed to have been effective in southern California until the early to mid 1900s, our results, generated from the non-parametric Mann-Whitney U test, do indicate that differences between the time periods exist. In the case of LOCAL fire events, intervals lengthen in all three forests and most significantly in LPF. Here LOCAL fire events have essentially been eliminated, leaving large events, which remain unchanged over time, as the dominant characteristic of the modern chaparral fire regime. Though not statistically significant, LOCAL interval lengths also increased in both ANF and SBF.

LANDSCAPE fire event intervals also lengthened across the three forests. However, the change is most evident in the two more eastern forests, ANF and, in particular, SBF. Again, only one of the comparisons yielded a statistically significant result at the 0.05 level; however, it is clear that large fire events, like small fire events, became less frequent across the region beginning sometime around the turn of the century. Presumably natural ignition rates have remained relatively constant over time period of this study while anthropogenic ignition rates have increased over time (Keeley & Fotheringham 2001, Keeley 2004). We hypothesize that changes in land management and fire control policies may possibly explain the observed increase in interval lengths since the early 1900s. Under moderate weather conditions, small fire events are relatively containable. Limiting the number and spread of small events, especially prior to and during the high fire season could effectively limit the number of large events that occur. We speculate that the reduction and control of LOCAL fire events has reduced but not eliminated the occurrence of LANDSCAPE fire events in the region.

