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Local-scale and regional climate controls on historical fire regimes in the San Juan Mountains, Colorado

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ABSTRACT

In ponderosa pine and mixed conifer ecosystems of the Southwestern US, regional-scale climate tends to synchronize fire years among study sites and increase fire extent or severity within a forest. At landscape scales (1–100 km^2), fire frequency and severity may also be influenced by local-scale differences in elevation and aspect, including fire barriers in rugged terrain. This study examines local-scale and regional controls of past fire regimes in three tributary watersheds of the San Juan Mountains of southwestern Colorado. In each watershed, we sampled fire-scarred trees and tree age structure and identified fire years and cohorts of post-fire tree recruitment. Fire frequency varied by aspect, and we observed the largest differences between the north- and south-facing aspects in the two largest basins. Fire severity was also different by aspect, with low-severity fire regimes on south-facing slopes and mixed-severity fire on north-facing slopes. The majority of fire years were unique, single-basin fires, indicating a lack of synchrony of fire years among basins, which we attributed to fire barriers and rugged terrain. We conducted Superposed Epoch Analysis (SEA) on two groups of fire years, to show average climate conditions before and during fire years. The first group were unique single-basin fires ($n = 27$) and the second group included all years when synchronous fire burned in two or three basins ($n = 15$). Both groups had significantly dry Palmer Drought Severity Index (PDSI) values during the fire year ($p < 0.01$), while the second group also showed significantly wet conditions for two years prior to the fire year ($p < 0.01$). Steep topography and fire barriers likely reduced the influence of regional climatic on the frequency and timing of fires for individual basins, though fires still burned during years of regional drought. Rugged terrain also contributed to asynchronous fire years among basins and longer fire return intervals compared with other ponderosa pine and mixed conifer forests in the region.

1. Introduction

Regional climate and local-scale topography are major controls on current and historical fire regimes. Fire regimes are characterized by the seasonality, frequency, severity and extent of fire events that burn through a forest stand or hillslope. At landscape scales (1–100 km^2), differences in fire frequency and severity relate to varying fuel loads and types on different hillslopes and locations within a landscape. At much broader scales, climate exerts a regional control on fire occurrence, often synchronizing fire activity across many topographic settings and landscapes throughout a region, especially during persistent and extreme climate events (e.g., droughts or pluvials).

In steeper landscapes, fire regime differences may be more pronounced, as microclimates and vegetation patterns vary greatly within short distances. Mesic north-facing slopes often have lower fire frequency and increased fuel loads, leading to more severe fire behavior during drought years (Beaty and Taylor, 2001; Heyerdahl et al., 2001). Rugged terrain, including many fire barriers (e.g., rock outcrops, steep ridges and stream channels), further influences variability in fire regimes and fire-climate relationships. Fire barriers may exert a greater control on fire frequency compared with hillslope-scale differences in aspect or elevation (Heyerdahl et al., 2001; Swetnam et al., 2001; Iniguez et al., 2008). For example, fire frequency was significantly different between a rugged and gentle landscape in southern Arizona, while there were no differences in fire frequency among aspect classes within each landscape (Iniguez et al., 2008). Rugged terrain also limits fire spread and isolates forest stands, resulting in a possible lack of synchrony with fire events in nearby sites (Iniguez et al., 2009; Korb et al., 2013). In contrast, gentle terrain with few fire barriers (e.g., plateaus

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and broad valleys) has more homogenous forest types and fuel loads, resulting in a strong association between fire activity and regional climate (Touchan et al., 1996; Fulé et al., 2003; Brown, 2006).

Few studies have focused on the influence of topography in steep and rugged landscapes of the Southwest, where the influence of regional climate may be modified by local-scale controls (Iniguez et al., 2008, 2009; Margolis and Balmat, 2009). A better understanding of local versus regional controls on fire regimes in steep and rugged landscapes is needed for science-based forest and fire management. In the past several decades wildfires have become larger and more severe, burning uncontrollably through many landscapes and forest types of the Southwest and western US (Westerling et al., 2006; Dillon et al., 2011). Extreme drought combined with dense forest conditions and high fuel loads in lower elevation forests have created extremely large patches of high-severity fire (Williams et al., 2010; Harris and Taylor, 2015). While the proportion of high-severity fire has increased in some ecosystems over the past century, yet topography and vegetation may still influence patterns of fire severity in recent wildfires (Miller and Thode, 2007; Harris and Taylor, 2015).

In preparation for future climate changes and drought conditions, forest managers are planning restoration efforts to increase resiliency and reduce fire risk (Fulé, 2008; Stephens et al., 2013). Management plans include thinning and prescribed burning treatments, in order to reduce the severity of future fires, maintain old-growth trees and species diversity. Site-specific information on pre-settlement tree densities, forest composition, and fire return intervals can provide ecological justifications for prioritizing treatments in different portions of a landscape (Fulé et al., 1997, 2009; Reynolds et al., 2013). Steep and rugged landscapes pose a challenge for managers, because fire regime parameters can vary greatly within short distances.

