Forest Ecology and Management 269 (2012) 10–18

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

# Forest restoration in a surface fire-dependent ecosystem: An example from a mixed conifer forest, southwestern Colorado, USA

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ARTICLE INFO

*Article history:*
Received 10 November 2011
Received in revised form 3 January 2012
Accepted 4 January 2012
Available online 2 February 2012

*Keywords:*
Adaptive management
Aspen
Ecological restoration
Ponderosa pine
San Juan Mountains
White fir

ABSTRACT

Over a century of fire suppression in warm/dry mixed conifer forests of southwestern Colorado, USA has resulted in changes that have disrupted feedback interactions between vegetation composition and structure and the accompanying natural fire regime. The ecosystem is now more susceptible to high intensity crown fires that were previously rare or absent in this forest type, which can lead to novel ecosystems. We established four replicated blocks of (1) thin/burn, (2) burn alone and (3) control treatments, each approximately 16-ha, to quantify the effects of restoration treatments on forest structure. We sampled in 2003 (pre-treatment) and in 2009 (post-treatment). There were no significant changes in the control and burn alone treatments for tree density, basal area, canopy cover and tree regeneration between pre- and post-treatment. Significant changes in the thin/burn treatments included: tree density declining 82% (582.7 trees $ha^{-1}$), principally white fir and Douglas-fir; tree canopy cover decreasing 36%; basal area declining 49% (12.5 $m^2 ha^{-1}$), primarily from white fir; aspen tree regeneration increasing by 362% (582.7 trees $ha^{-1}$), and white fir regeneration decreasing by 94% (249.1 trees $ha^{-1}$). Overstory trees that died tended to be younger, shorter, and/or smaller in diameter. Multivariate analysis of tree basal area by species in the thin/burn treatments in 2009 showed a strong directional shift away from 2003 pre-treatment data towards the reconstructed historical (1870) forest structure. Burn alone treatments were distinct from controls after treatment in 2009 but did not resemble reconstructed 1870 forest structure. Thin/burn treatments moved warm/dry mixed conifer forests in southwestern Colorado rapidly along the trajectory toward historical reference conditions by altering forest composition and structure. Burn alone treatments were less effective but also less costly. Forest restoration will make forests more resilient to stand-replacing fires and subsequent transitions to novel ecosystems under a warmer, drier climate.


## 1. Introduction

There is abundant evidence that 20th century fire suppression in pure ponderosa pine and low elevation mixed conifer forests in the southwestern United States has resulted in changes to forest composition, structure and ecological processes (Brown et al., 2001; Grissino-Mayer et al., 2004; Brown and Wu, 2005; Heinlein et al., 2005; Fulé et al., 2009; Evans et al., 2011). Paleoecological studies in the Southwest (Toney and Anderson, 2006; Allen et al., 2008; Bigio et al., 2010) and other regions with similar vegetation types (Whitlock et al., 2003) have extended the long-term historical fire record to the millennial scale providing further evidence that the absence of fire in the 20th century represents an anomaly in forests where the regular occurrence of low intensity surface burning was previously common.

Mixed conifer forests in the San Juan Mountains of Southwest Colorado occur along a continuum from warm/dry to cool/moist sites (Romme et al., 2009). Moisture and temperature are the primary drivers that influence species composition and fire regimes for these two mixed conifer forest types. Warm/dry mixed conifer is dominated by fire-resistant ponderosa pine (*Pinus ponderosa* var. *scopulorum* P. & C. Lawson) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beinssn.) Franco) but also includes species adapted to mesic conditions such as white fir (*Abies concolor* (Gordon & Glendinning) Hoopes.) and aspen (*Populus tremuloides* Michx.). Warm/dry mixed conifer is located adjacent to, but generally higher in elevation than, pure ponderosa pine stands. Surface fires were frequent before 1868, burning with multi- to sub-decadal frequency in the warm/dry mixed conifer (Grissino-Mayer et al., 2004; Fulé et al., 2009). Cool/moist mixed conifer is dominated by white fir and Douglas-fir, as well as aspen and blue spruce (*Picea pungens* Parry ex Engelm.). Historically, fires in cool/moist mixed conifer forests burned at sub-decadal to century frequency with a mixed-severity fire regime, where surface and crown fire

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doi:10.1016/j.foreco.2012.01.002

behavior could occur during the same fire event (Margolis and Balmat, 2009; Romme et al., 2009). Feedback cycles between vegetation composition and structure and the accompanying disturbance regime (e.g., fire frequency and intensity) are well documented (Miller and Urban, 2000; Beaty and Taylor, 2001; Martin and Kirkman, 2009). Over a century of fire suppression in warm/dry mixed conifer forests has shifted species composition toward more mesic, shade tolerant species such as white fir and Douglas-fir, increased tree density, and increased surface and aerial fuels (Cocke et al., 2005; Crouse, 2005; Fulé et al., 2009), making them more susceptible to stand-replacing fires which can lead to novel ecosystems (Seastedt et al., 2008). For example, in 2011, warmer than average temperatures and drought in the southwestern United States created conditions favorable for wildfire. The Wallow Fire became the largest wildfire in Arizona recorded history (217720 ha) and the Las Conchas Fire became the largest wildfire in New Mexico recorded history (63371 ha). In contrast to historical surface fires, these recent fires burned as both mixed severity and stand-replacing crown fires in ponderosa pine and low-elevation mixed conifer stands. Future stand regeneration in the severely burned areas may represent novel ecosystems on new successional trajectories away from historical stand characteristic. For example, Savage and Mast Nystrom (2005) found conversion of ponderosa pine to non-forested grass or shrub communities in stands that experienced severe crown fires in the southwestern United States.