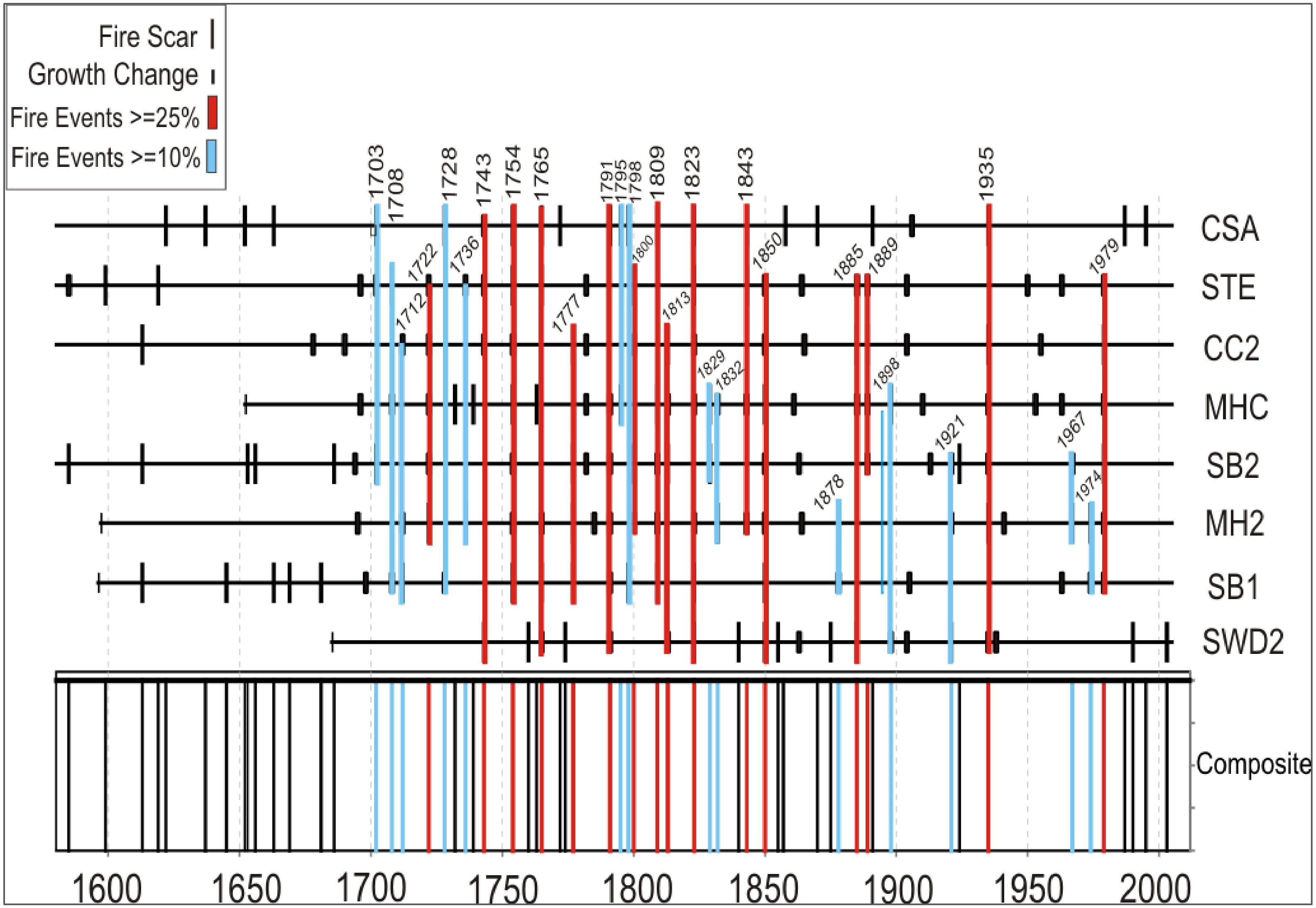
D. Fire History charts



Los Padres National Forest fire history chart (1600 – 2005)



Angeles National Forest fire history chart (1695 – 2005)



San Bernardino National Forest fire history chart (1695 – 2005)

LANDSCAPE fires have dominated the three national forests for the last 3-400 years and likely much longer. While the frequency of these events may have changed in recent years, their occurrence does not appear to be an artifact of fire suppression as has been argued by some in the research community. In addition to large-scale fires, it is also apparent that numerous smaller (LOCAL) fires have been occurring over this time period as well. The presence of these small fire events in conjunction with large fire events refutes the idea that numerous small fire events could eliminate or reduce the occurrence of large fire events.

However, it should be noted that fire suppression may be playing some role in shaping the contemporary fire regime. In all three graphs, there are obvious changes in the frequency and patterns of fire events beginning in the mid-to-late 1800s and early 1900s. While, climatic changes may be one possible driver of these changes, this time period also marks an era of relatively rapid development and substantial changes in land management policies. By the mid 1850s, Spanish missionaries had brought most of the native population into the coastal mission villages and out of the more mountainous areas of the region which, in turn, eliminated the primary source of anthropogenic ignitions. During this time, Spanish settlers began converting native coastal and interior chaparral to more palatable grasses for cattle production. While fire was often used to clear land, according to most accounts, intentional burning was done in a limited fashion as the Spanish settlers were keen to the dangers of wildfire in chaparral environs. Though natural ignitions likely went uncontrolled, these policies ushered in a period of de-facto fire suppression which may drive the changes we observe in the tree-ring record.

Modern fire suppression is not considered to be effective in California until the early 1900s as the steep terrain, volatile vegetation and extreme fire weather limited the effectiveness of fire control efforts until aerial support came into play. However, even today, under extreme weather conditions it is debatable whether or not fire suppression is effective. The source of large fires events is often a small fire event that "blows up" during extreme weather conditions. If small fire events were to be controlled and contained prior to extreme weather events, then a potential source of large fire events is capped. While both past and present fire suppression efforts were likely ineffective in combating large fires, such efforts have been effective in containing and eliminating the occurrence of smaller fire events. This scenario would be one possible explanation for the changes we observe in the tree-ring record over the past century.