Fire severity indicates the effects of fire on vegetation and soils, ranging from light charring to complete mortality and consumption of fuels (Shakesby and Doerr, 2006; Keeley et al., 2009). At the scale of a forest stand, high-severity refers to crown fire and complete tree mortality, and significant heat is transmitted to the underlying soil layers. Low-severity surface fires burn in the understory, leaving mature trees intact and charring understory fuels. Mixed-severity fire describes neighboring patches of low- and high-severity fire effects within a defined area (0.1 ha plot or a 10 ha hillslope) (Agee, 2005; Heyerdahl et al., 2012). Mixed-severity behavior was often a component of historical fire regimes in many steep and rugged landscapes, and it is important to better understand the controls on fire behavior within these landscapes (Korb and Wu, 2011).

This study evaluates the relative influence of regional climate and local-scale topographic controls on fire regimes in the San Juan Mountains of southwestern Colorado. We studied two types of local-scale topography: the influence of aspect on fire frequency and severity, and the influence of landscape-scale terrain (fire barriers) on fire frequency. Steep topography and complex vegetation patterns contribute to a high amount of variability in historical fire regimes in the region (Grissino-Mayer et al., 2004; Fulé et al., 2009; Korb et al., 2013), yet landscape-level controls on fire frequency and severity are not well documented. We then scaled up to understand the influence of regional climate on fire frequency and synchrony among watersheds.

We applied a combination of dendroecological methods (fire-scarred trees and age structure) to characterize the historical fire regimes prior to Euro-American settlement (~1880) of three tributary watersheds (Margolis and Balmat, 2009; Heyerdahl et al., 2012; O'Connor et al., 2014). This characterization was carried out at three scales: (1) At the scale of hillslopes (i.e., forest stands), we evaluated the influence of aspect on fire frequency and severity. (2) At watershed scales, we investigated the influence of rugged terrain with fire barriers on fire frequency by comparing our results with other sites in the region (Grissino-Mayer et al., 2004; Brown and Wu, 2005; Fulé et al., 2009; Korb et al., 2013). Finally (3), we evaluated regional climate controls on fire occurrence, by analyzing fire-climate relationships and fire synchrony among the three watersheds. This study is an important component of a larger effort to document millennial-length fire history derived from alluvial-sediment records in the region (Bigio, 2013).

2. Methods

2.1. Study area

The study area is located in the western San Juan Mountains, where tributary watersheds drain into broad, glacially-carved valleys (Fig. 1, Table 1). The two largest watersheds, Haflin Creek (420 ha) and Stephen's Creek (1560 ha) are located on the western side of the study area. These watersheds have an east–west trending stream channel and riparian vegetation in the valley bottom. The south-facing slopes are dominated by ponderosa pine-oak stands, which include small percentages of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), Rocky Mountain juniper (*Juniperus scopulorum*) and piñon (*Pinus edulis*). The north-facing slopes have an even mix of Douglas-fir and white fir with small percentages of ponderosa pine, limber pine (*Pinus flexilis*) and quaking aspen (*Populus tremuloides*). The hillslopes are dissected by sharp ridges, and fire barriers include tallus slopes, bedrock outcrops, and the stream channel in the valley bottom. The third and smallest basin was named 'Marina' (70 ha), and is located about 25 km to the east, near the Vallecito Reservoir. The Marina basin has a homogenous cover of warm-dry mixed conifer with patches of aspen regeneration in the center of the basin. The Marina basin has east and west-facing slopes with few barriers to fire spread. The mean annual temperature for the region is 8.3 °C, and the mean annual precipitation is 490 mm. The lowest monthly mean rainfall occurs in June (15 mm) and the highest monthly mean is August (65 mm) (www.wrcc.dri.edu). We calculated these climate averages from measurements taken at a USGS coop station (#052432) in Durango, Colorado.

In the San Juan Mountains, historical surface fire frequencies (prior to 1880) in the pine-oak forest type were 7–14 years with longer fire return intervals (20–30 years) in the warm-dry mixed conifer type (Grissino-Mayer et al., 2004; Brown and Wu, 2005; Fulé et al., 2009; Bigio et al., 2010; Korb and Wu, 2011). In mesic stands of cool-moist mixed conifer, there were longer return intervals for surface fires (20–40 years) with patches of high-severity fire in some sites (Wu, 1999; Korb and Wu, 2011). The natural fire regime of frequent surface fires was disrupted around 1880 when Euro-Americans settled in the region (Grissino-Mayer et al., 2004; Korb and Wu, 2011). Cattlemen and sheep herders brought livestock for grazing, which reduced grass cover and fine fuels, and prevented surface fires from spreading in the understory. Over the past century, tree densities in pine-oak and mixed-conifer forests have increased significantly and species composition is now dominated by small diameter shade-tolerant firs in the understory (Fulé et al., 2009; Korb and Wu, 2011; Korb et al., 2012). Large fires were absent from the region throughout the 20th century, because active fire suppression was effective at putting out natural and human-caused fires. During the severe drought year of 2002, however, the Missionary Ridge Fire burned in the western San Juans, covering more than 30,000 hectares with a significant proportion of moderate and high-severity fire. Our study sites are within this burned area, though the results are intended to provide site-specific information about fire regimes in similar forest types