

Interannual to Decadal Drought and Wildfire in the Western United States

PAGES 545, 554–555

Twentieth-century wildfire suppression and land management policies have promoted biomass accumulations in some ecosystems in the western United States where wildfire is a natural and necessary element. These changes have fueled large, stand-replacing crown fires in southwestern ponderosa pine forests, where they were rare under natural fire regimes [Allen *et al.*, 2002].

Current policy contemplates massive ecosystem restoration involving prescribed fires and mechanical fuel reductions on millions of hectares and the subsequent re-introduction of pre-suppression fire regimes [USDA and USDI, 2002]. Success critically depends on understanding past and present fire regimes. The current western drought and the potential for climatic change to increase the frequency and magnitude of the region's droughts [Smith *et al.*, 2001] further emphasize the need to understand short- and long-term climate-fire relations.

As a result of modeling the areas burned annually in the western United States over the past 3 centuries, we have found that managed wildfire regimes still contain strong climate signals that are similar to paleo-fire reconstructions. Moreover, El Niño-Southern Oscillation and Pacific Decadal Oscillation patterns appear to modulate western fire activity.

Modeling Western Wildfire

Studies of western climate and wildfire variability rely on 20th-century records of fire suppression agencies and reconstructions of annual wildfire activity derived from fire-scar dendrochronologies covering primarily the 18th and 19th centuries [Swetnam and Baisan, 2003; Westerling *et al.*, 2003].

There is little temporal overlap of modern documentary and tree-ring records, because livestock grazing and active fire suppression early in the 20th century effectively terminated the extensive fires that fire-scarred trees recorded in many areas. This makes it difficult to place the

short record of historically observed fire regimes into the broader context of variability in western fire and climate as reconstructed from paleo proxies. It also hampers direct calibration of regional fire-scar time series with documentary records of areas burned or instrumental climatic records. Moreover, modern wildfire regimes (and record-keeping) are highly influenced by ongoing changes in management personnel and policy. Even without such changes, increasing fuel loads from decades of fire suppression are apparently decreasing the effectiveness of fire suppression efforts in some ecosystems [Allen *et al.*, 2002]. Consequently, even with a record spanning most of the last century, it is difficult to discern the effects of natural variability—including climatic variations—from those of land use and management on wildfire.

These problems of climate-fire signal detection were addressed in historical time series by modeling the annual area burned during the past 3 centuries. A statistical model was calibrated using documentary records of area burned by state on federal, state, and private lands for 1916–1978 and the 20th-century portion of Cook *et al.*'s [1999] tree-ring width reconstruction of the summer Palmer Drought Severity Index (PDSI) for 1700–1978 for the western U.S. PDSI is useful as a predictor of wildfire activity, since it integrates precipitation and temperature anomalies over several months to several seasons. It serves as a proxy for fuel and soil moisture conditions during the wildfire and growing seasons. Dry conditions during the fire season can increase the ignitability and flammability of fuels, while wet conditions can promote the accumulation of fuels through new growth and fire suppression.

Westerling *et al.* [2002] have successfully used these relationships to forecast western wildfire area burned using Canonical Correlation Analysis (CCA). The same methodology was applied here to model indices of annual western area burned for 1700–1978. Reconstructed June–August PDSI from a 2° x 3° grid for 28°N to 50°N latitude and 100°W to 124°W longitude for the current and previous summer were transformed into four principal component (pc) predictors representing 58% of total

variance in PDSI. Similarly, area-burned time series for the 11 states covering the same region were normalized using a log₁₀ transform and summarized by four pcs representing 83% of total variance for the transformed predictands. A linear model was constructed from the first four pairs of a CCA using these pcs. These model coefficients were then applied to the full length of the PDSI series (1700–1978) to generate a statistical reconstruction of area burned in each state as a function of regional patterns in PDSI over two summers.