E. Fire-Climate Analysis

LOCAL fire events

	Precipitation			**Temperature**			**ENSO**			**PDSI**		
Forest	*Fire year*	*1 yr lag*	*2 yr lag*	*Fire year*	*1 yr lag*	*2 yr lag*	*Fire year*	*1 yr lag*	*2 yr lag*	*Fire year*	*1 yr lag*	*2 yr lag*
SBF	*	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns
ANF	**	ns	ns	*	ns	*	ns	ns	ns	**	ns	ns
LPF	***	ns	ns	ns	ns	ns	ns	ns	*	***	ns	ns
ALL	***	ns	ns	*	ns	ns	ns	ns	ns	***	ns	ns

Our investigations of fire and climate associations, using Superposed Epoch Analysis (SEA), revealed significant relationships between LOCAL fire events, drought (PDSI) and years of below average precipitation for all three forests. This relationship was only evident during the year of the fire event meaning that previous years conditions were not a significant factor in driving fire occurrence. Both PDSI and precipitation exhibited a stronger statistical relationship to fire occurrence in LPF than in ANF and SBF.

A significant relationship was also observed between temperature and fire occurrence in ANF. Above average temperatures in both the year of the event and two years prior appear to significantly affect fire occurrence in ANF. When data from all three forests is aggregated significance is achieved during the year of the fire event.

The relationship between LOCAL fire events and ENSO are non-existent with one exception, which is a significant relationship between El Nino events two years prior to the fire event in LPF. Here we can only speculate that the moisture deleivered two years prior to the fire event may have assisted in building a abundant fuel source, which fed the blaze.

'*' = significant at 0.05
'**' = significant at 0.01
'***' = significant at 0.001 or less

LANDSCAPE fire events

	Precipitation			**Temperature**			**ENSO**			**PDSI**		
Forest	*Fire year*	*1 yr lag*	*2 yr lag*	*Fire year*	*1 yr lag*	*2 yr lag*	*Fire year*	*1 yr lag*	*2 yr lag*	*Fire year*	*1 yr lag*	*2 yr lag*
SBF	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
ANF	*	ns	ns	ns	ns	*	ns	*	*	**	ns	ns
LPF	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns
ALL	***	ns	ns	ns	ns	ns	ns	ns	ns	***	ns	ns

LANDSCAPE fire events exhibited a strong significant relationship with drought (PDSI) and fire occurrence during the year of the fire event for all three forests. Links between low precipitation years and fire occurrence were only statistically significant in ANF and when data from all three forests were aggregated.

No significant relationship between temperature and fire occurrence was observed except for above average temperatures two years prior to fire occurrence in ANF. Likewise, only in ANF did we observe any links between ENSO and fire occurrence. A one year and two year lags between El Nino events and LANDSCAPE fires were found to be moderately significant.

The connection between drought, lack of precipitation and fire are fairly obvious. However, the significant connections between ANF fire events, ENSO (El Nino conditions) and temperature are more curious. The ANF lies at the edge of moist, coastal influences from the Pacific Ocean but also at the edge of the warm, dry Mohave Desert. We postulate that its geographic position puts the forest in a position to be uniquely influenced by fluctuations in annual temperatures and precipitation more so than the more coastal LPF and more interior SNF.

'*' = significant at 0.05
'**' = significant at 0.01
'***' = significant at 0.001 or less

V. Management implications

Using dendrochronology in southern California chaparral landscapes

Across many of the forests of the western United States, dendrochronology has been used to accurately describe temporal and spatial patterns of historical fire regimes. By providing baseline reference conditions of historical fire regimes, land managers can use this information to inform their current and future fire management strategies and plans. Our highly successful corroboration of the tree-ring record with the California Fire History Atlas indicates that using bigcone Douglas-fir fire scars and growth anomalies are a useful method for reconstructing fire history in chaparral dominated landscapes.

Prior to this research endeavor, limited dendrochronolgical research has been conducted in southern California, particularly in low to mid elevation sites, due to what was presumed to be a lack of datable material. Our research has not only provided land managers with the first spatially explicit, multi-century fire history for chaparral dominated landscapes, it also highlights the possibilities for extensive future dendrochronological research in this region.

Chaparral Fire History

Our reconstruction of chaparral fire regimes across three southern California National Forests has shed light upon one of the hotly debated topics in fire ecology. Previous work had debated whether the large fires that are now common in the modern landscapes of the region were a result of land management activities (mainly fire suppression) or a result of natural conditions that when coupled with increasing number of human ignitions promote such widespread events.

