Forest Ecology and Management 325 (2014) 49–59

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Climate and land-use effects on wildfire in northern Mexico, 1650–2010

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ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form 26 March 2014
Accepted 27 March 2014
Available online 23 April 2014

Keywords:
Climate
Fire history
Fuels
Interannual climate
Mexico
Palmer Drought Severity Index (PDSI)

ABSTRACT

Characterizing climate controls on fire regimes, and disentangling the effects of human relative to climate influences, has been difficult in forests of the western U.S. due to the nearly ubiquitous legacy of fire exclusion that began in the middle to late 19th century. However, the Sierra San Luis of northern Mexico, just across the border from Arizona and New Mexico, offers an opportunity to examine the influence of climate and land-use on fire history largely without the effects of modern fire exclusion. Pine forests in portions of the Sierra San Luis remain ungrazed and unlogged to this day, while other portions of the Sierra were not logged until ca. 1952–1954 or grazed until the early 1930s. Historical and modern fire regimes closely reflect these differences in land-use through time. Fires were relatively frequent in all sites until 1932, but continued at high frequency only in the sites without grazing or logging. Notably, the influence of drought and antecedent conditions for fires changed over time. From 1650 to 1886 (early period), fires occurred during drought years, with little influence of climate in antecedent years. However, from 1887 to 2003 (modern period), drought in the year of fire became generally unimportant and fires instead occurred following wet years. Above-average precipitation promotes accumulation of fine fuels, which apparently has been the primary constraint on fire ignition and spread in this semi-arid ecosystem during the modern period. Percentage of scarring aligned with multi-year fluctuations in Palmer Drought Severity Index (PDSI), with higher percent scarring in wet periods ($\overline{X}$ = 19.371) and lower scarring in dry periods ($\overline{X}$ = 13.778). Native American burning was not an important driver of past fire frequency, even though the study area lies within the historical homeland of the Chiricahua Apache people. We found no change in frequency of fires when Apaches were effectively removed in 1886. Climatic controls, rather than Apache wartime and peacetime periods, more easily explain changes in frequency over time. Projected increases in climate variability in the Southwest highlight the need to understand antecedent climate conditions conducive to fire occurrence in fuel-limited systems, including comparisons of historical to current climate–fire relationships. The relict forests of the Sierra San Luis, where fires continue to burn today with only minimal human interference, provide a rare look at these relationships.

1. Introduction

Managing for resilient forests in western North America, particularly with increasingly large, frequent, and destructive wildfires, requires understanding linkages among climate, land-use, and fire occurrence. Understanding such patterns is necessary for both long-range forecasting and assessing forest responses to climate change (Morgan et al., 2001). However, modern land-use changes have been so pervasive in the last 100 years that few montane forests in western North America continue to function under historical influences of climate variations and uninterrupted fire regimes (Stephens and Fulé, 2005). Widespread landscape changes were already prevalent by the early 20th century (Leopold, 1924) following extensive overgrazing, fire suppression, timber harvest, and other impacts that accompanied intensive Euro-American settlement beginning in the middle to late 19th century. Frequent surface fires were generally eliminated by the late 1800s in most lower-elevation conifer forests of western North America, fundamentally altering stand dynamics and fire regimes (Weaver, 1951; Covington and Moore, 1994; Swetnam et al., 2001).

The U.S. Southwest has the longest and most detailed tree-ring records of climate and fire history in the world (Swetnam and Betancourt, 1998). These records have emphasized the importance of interannual moisture variability on fire occurrence in arid regions where wet years may be particularly important for stimulating fine fuel production to carry fires during a subsequent

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http://dx.doi.org/10.1016/j.foreco.2014.03.048
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drought year (Baisan and Swetnam, 1990; Vankat, 2013). The most widespread fire year in the Southwest (1748), for example, followed the greatest amplitude of interannual wet to dry switching (1747–1748) on record (Swetnam and Betancourt, 1998). This pattern of increased fire activity during periods of rapid, high amplitude switching between wet to dry years characterized most of the Southwest for several centuries leading up to the late 19th century (Swetnam and Betancourt, 1998). It is notable however, that tree-ring based fire records generally end in the middle to late 19th century, with the onset of fire exclusion, precluding comparisons of 20th century climate-fire relationships.

Interannual climate-fire relationships for the Southwest in the mid-to-late 20th century have been described using modern data on wildfire area burned each year, recognizing that the patterns are also influenced by the legacy of more than a century of fire exclusion efforts and continued fire suppression. These analyses have demonstrated strong associations with antecedent wet conditions, but reveal little or no importance of drought conditions in the year of fire (Westerling and Swetnam, 2003; Westerling et al., 2003; Crimmins and Comrie, 2004; Littell et al., 2009). These modern interpretations thus differ from historical tree-ring based climate-fire relationships, which emphasize both wet antecedent and dry fire years. Westerling and Swetnam (2003) also used 20th century wildfire area burned data to statistically reconstruct or hind-cast historical area burned during the past three centuries. Interestingly, they found greater correlation to drought (Palmer Drought Severity Index, PDSI) in their statistical reconstructions and with historical tree-ring data than for the modern documentary data used to train the models. All of this suggests caution in assuming a static climate–fire relationship through time.