Comparing Paleo-Fire Reconstructions

Since the fire history data available for this study were coarsely aggregated, we focus on broad spatial patterns at regional scales. While fire scar-derived fire histories have been reconstructed for many sites in the West, the southwest (in Arizona and New Mexico) has the most regionally extensive and well-replicated network, suitable for comparison to statistical reconstructions of area burned aggregated by state (Figure 1) [Swetnam and Baisan, 2003].

There was remarkably close agreement between the sum of the statistical reconstruction (SR) of area burned for Arizona and New Mexico, and the fire scar-derived reconstruction (FSR) of annual fire extent for the Southwest (Figure 1). Interestingly, the correlation between the SR and FSR is higher ($\rho=0.61$) than the correlation between the SR and the documentary record of area burned for 1916–1978 that was used to train the statistical model ($\rho=0.49$). The lower correlation with the documentary record may be due to changes in fire detection and reporting, as there was a four-fold increase in area protected by state and federal agencies during the record. Changes in fuel and fire dynamics in the late 20th century may also have led to changes in climate-fire responses. Prior to the increase in area protected in 1962, the correlation between observed and statistical reconstructions of southwestern area burned was higher ($\rho=0.66$).

Annual areas burned from the SR and FSR for the southwest were associated with similar large-scale patterns in PDSI—abnormally dry conditions ranging from Texas and southern California to southern Wyoming coincident with anomalously wet conditions in the northwest during the fire season and anomalously wet conditions in much of the west the preceding summer (Figure 2). These patterns were consistent with positive moisture anomalies promoting fuel accumulation and negative moisture anomalies promoting fuel flammability. They

also demonstrate the regional coherence of the climate signal in western wildfire, and strongly suggest a link between ENSO-related climate variability and wildfire.

ENSO, PDO, and Western Wildfire Area Burned

Correlations between the southwest FSR and SRs of annual area burned for each state also indicate a strong regional pattern in wildfire, characterized by an inverse relationship between wildfire area burned in the northwest and in the southwest. This dipole pattern was similar to the pattern of strong correlations between *Biondi et al.*'s [2001] reconstructed Pacific Decadal Oscillation (PDO) and area burned by state for both the historical record (1916–1978) and the reconstruction (1701–1900).

This result should not, in retrospect, be surprising, since PDO phase is thought to enhance or suppress ENSO events (depending on the region), and the ENSO cycle is the strongest source of interannual climate variability in much of the western United States and is known to affect fire occurrence [Svetnam and Betancourt, 1990]. As a useful oversimplification, El Niño (La Niña) events tend to bring drier (wetter) conditions to the northwest and wetter (drier) conditions to the southwest, and tend to be stronger when the PDO is in its warm (cool), positive (negative) phase [Gershunov and Barnett, 1998]. In general, precipitation anomalies are commonly in anti-phase between the northwest and southwest, with a conspicuous “dipole” wet/dry (and vice versa) spatial pattern that apparently has varied in strength on interannual and decadal scales over the past 300 years [Dettinger et al., 1998]. The latitudinal position of the switching of wet to dry (and vice versa) between the northwest and southwest has also varied through time, but typically has been in the area of approximately 45° north (i.e., northern California and through the northern Great Basin).

In contrast with the southwest, fire activity in the SRs for the northwest and California is greatest during El Niño events coinciding with a warm, or positive, PDO and often following a sequence of El Niño events (Figure 3). This is consistent with the idea that the northwest is often drier than average during El Niño events. Wildfire in the northwest was associated with 1 or more dry years (Figure 2), as might occur during periods of frequent El Niños. While southern and central California have experienced wet conditions during El Niños in recent decades, it is not inconsistent for the statewide SR to look more like that of the northwest.