Novel ecosystems and rapid 21st century environmental change challenge the use of ecological history (reference conditions) as a tool to characterize targets for ecological restoration (Choi, 2007; Jackson and Hobbs, 2009). We argue, however, that under a warmer and drier climate, the use of site-specific reference conditions is a scientifically sound target for forest stand conditions in surface fire-dependent forest ecosystems because they increase resiliency to uncharacteristic fire behavior, increasing the likelihood of maintenance of ecological goods and services these ecosystems provide (Jackson and Hobbs, 2009). Reference conditions are not a snapshot in time but rather represent a range of historical variability and evolutionary adaptations developed over thousands of years (Fulé, 2008). Specifically, ponderosa pine evolutionary adaptations to drought, deep taproots and self-thinning lower branches, and surface fire, thick bark and protected buds, provides a broader definition of reference conditions to include a long-term functional view (Fulé, 2008). As a result, restoring pine dominated surface fire-dependent forest ecosystems to reference conditions can reduce the potential loss of these ecosystems under a warmer and drier climate. One approach to identifying reference conditions is to compare contemporary and pre-European settlement forest conditions and fire regimes (Fulé et al., 1997; Stephenson, 1999) to guide ecological restoration (Brown et al., 2008). Fulé and others (2009) reconstructed past forest conditions ca. 1870 and the historical fire regime for our study site using dendrochronology. In 2002, we initiated a controlled experiment in warm/dry mixed conifer forest of the San Juan Mountains, Colorado, to assess forest change and test restoration alternatives on the overstory and the herbaceous understory (Korb et al., 2007). We established four replicated blocks, each approximately 16 ha, of three treatments: (1) thin/burn, (2) burn alone, and (3) control. The burn alone treatment was included to determine if restoration goals could be achieved without tree thinning. All treatments were tested against site specific dendrochronological reconstructed reference conditions (Fulé et al., 2009). Site reference conditions at our mixed conifer site illustrated total basal area was on average 11 $m^2\,ha^{-1}$ with ponderosa pine representing nearly two-thirds of the basal area and total tree density was on average 142 trees $ha^{-1}$ in 1870.

We have two objectives for this paper: (1) quantify post-treatment differences in forest composition and structure among treatments and compare post-treatment stands with site specific reference conditions; and, (2) quantify changes in untreated controls over a six year period (2003–2009) to assess the stability of warm-dry mixed conifer stands.

## 2. Methods

### 2.1. Study area

The study area is located in the San Juan Mountains, in southwest Colorado (N 37.296, W 107.228) on the San Juan National Forest. The site consists of 15–30% slopes on south-facing aspects. Elevations range from 2438 to 2743 m. The dominant soil type is Dutton loam, a silty clay loam (USDA Forest Service, 2004). Average daily temperatures range from a maximum of 25.7 °C in July to a minimum of −17 °C in January. Average annual precipitation is 55.4 cm, with the greatest amounts occurring in July and August. Precipitation from November to March is dominated by snowfall, with an average annual total of 326 cm (Western Regional Climate Center, Pagosa Springs, 1906–1998, <http://www.wrcc.dri.edu>). Forest vegetation includes ponderosa pine, Douglas-fir, white fir, and aspen. The midstory and understory are dominated primarily by white fir and Douglas-fir, with a variety of shrubs including Gambel oak (*Quercus gambelii*), snowberry (*Symphoricarpus rotundifolius*), and serviceberry (*Amelanchier alnifolia*). Past disturbance history includes sheep grazing beginning in the late 1800s and cattle grazing since the early 1900s. Fire suppression has been management policy since the early twentieth century. A single timber harvest occurred between 1990 and 1993, using a selective system that removed 51% ponderosa pine, 33% white fir, and 16% Douglas-fir evenly across the study area (USDA Forest Service, 2004).

### 2.2. Experimental design

We established four replicate blocks of three randomly assigned treatment units, each approximately 16 ha in size (Fig. 1). Existing roads were used to delineate the blocks because the roads served as safe firelines, causing the blocks to be irregular in shape. The three treatments were (1) thin/burn, (2) burn alone, and (3) an untreated control. We did not include a thin alone treatment because the goal of forest restoration is to restore ecological function, which is not possible without a burn treatment in ecosystems that historically were dominated by surface fires. The thinning prescription retained all living trees that established in 1870 or earlier as identified by size, bark color, and canopy architecture (Fulé et al., 2009). If remnants (e.g., snags, logs, and stumps) were present in 1870 but were no longer alive, we kept live post-settlement trees as a substitute for those remnants. An average of two younger trees of the same species, within 20 m of the remnant if possible, was retained for each dead remnant encountered (see Fulé et al., 2001 for a detailed description of the thinning prescription). Because of past cutting of ponderosa pine and 20th century establishment of non-pine species (Fulé et al., 2009), there was a relatively high number of pine remnants and a relatively low density of potential pine replacements. Therefore, the trees designated for thinning were mostly white fir and some Douglas-fir. Aspen are highly susceptible to fire so none were thinned, because we assumed that many would be killed by burning. Crews thinned the thin/burn units with chain saws during the summer and fall 2004 with a cost of $926/hectare. Wood was not removed due to restrictions on road access, so logs and limbs were lopped and scattered. Old-growth trees were not raked to remove fuels around tree boles. Fire crews did prescribed burning in fall 2007 (Blocks 1 and 2) and fall 2008 (Blocks 3 and 4) using strip headfires with a cost of $370/hectare. Fire crews were unable to burn all units during the same time period because of regulations on smoke output.