In each forest, our results suggest that widespread fire events similar to those seen today have been occurring for at least the past 300 to 400 years. This fact would appear to indicate that fire suppression efforts have not been the primary cause of these events though there is some evidence that suggests it may be playing some role in shaping the contemporary regime. Some researchers have hypothesized that numerous small fires created a mosaic of age classes within the historic chaparral landscape that limited fire spread. They argue that modern fire suppression has effectively converted the naturally heterogeneous landscape into a homogenized one that supports and drives the modern widespread fire events. Our findings support the notion that smaller, more localized fires were more numerous and frequent in the past and have been nearly eliminated from the contemporary regime. We acknowledge that modern day fuel loads and connectivity are likely different than those of the past; however, it appears that they never played a role in limiting the spread of chaparral driven fires.

Understanding that landscape scale fires are inevitable in the chaparral dominated regions of southern California will help land managers plan and prepare for such events in the future. Controlled burns in high elevation forests, when weather conditions are moderate, as well as properly managed thinning will reduce fuel continuity and help to prevent upper elevation fires from spilling over into low to mid elevation chaparral landscapes. However, such events are inevitable, especially in the face of extreme fire weather, and land managers would be wise to focus their efforts on fire prevention, WUI planning and working with surrounding communities to development fire-safe communities.

Fire – Climate connections

The strongest connections between the occurrence of fire and climatic drivers occur in the year of the fire event. LOCAL fire events tend to occur in year's where precipitation is below normal and drought conditions exist. There also appears to be a modest connection to above average temperatures in the year of the event, however this connection is only evident in ANF and when all data from the region are aggregated.

When we examined LANDSCAPE fire events, only the connection to drought conditions in the year of the fire event remains as a statistically significant climatic driver with few exceptions. Below average precipitation is significantly linked to the occurrence of large fire events in ANF. We also observed a link between low precipitation and the aggregated regional fire dates from all three forests.

Our findings suggest that drought conditions driven by below average precipitation during the southern California winter can result in an increased likelihood of LOCAL fire events the following year. Additionally, above average temperatures appear to drive the occurrence of small fire events across the southern California region as well, in particular ANF. With this in mind, during years of scant rainfall, land managers can expect and prepare for an abundance of small fire events. Containment of these events, particularly when they occur in late summer and early fall, is critical to averting larger, more catastrophic fire events.

LANDSCAPE fire events exhibit a strong connection to drought in the year of fire events as well; however the link to precipitation is weaker than that seen in LOCAL fire events. We suspect that while prolonged drought and dry winters likely play a role in preparing the landscape for fire, it's more likely that large-scale fire events are a result of small, localized fires being pushed and driven by strong, autumnal Santa Ana winds. This mechanism, abundantly observed in the 20th century, would explain a weaker documented connection of LANDSCAPE fires to antecedent climate conditions.

VI. Relationship to other recent findings and ongoing work

This research represents the first multi-century, regional examination of chaparral fire regimes in southern California. Previous analyses have been limited in temporal (Moritz 1997, Keeley & Fotheringham 2001, Moritz 2003, Keeley & Zedler 2009) and spatial (Mensing et al. 1999) scope. Our results confirm and expand upon several of the existing hypotheses that have been developed for the region (Minnich & Chou 1997, Moritz 1997, Mensing et al 1999, Keeley & Fortheringham 2001, Moritz 2003).