For 1980–1990, there is an overlap between annual area burned records aggregated by state, and detailed, digitized fire occurrence data reported by federal agencies managing much of the western wild lands. For this period, the area burned over the whole of California was most strongly correlated with fire activity in the northernmost part of the state, near the Oregon border. In other comparisons of fire scar records from the southwest, Sierra Nevada, and Washington and Oregon (not reported here), it appears that during some decades, the Sierra Nevada fire occurrence time series

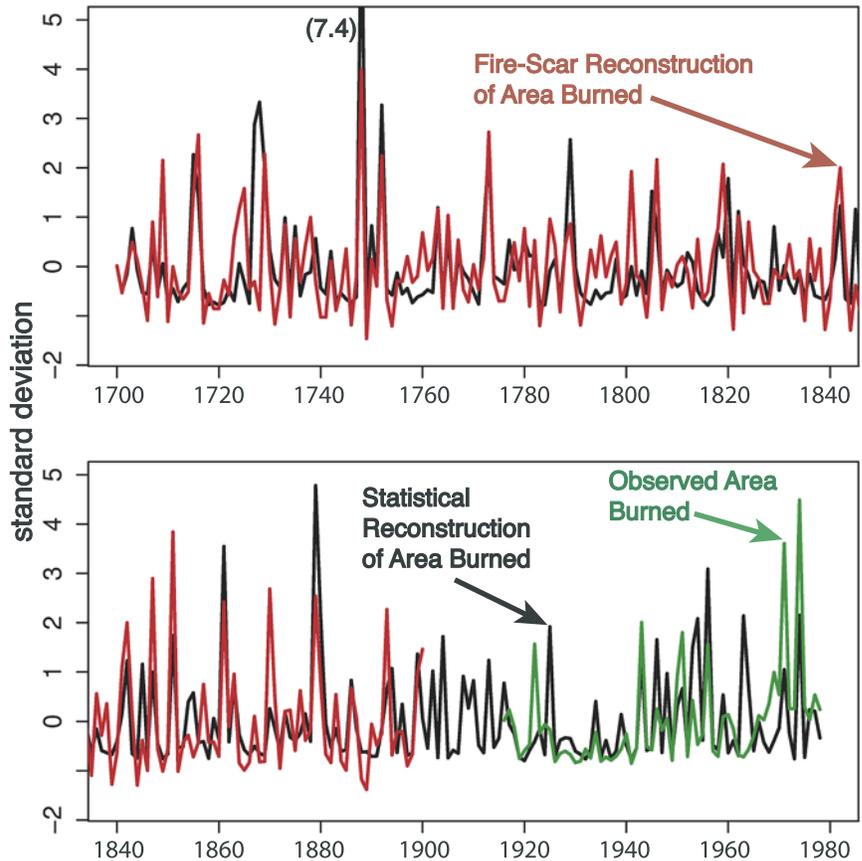


Fig. 1. This comparison shows the statistical reconstruction of the southwestern area burned (1701–1978, black line), the observed area burned for Arizona and New Mexico (1916–1978, green line) used to train the statistical model, and the regional fire-scar index of fire occurrence (1700–1900, red line). Spearman's rank correlation between the observed and statistical reconstruction is 0.49 for the 1916–1978 training period and 0.71 for 1916–1962, prior to the beginning of a four-fold increase in area protected from wildfire. The rank correlation between the statistical reconstruction and the fire-scar reconstruction (1700–1900) is 0.61.

was synchronous with the Washington and Oregon time series, and during other decades it was synchronous with the southwest time series. This is consistent with *Dettinger et al.* [1998] finding that the pivot point of the wet/dry dipole tends to shift south or north on decadal time scales. Fire activity for California may be entrained with the northwest when the pivot point is located to the south and with the southwest when it is shifted to the north.

Reconstructed area burned for Arizona, Nevada, Utah, Colorado, and Wyoming was greatest during La Niña years enhanced by a cool (negative) PDO. Unlike the northwest, where persistent dry conditions are associated with reconstructed area burned, the southwest and Mountain states tend to experience their most extreme fire years after a wet-dry sequence (Figure 2). With respect to the ENSO cycle, this manifests itself as the largest fire years occurring in association with an El Niño-La Niña sequence, often following a major shift from positive to negative PDO (Figure 3b).

