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Changes in forest structure since 1860 in ponderosa pine dominated forests in the Colorado and Wyoming Front Range, USA

Mike A. Battaglia[a,*], Benjamin Gannon[b], Peter M. Brown[c], Paula J. Fornwalt[a], Antony S. Cheng[b], Laurie S. Huckaby[a]

[a] USDA Forest Service, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, CO 80526, United States
[b] Colorado Forest Restoration Institute, Colorado State University, Fort Collins, CO 80523, United States
[c] Rocky Mountain Tree-Ring Research, 2901 Moore Lane, Fort Collins, CO 80526, United States

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ABSTRACT

Management practices since the late 19th century, including fire exclusion and harvesting, have altered the structure of ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) dominated forests across the western United States. These structural changes have the potential to contribute to uncharacteristic wildfire behavior and effects. Locally-relevant information on historical forest structure can improve efforts to restore more fire adapted conditions. We used a dendrochronological approach to reconstruct pre-settlement era (ca. 1860) structure for 170, 0.5-ha plots in montane ponderosa pine-dominated forests of the Colorado and Wyoming Front Range. Historical reconstructions were quantitatively compared with current conditions to highlight key departures. In lower montane forests, historical basal area averaged 6.3 m^2 ha^{-1}, density averaged 97 trees ha^{-1}, and quadratic mean diameter (QMD) averaged 26.5 cm, while current basal area averaged 17.6 m^2 ha^{-1}, density averaged 438 trees ha^{-1}, and QMD averaged 24.3 cm. Similar trends were observed in upper montane forests, where historical basal area averaged 9.5 m^2 ha^{-1}, historical density averaged 163 trees ha^{-1}, and historical QMD averaged 29.4 cm, while current basal area averaged 17.2 m^2 ha^{-1}, current density averaged 389 trees ha^{-1}, and current QMD averaged 25.2 cm. Most differences between historical and current conditions were significant. Across the montane zone, ponderosa pine dominated historical (88% and 83% of basal area in the lower and upper montane, respectively) and current forests (80% and 74% of basal area, respectively), but pine dominance decreased primarily due to infilling of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Much of this establishment occurred around the period of settlement (1861–1920) and continued throughout the 20th century. Results from this study help inform ecological restoration efforts that seek to integrate elements of historical forest structure and aim to increase the resilience of Front Range ponderosa pine forests to future wildfires and a warmer climate.

1. Introduction

Historically, relatively frequent, low- to mixed-severity fire shaped the structure of ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) dominated forests across the western United States (U.S.), creating and maintaining heterogeneous but generally open conditions (Hessburg et al., 2000; Larson and Churchill, 2012; Reynolds et al., 2013; Bigelow et al., 2017; Addington et al., 2018). Since the mid- to late-19th century, the structure of these forests has been increasingly affected by human land and fire management practices. Logging, livestock grazing, and mining activities during the Euro-American settlement era, combined with post-settlement fire suppression, have increased stand density and homogeneity across much of the ponderosa pine range (Covington and Moore, 1994; Belsky and Blumenthal, 1997; Hessburg and Agee, 2003; Hessburg et al., 2005). Fire behavior simulation studies from across the western U.S. have demonstrated that this change in forest structure has led to increased potential for crown fire initiation and spread (Fulé et al., 2002; Brown et al., 2008; Van de Water and North, 2011; Taylor et al., 2014). These dense structural conditions are more susceptible to uncharacteristically large, high-severity wildfires that often produce undesirable ecological and social outcomes (Paveglio et al., 2015). For example, recent wildfires have created large patches of complete tree mortality (Waltz et al., 2014; Steel et al., 2015; Collins et al., 2017), resulting in sparse post-fire tree regeneration (Keyser et al., 2008; Collins and Roller, 2013; Chambers et al., 2016; Rother and Veblen, 2016; Owen et al., 2017), the loss of

* Corresponding author.
E-mail address: mbattaglia@fs.fed.us (M.A. Battaglia).

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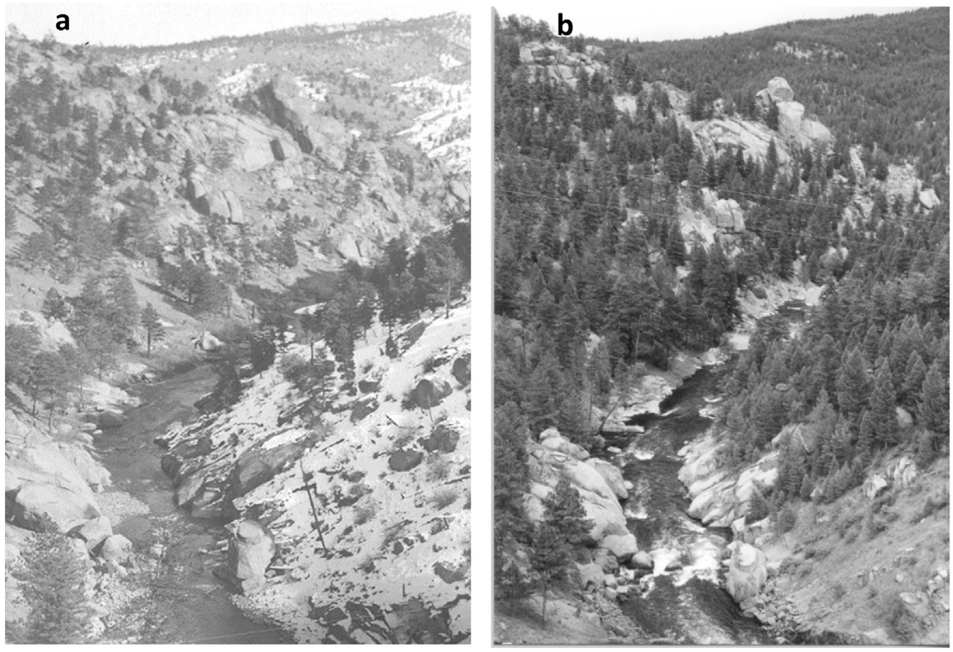