Minnich and others (Minnich & Chou 1997, Minnich 2001, Minnich & Goforth 2007) have long suggested that the contemporary mega-fires are a product of anthropogenic making. In particular they argue that the systematic suppression of ignitions in the 20th century era has eliminated the naturally occurring mosaic of chaparral age classes whose existence created a natural barrier to fire spread, even in extreme Santa Ana conditions. The elimination of these multiple, small events has lead to increased fuel continuity and homogenization of the landscape. The end result is that the contemporary landscape is now predisposed to landscape-scale burns. Our research does indeed find a drop-off in the frequency of localized events in the 20th century, with the most significant change seen in Los Padres National Forest. This change is likely due to the increased ability of land managers to extinguish starts before they reach landscape-scale proportions. What we do not see, however, is an increase in the number of landscape-scale events during this same time frame. In fact the frequency of large events has decreased in two forests (Angeles and San Bernardino) and remained consistent in the other (Los Padres). This evidence would seem to indicate that large-scale fire events, occurring at multi-decadal intervals, have been common across the southern California landscape for at least the last 400 years. This interpretation is consistent with much of the work Keeley and others (Moritz 1997, Conard & Weisse 1998, Mensing et al 1999, Keeley & Fortheringham 2001, Moritz 2003, Keeley & Zedler 2009) have put forth. Supporters of this theory have pointed to extreme wind conditions that occur at the driest time of the year are the primary driver of such events (Mensing et al 1999, Keeley & Fortheringham 2001, Moritz 2003, Moritz et al. 2010).

Our work most closely ties into the work done by Mensing et al. (1999) near the Los Padres area. Here, using wind-blown charcoal sediments from a varve sample extracted from the Santa Barbara Basin as a proxy for fire size and frequency, they found roughly 25 year return intervals for large fire events (greater than 20,000 ha) over the past 560 years. This figure remained relatively consistent over the entire temporal expanse of the study which includes three unique land management styles (native, Spanish and modern). Within this same region we found nearly identical return intervals (27 years) for our large fire events over a similar timeframe.

Landscape-scale fires, presumably driven by strong, erratic winds occur on a multi-decadal basis and appear to be a natural, regional phenomenon and not a product of anthropogenic land management. Giving additional weight to this theory is the fact that when MFIs at smaller scales are examined we also observed multi-decadal intervals. At the stand level, the average MFI across all three forests is 21.2 years and at the point level the average MFI is 28.3 years. When return intervals remain relatively unchanged across spatial scales, it is indicative of a fire regime dominated by landscape-scale events. Multiple lines of evidence drawn from this research leads us to conclude what many scholars and land managers have come to understand regarding large fire events in chaparral landscapes. The dynamics of megafires, past and present, are closely connected to Santa Ana winds that occur at the height of the annual southern California drought. Furthermore, recent work by Moritz et al. (2010) finds that particular sections of the southern California landscape that are more prone to high winds tend to produce the most and biggest blazes in the region.

While the results of this research refute the notion that a mosaic of chaparral age classes prevented landscape-scale fires from occurring in the recent past, it also reveals that small fire events were relatively common as well. Our estimated mean return interval for localized fire events ranges from 13 to 20 years. Some have argued that native chaparral species would not be able to tolerate this level of frequency as several reports have demonstrated that most key species require at least 15 years to produce viable seed banks. However, our mean return fire interval is not equivalent to the so-called "population MFI", which is the average time between fires occurring at any random point in the sampled area. MFI is defined here simply as the average interval between *any* detected fire occurring anywhere within a sampled area (Romme et al. 1980). Across all three National Forests, the average MFI at the point level is 28.3 years, which is well within the viable reproduction timeframe of chaparral species.

VII. Future Work Needed

There is an abundance of opportunities for additional dendrochronology work that would greatly enhance the findings of this research. Further collections in and around existing study areas would improve the temporal resolution of our dataset while more intensive sampling within existing study areas will provide for a more detailed and robust reconstruction of fire sizes, which is something we were only able to touch upon in this work (Lombardo et al. 2009). Furthermore, establishing study sites in Cleveland National Forest, the southernmost mountain range in the region, would be a valuable contribution that would expand the spatial range of this research.

Opportunities exist to connect the results of our mid-elevation based data with that collected by Scott Stephens, Carl Skinner and Rick Everett. This group collected fire-scar data, using JFSP funding, to reconstruct mixed conifer forest fire histories across the same ranges. Further examination of the historical linkages between these two fire regimes is needed and would supplement the individual findings of each research effort. If substantive links are found, then expanded dendrochronolgy work across this gradient would be warranted.