These fire-scar and statistical reconstructions for the southwest are valuable as indices of western climate and wildfire variability on annual to decadal scales. The 20th-century wildfire history was heavily influenced by

human intervention. Nevertheless, our statistical reconstructions of southwestern wildfire area burned—calibrated on modern fire occurrence and climatic data—closely matched the tree-ring reconstructed time series of regional fire activity over the past 300 years. This cross-validation of paleo and modern fire records supports the inference that the paleo climate-fire associations are accurately reflecting relationships that have persisted into the 20th century. Therefore, paleo-fire reconstructions, such as those described here, are likely to provide insights on interannual to decadal-scale climate-fire associations that may be useful in the modern era, including the development of potential forecasting tools.

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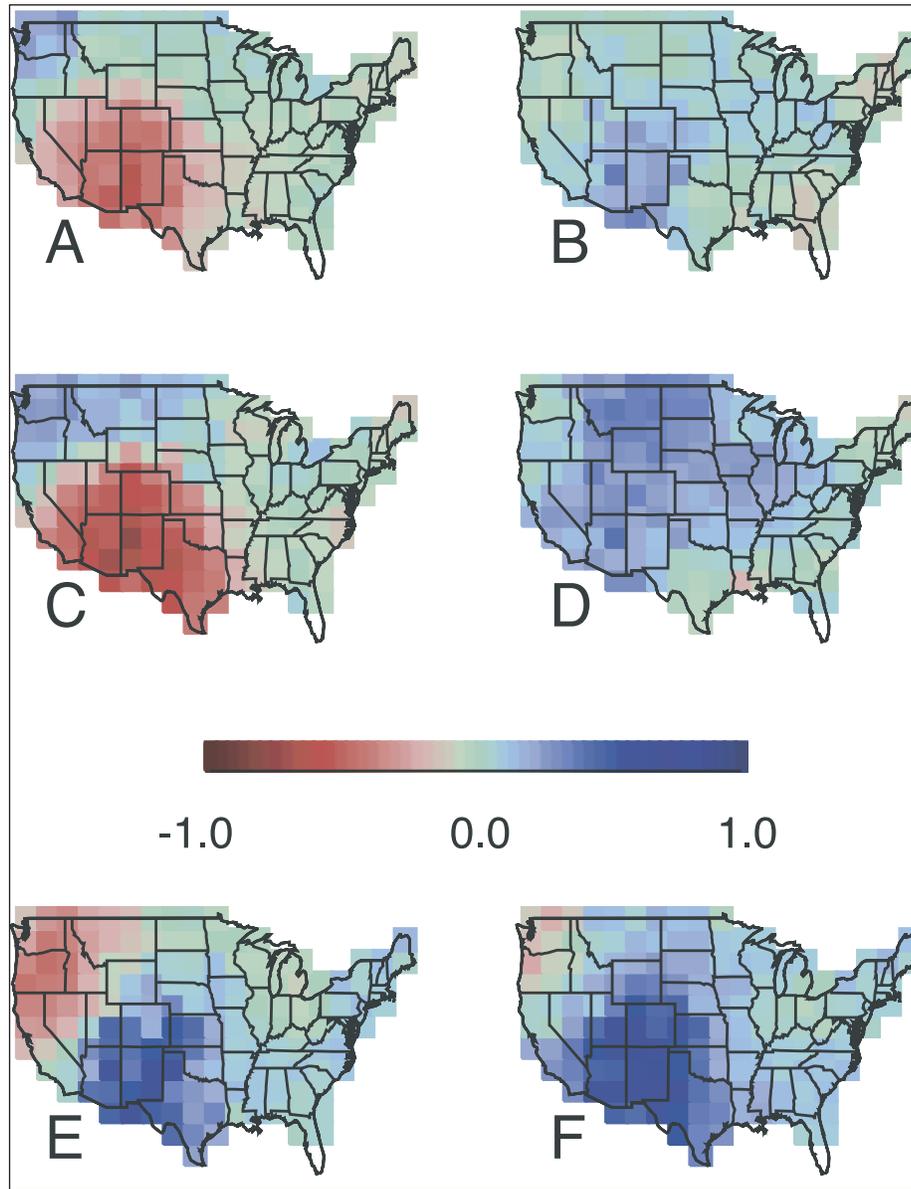


