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Variability of warm/dry mixed conifer forests in southwestern Colorado, USA: Implications for ecological restoration

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ABSTRACT

There is a need to quantitatively describe forest types and their associated natural fire regimes in the western US to understand their variability and to develop strategies to restore fire dependent landscapes to reduce ecological problems that might ensue from forest structure and fire regime generalizations. We established three study sites in warm/dry mixed conifer across a west–east transect in southwestern Colorado to determine variability in the historical fire regime and fire–climate relationships and to quantify how diverse warm/dry mixed conifer forest composition and structure are along the same west–east transect. At each study site we collected cross-sections from dead fire-scarred trees to reconstruct fire history and established study plots to characterize forest structure. The three warm/dry mixed conifer sites exhibited different fire histories. One site was characterized by numerous smaller fires as well as larger fires that appeared to burn most of the study site with the other two study sites characterized by relatively infrequent, large fire events. There were more unique fire years at each site than synchronous fire years shared by any sites. Current forest stand structure, after extended fire exclusion and past logging across the three sites, also varied with a reverse-*J* distribution indicating strong dominance by small trees for two of the study sites and a truncated age distribution at the other site. Our research illustrates that historical fire regime variability exists within the same vegetation type in a relatively small, ~50 km, geographic locality emphasizing the role that other topographic variables play in determining fire regimes and forest structure. Our findings demonstrate the need to develop site-specific reference conditions and for managers to exercise caution when extrapolating fire regimes and forest structure from one geographic locality to another given a projected warmer climate making conditions more favorable to frequent, large wildfires.

1. Introduction

Mixed conifer is one of the most complex forest types in the western United States. Mixed conifer forests in the American Southwest (Arizona, New Mexico, and southern Colorado and Utah) cover approximately 1,000,000 ha (Dieterich, 1983) between the generally lower elevation ponderosa pine (*Pinus ponderosa* P. & C. Lawson) and the higher elevation Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.] forest types. Southwestern mixed conifer forests have been classified in two categories, warm/dry and cool/moist, which denote the ends of a xeric–mesic continuum (Romme et al., 2009). Warm/dry mixed conifer is generally located at the lower elevation of the continuum on predominately southerly aspects and is dominated by fire resistant ponderosa pine (*P. ponderosa*) and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] but also includes species adapted to mesic conditions such as white fir [*Abies concolor* (Gordon and Glendinning) Hoopes.] and aspen (*Populus tremuloides* Michx.) and sometimes southwestern white pine (*Pinus strobiformis* Engelm.). Surface fires burned with sub- to multi-decadal frequency prior to Euro-American settlement (late 1800s) in warm/dry mixed conifer (Grissino-Mayer et al., 2004a; Fulé et al., 2009). Cool/moist mixed conifer is usually located at the higher elevation of the continuum on predominately northerly aspects and is dominated by mesic-adapted conifers and aspen. Fires in cool/moist mixed conifer forests burned with a sub-decadal to century frequency where surface and crown fire behavior could occur during the same fire event (Margolis and Balmat, 2009; Romme et al., 2009).

Fire suppression along with grazing in the 20th century, which disrupted fine fuel continuity, has increased stand density in warm/dry mixed conifer. Species composition shifted from

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shade-intolerant ponderosa pine to shade-tolerant species such as white fir and Douglas-fir (Mast and Wolf, 2004; Brown and Wu, 2005; Fulé et al., 2009). There has also been increased continuity of vertical and horizontal fuels (Cocke et al., 2005; Margolis and Balmat, 2009). As a result of these changes, a current focus for scientists and land managers is to restore forest stand characteristics that were historically adapted to frequent surface fire but are now at risk of crown fire (Fulé et al., 2003; Heinlein et al., 2005; Falk, 2006). In adjacent pure ponderosa pine forests there is an abundance of research describing the range of variability in stand structure and historical fire regimes prior to Euro-American settlement in the American Southwest (Covington et al., 1997; Fulé et al., 1997; Swetnam and Baisan, 2003; Grissino-Mayer et al., 2004a; Moore et al., 2004; Brown and Wu, 2005). A diverse range of scientifically viable restoration approaches has been proposed to reflect the heterogeneous spatial and temporal forest patterns and fire regimes at local and landscape scales in ponderosa pine in the Intermountain West (Covington et al., 1997; Allen et al., 2002; Iniguez et al., 2008).