The importance of Native Americans in modifying pre-Euro-American fire regimes has also been emphasized in the Southwest U.S. – Mexico borderlands region (Pyne, 1982; Swetnam et al., 2001) and elsewhere in the West (e.g., Vale, 2002; Fry and Stephens, 2006; Biondi et al., 2011). Ample debate continues on the relative importance of changes in climate relative to human activities, such as the elimination of Native American burning followed by Euro-American fire exclusion, as drivers of changing fire regimes in modern times (Anderson, 2006; Allen, 2002; Vale, 2002).

Apache wartime periods, in particular, have been proposed as a potential explanation of unusual back-to-back fire years, and overall higher fire frequency periods, unique to several U.S. – Mexico borderland mountains prior to the late 19th century (Morino, 1996; Seklecki et al., 1996; Kaib, 1998; Swetnam et al., 2001), although these events occurred in tandem with variation in climate drivers. Kaib (1998) found that for over 200 fire-related quotations in Spanish, Mexican, and American archival documents relevant to the Southwest, more than 70% were in the context of warfare with the Apache people (Swetnam and Baisan, 2003). These wartime periods include the Apache–Spanish wartime period (WTP1) 1748–1790, and Apache–Mexican/American wartime period (WTP2) 1831–1886 (Seklecki et al., 1996; Kaib, 1998) which correspond to increased fire frequency for several sites in close proximity to our study sites in the Sierra San Luis (Swetnam and Baisan, 2003). Similarly, peacetime periods were often associated with distinct treaties that helped maintain order and correspond to periods of reduced fire frequency (Kaib, 1998). The termination of frequent fires in the Southwest U.S. – Mexico borderlands also coincides with the removal of the Apaches to reservations after 1886 (Seklecki et al., 1996).

To differentiate among these various influences on historical and modern fire regimes, requires examining climate–fire relationships in conjunction with land-use changes for regions having different land-use history but similar climate, environment, and biota (Fulé et al., 2012). In parts of northern Mexico, where intensive livestock grazing did not occur until post-revolutionary land reforms in the mid-20th century and fire suppression remains generally ineffective even today, frequent surface fires continued to occur long after they were eliminated from otherwise similar forests on the U.S. side of the border (Dieterich, 1983; Baisan and Swetnam, 1995; Fulé et al., 2011, 2012). Our research is focused on one such site which includes relict forests that have had little or no grazing, logging, or other intensive modern land-use history. This area is also located in the former Chiricahua Apache territory, the international border serving important purposes in Apache raiding and warfare. The mountains of northern Mexico along the international border within and surrounding our study sites were the last refugia for Apaches decades after others were confined to reservations in the U.S. (Leopold, 1937; Goodwin and Goodwin, 2002). Geronimo and his band of Chiricahua Apaches surrendered to General Nelson Miles in 1886, effectively ending the Indian wars and prompting intensive settlement and land-use changes throughout the U.S. Southwest (Seklecki et al., 1996). However, fear of small bands of Apaches who continued to occupy the mountains of northern Mexico persisted well into the 20th century after Geronimo's surrender, and likely helped keep land-use impacts in Mexico from mirroring those on the U.S. side of the border (Leopold, 1937; Seklecki et al., 1996; Goodwin and Goodwin, 2002; Knight, 2009).

Thus, our research was able to address overlapping influences of both historical and more recent climate and land-use history on fire regimes. We had two primary objectives: (1) to understand climate–fire relationships and changes in these relationships over time, particularly for the post-1886 modern period for which there is paucity of such data; and (2) to investigate the relative influence of climate, Native American burning, and 20th-century land-use activities on fire occurrence and extent. We hypothesized: (1) that large fire years have been closely associated with interannual wet–dry variability whereas small fire years lack a clear climate signal; (2) that these relationships have remained similar throughout both the historical and modern periods; (3) that shorter fire intervals during the historical period consistently overlapped with Apache wartime periods, but not with periods of high interannual wet–dry variability, indicating a primary influence of Native American burning on fire occurrence and extent; and (4) that fire occurrence ended abruptly in those parts of our study area where grazing and logging began in the mid-20th century (similar to what happened north of the international border half a century earlier), but that fires continued to occur frequently in places where these land-use changes did not occur.

2. Methods

2.1. Study area

The Sierra San Luis in northern Mexico encompasses the highland region straddling Chihuahua and Sonora and is comprised of the larger canyons and mountain land features of the northernmost extension of the Sierra Madre Occidental. The Sierra San Luis is part of an array of mountains referred to as the Madrean Sky Island Archipelago, which is the confluence of four biogeographical regions; the Rocky Mountains, the Sierra Madre Occidental, and the Sonoran and Chihuahuan deserts. This convergence results in high biological diversity and species endemism and is part of the two richest floras of mega-Mexico – which ranks as one of the three top mega-diversity centers of the world (Rzedowski, 1991; Felger and Wilson, 1994; Van Devender et al., 2013). It is, however, the divergence in modern land-use history that creates unique opportunities to study ecological differences in Mexico. Aldo Leopold recognized this opportunity in 1937, which he pursued until his