Fig. 2. Shown here are Spearman's rank correlations for the fire scar-derived reconstruction (FSR) of southwest wildfire area burned (1701–1900) and (A) Summer Palmer Drought Severity Index (PDSI), and (B) preceding summer PDSI. Spearman's rank correlations for the SR of southwest wildfire area burned (1701–1978) and (C) summer PDSI, and (D) preceding summer PDSI. Spearman's rank correlations for statistical reconstruction of northwest wildfire area burned (1701–1978) and (E) summer PDSI, and (F) preceding summer PDSI.

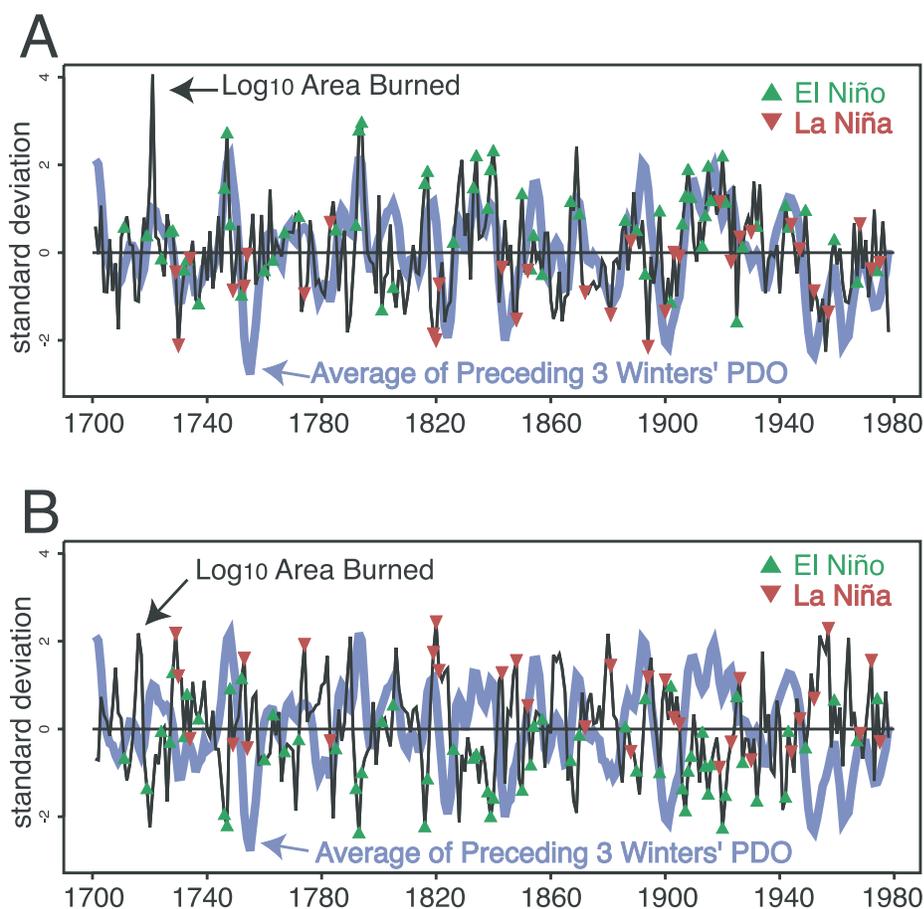


Fig. 3. (A) The reconstructed area burned in California, Oregon, and Washington tends to be higher in El Niño years during a warm Pacific Decadal Oscillation (PDO) and lower in La Niña years during a cool PDO, often after a series of El Niños; (B) in Arizona, Nevada, Utah, Colorado, and Wyoming, higher area burned is associated with La Niñas during a cool PDO, often following El Niños and major shifts from positive to negative PDO. ENSO is from Cook's [2000] Niño 3 index reconstruction.

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