Much less information exists about the range of site-specific variability of warm/dry mixed conifer forest composition, structure and fire regimes prior to Euro-American settlement in the American Southwest, particularly in southwest Colorado (Grissino-Mayer et al., 2004a; Korb et al., 2007; Fulé et al., 2009). Given the extensive coverage of warm/dry mixed conifer in this region, these previous studies may not provide an accurate description of variability in warm/dry mixed conifer making additional research valuable. Grissino-Mayer and others (2004a) reconstructed fire regimes in ponderosa pine forests across an elevation gradient in southwest Colorado and found mean fire intervals lengthened with increased elevation with low elevation ponderosa pine sites having 6–10 year mean fire return intervals (MFIs) and higher elevation warm/dry mixed conifer sites having longer MFIs of 18–20 years. Beginning in 2002, we initiated a study within the same region to determine reference conditions of historical fire regime and fire–climate relationships, forest composition, and forest structure for warm/dry mixed conifer at Lower Middle Mountain in southwest Colorado and found mean fire intervals of 24–36 years prior to 1870 (Fulé et al., 2009). We quantified how these variables changed since 1870 and designed and tested three restoration alternatives (thin/burn, burn only, and untreated controls) on four replicated blocks, each approximately 16 ha (Korb et al., 2007; Korb and Fulé, 2008; Fulé et al., 2009). The present study expands upon the Lower Middle Mountain experiment to determine (a) how representative the restoration treatment findings are for the surrounding warm/dry mixed conifer on the San Juan National Forest, and (b) if site-specific information to guide the development of ecological restoration prescription treatments by land managers is required for warm/dry mixed conifer in southwest Colorado.

There is a need to quantitatively describe forest types and their associated natural fire regimes in the western US to understand their variability and to develop strategies to restore fire dependent landscapes to reduce ecological problems that might ensue from forest structure and fire regime generalizations and to evaluate the impacts of recent large wildfires on forest structure (Schoennagel et al., 2004; Beaty and Taylor, 2008). This is especially important because warmer temperatures (ICPP, 2007) have increased fire season length thus amplifying the number of large fires in the western US (Westerling et al., 2006; Littell et al., 2009). To address this need we established a west–east transect of three study sites, including Lower Middle Mountain, at similar latitude (37°N) and elevation range (~2350 to 2750 m) to quantify warm/dry mixed conifer forest composition, structure and fire regime variability. We hypothesized that fire–climate relationships would be similar with climate synchronizing fire occurrence across the three study sites and there would be little variability in forest composition, structure and fire regime among our study sites because of relatively similar latitude and elevation. The main purpose of this paper is to address the following questions: (1) how variable was the historical fire regime and fire–climate relationships in warm/dry mixed conifer across a west-east transect at relatively similar latitude and elevation over ~50 km on the San Juan National Forest? and (2) how diverse is warm/dry mixed conifer forest composition and structure along the same west–east transect?

2. Methods

2.1. Study area

The study area is located in the San Juan Mountains, San Juan National Forest, in southwestern Colorado. Our three study sites, Grassy Mountain, Lower Middle Mountain, and Jackson Mountain represent a west–east transect of warm/dry mixed conifer stands on the San Juan National Forest at similar latitude (37°N) and elevation range (~2350 to 2750 m) covering a distance of ~50 km (Fig. 1). Warm/dry mixed conifer forests occupy 50,525 ha of the San Juan National Forest. Dominant tree species include ponderosa pine, Douglas-fir, white fir and aspen at all three sites. The midstory and understory for all sites were dominated primarily by Douglas-fir and white fir and a variety of shrubs including Gambel oak (*Quercus gambelii*), snowberry (*Symphoricarpus rotundifolius*), and serviceberry (*Amelanchier alnifolia*). Past disturbance history for all sites include sheep and cattle grazing and timber harvesting since the late 1800s with fire suppression as the management policy since the early twentieth century. The Grassy Mountain and Lower Middle Mountain study sites are generally south-facing with 16–20% average slopes. Jackson Mountain is generally east-facing with a 19% slope average. Daily temperatures range from an average maximum of 27.1 °C in July to a minimum of −14.5 °C in January at Grassy Mountain. The greatest amounts of precipitation occur in July and August due to summer thunderstorm activity with precipitation from November to March dominated by snowfall with an average annual snow total of 293 cm (Western Regional Climate Center, Vallecito Dam, 1917–2010, www.wrcc.dri.edu). The Lower Middle and Jackson Mountain study sites have average daily temperatures range from a maximum of 25.7 °C in July to a minimum of −17 °C in January with similar precipitation patterns at Grassy Mountain and an average annual snowfall total of 326 cm (Western Regional Climate Center, Pagosa Springs, 1906–1998, www.wrcc.dri.edu).

2.2. Field methods

This study utilized fire history legacy data collected by the Forest Service at three different mixed conifer sites. For each collection, fire scarred samples were collected from dead wood (logs, stumps, and snags) specimens. No live trees were sampled due to local Forest policy. The lack of live samples was not problematic as dead wood samples were able to provide coverage into the 20th century. The Jackson Mountain fire history was collected in 1997 (Wu, 1999) adjacent to the west end of the forest structure plots. The Jackson Mountain search area was approximately 190 ha. No significant natural barriers exist between the fire history collection area and forest structure plots; therefore, we felt we could reasonably apply the fire history to the forest structure plots established in this study. The Lower Middle Mountain and Grassy Mountain fire history collections were gathered by the Forest Service in 1999 and 2006 respectively, for environmental analyses in association with planned fuels projects. Fire history collection areas and forest structure plots had complete overlap