One of the key assumptions of this work is the spread of fire within and between bigcone Douglas-fir stands. By collecting supplemental data from within existing stands, we will better understand the spread of fire both within and between these unique conifer stands. The question of how and why fire spread across these landscapes leads us to question the relationship between fire scars and growth change events we documented within the tree-ring record. In Los Padres National Forest, the data suggest a rapid change in scarring rates occurred at the end of the 19th and beginning of the 20th century. We speculate that the change could be due to fire suppression influences on fuel loads and continuity or perhaps even driven by climatic factors. One way to approach this question would be to calibrate modern remotely sensed fire severity with the observed tree-ring record to determine if there is a significant link between severities, scarring and abrupt changes in tree growth.

Additional fire-scar data would also enhance our ability to relate fire events to climatic drivers. Keeley (2004) demonstrated definitive connections on southern California landscapes between fire occurrence and size and climatic drivers in the 20th century. However, other dendrochronology-based work has failed to provide substantive associations (Everett, Pers. Comm.). Our data do show some strong connection does exist, however, in many cases no significant findings are seen. Additional data collection and further investigations would allow us to develop a baseline to assess the effects of climate change and contemporary influences on the relationship between chaparral fire regimes and climate. Furthermore, development of this historic frame of reference would provide land managers with a predictive forecasting tool that could be used to more efficiently allocate resources in times and areas of need.

While there is undoubtedly some connections between antecedent climate and chaparral fire regimes, extreme weather conditions driven by annually occurring, autumnal Santa Ana winds play a critical role in shaping the local fire environment. Recently, Moritz et al (2010) published a predictive Santa Ana wind event map that overlaps with all of our sampled areas. Comparing our multi-century tree-ring dataset with these maps could shed light upon the role of Santa Ana winds in promoting large fire events. If areas that are prone to extreme winds overlap with tree-ring sites that have a historical pattern of large events then it would further support our conclusion that fire suppression is not responsible for the modern landscape-scale fires and that these blazes are primarily a product of the Mediterranean- influenced chaparral environment and unique, geographically-driven extreme wind events.

Finally, this research will provide a historical point of reference for land managers as they debate and determine the role of management in chaparral landscapes. The information gleaned from this work and future endeavors will serve to assist managers, planners and the general public in their efforts to balance the ecological needs of the landscape with the needs of a burgeoning and ever-expanding wildland-urban interface. Historical tree-ring data taken from stands adjacent to communities, supplemented by the broader dataset derived from the larger region, would be useful to communities looking to become more "firewise" and adaptive to their surrounding communities.

VIII. Deliverables

Proposed	Status
Annual Progress Report	Submitted to JFSP
Field collections	Multiple specimens of fire-scarred PSMA trees are currently being stored at the UA Laboratory of Tree-Ring Research. They will be permanently stored in a new, state-of-the-art facility that is scheduled to break ground next year. The pieces will be available for future use and observation.
Data analysis and synthesis	Raw data and analytical results including metrics of fire regime, tabulation of fire years by site and fire-climate relationships is prepared and available for use for any of the interested Forests.
Two Peer-reviewed scientific publications	One paper has been published in *Fire Ecology.* Two additional manuscripts are currently being prepared for submission to peer reviewed journals.
Public and stakeholder education	Poster about fire in chaparral/PSMA landscapes for public viewing at four southern California National Forest visitor centers.
Technical information transfer to USFS fire & land managers	A workshop was conducted for academic and land managers in the summer of 2008 in Los Padres National Forest. The results of the project were presented and a tour of one of the field sites was given by our team. Our sampling technique and dating procedure were also demonstrated on site. Multiple on-site visits were made to the lab from experts in the field (Keeley and Minnich among others.) All were given a tour of the lab during which the sampled materials and associated data were thoroughly discussed.
Presentation of results to scientific	A total of 5 presentations were made at professional and academic

and professional communities	conferences along with one poster presentation.
Internet	A summary of the project, and main findings available on the LTRR web site. Currently in progress.
Final Report and data transfer	Final Report has been prepared and submitted to JFSP. A copy of the report will be made available to each southern California National Forest.

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Keith Lombardo, Thomas W. Swetnam and Christopher H. Baisan. Multi-century reconstruction of chaparral fire history in three southern California National Forests: Preliminary results and future directions. GeoDaze Conference, Tucson, AZ April 2008 (1st runner-up; Best Poster).

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Graduate education

Lombardo, Keith J. Multi-century reconstruction of chaparral fire history using fire-scarred bigcone Douglas-fir in three southern California National Forests. PhD Dissertation, Department of Goegraphy and laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ (Thomas Swetnam, advisor).

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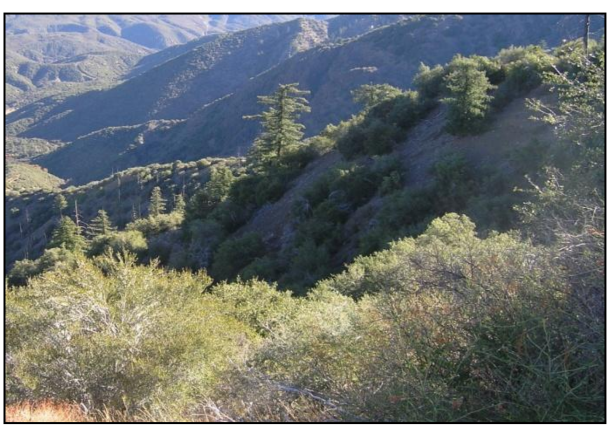
Publication in preparation

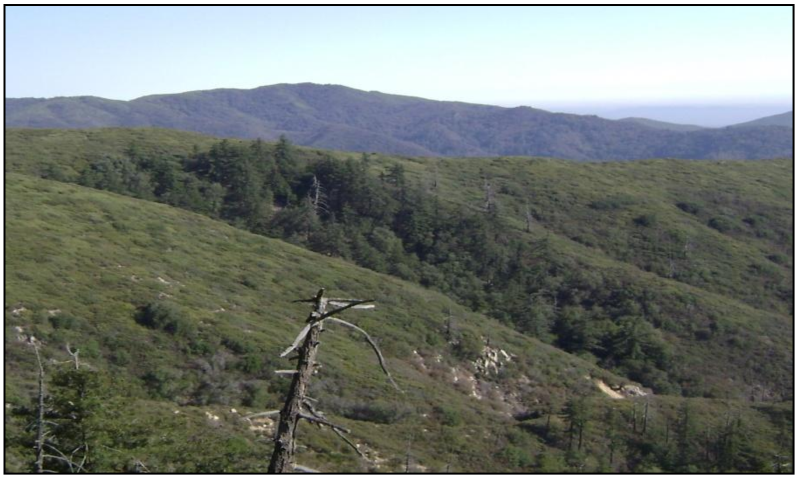
Lombardo, K.J., T.W. Swetnam and C.H. Baisan. Fire in the mountains: A regional, multi-century fire history of southern California chaparral landscapes.

Lombardo, K.J., T.W. Swetnam and C.H. Baisan. Climatic effects on historical chaparral fire regimes.

Selected photos



Bigcone Douglas fir individual within the chaparral of Los Padres National Forest



Typical Bigcone Douglas-fir stand with surrounding chaparral vegetation on all sides. Photo taken in Cleveland National Forest.

Team member Chris Baisan sampling a previously felled Bigcone Douglas-fir stump in San Bernardino National Forest.

A fire-scarred bigcone Douglas-fir sample collected from Nordoff Ridge in Los Padres National Forest.

Bigcone Douglas-fir stand along the Pacific Crest Trail in Angeles National Forest.

Patch of bigcone Douglas-fir (and Canyon Live Oak) that was burned, but survived, the 2006 Day Fire in Los Padres National Forest.

Approaching the same stand from above. Clear evidence of the 2006 Day Fire was found in the tree-ring record of the samples taken from this stand.