Fig. 1. Paired photographs demonstrating forest conditions along the South Platte River on the Pike National Forest, Colorado in 1903 (a) and 1999 (b). The 1903 photograph is from the Denver Water Department archives. The 1999 photograph is credited to Laurie S. Huckaby, USFS.

already-rare old trees (Spies et al., 2006; Kolb et al., 2007; Fornwalt et al., 2016), alterations to threatened species habitat (Kotliar et al., 2003; Stephens et al., 2016), and increased erosion and sedimentation of water supply systems (Moody and Martin, 2001; Rhoades et al., 2011; Smith et al., 2011). Human development in ponderosa pine dominated forests further exacerbates the situation as policymakers and land managers face pressure to continue suppressing all wildfires – even ecologically appropriate ones – within and surrounding developed areas – to protect life, property, and highly-valued assets (Theobold and Romme, 2007).

In response to recent large and severe wildfires, national-level policies – including the 2000 National Fire Plan, the 2003 Healthy Forests Restoration Act, and the 2009 Forest Landscape Restoration Act that established the Collaborative Forest Landscape Restoration Program (CFLRP) – have directed federal land management agencies to fund programs that restore resiliency and sustainability to ponderosa pine dominated and other frequent-fire forests (Schultz et al., 2012). It is widely held that the scientific rationale and guidance for restoration, through these policies, should be grounded in an understanding of local historical range of variability (HRV) of forest structure and fire regimes (Morgan et al., 1994; Landres et al., 1999; Keane et al., 2009). Much of our knowledge of historical ponderosa pine forest structure in the southern Rocky Mountains comes from the southwestern U.S. where open, low density, uneven-aged forests of medium- to large-sized trees were associated with frequent (1–12 years), low-severity fire regimes (Fulé et al., 1997; Allen et al., 2002, Reynolds et al., 2013). However, studies in other regions suggest fire regimes for some ponderosa pine dominated forests were characterized by a wider range of fire frequency and severity (Brown et al., 1999; Baker et al., 2007, Sherriff and Veblen, 2007), which contributed to a more heterogeneous forest structure than described for the southwest (Perry et al., 2011; Addington et al., 2018). Furthermore, differences in biophysical characteristics such as elevation, topography, geology, and climate, can drive local variation in historical forest structures and fire regimes (Larson and Churchill, 2012; Lydersen et al., 2013; Churchill et al., 2013; Johnston et al., 2016; Johnston, 2017; Rodman et al., 2017). Thus, a thorough understanding of local historical variation is critical to forming ecologically-appropriate restoration goals (Brown et al., 2004; Schoennagel et al., 2004).

In ponderosa pine-dominated forests of the Colorado and Wyoming Front Range, elevation has been identified as a dominant control on the historical fire regime (Sherriff and Veblen, 2007; Sherriff et al., 2014). Historical mean fire return intervals ranged from ~10–60 years (Veblen et al., 2000; Brown and Shepperd, 2001; Hunter et al., 2007; Sherriff and Veblen, 2007; Brown et al., 2015) with lower elevations experiencing more frequent fires. In lower montane forests, where ponderosa pine was the major component and often the only overstory tree species, fires were relatively frequent (10–20 years) historically and dominated by low-severity fire effects (Sherriff and Veblen, 2007; Sherriff et al., 2014; Brown et al., 2015). In the upper montane zone, where greater proportions of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Mirb. Franco)), aspen (*Populus tremuloides* Michx.), and lodgepole pine (*Pinus contorta* Douglas ex Loudon) intermixed with ponderosa pine, historical fire return intervals were longer (20–50 + years) and more heterogeneous with patches (10–100 ha) of stand-replacing and moderate-severity fire (where fire reduces the basal area or canopy cover 20–70%) (Brown et al., 1999; Schoennagel et al., 2011; Sherriff et al., 2014). Differences in historical fire regimes across the elevational gradient of the Front Range suggest that historical forest structure, and thus restoration goals, might also vary across lower and upper montane zones (Sherriff et al., 2014; Addington et al., 2018).

A collaborative group of stakeholders identified over 300,000 ha of Front Range ponderosa pine-dominated forests in need of restoration (Underhill et al., 2014), but the lack of broad-scale scientific information on historical forest structure has been a barrier to progress (Cheng et al., 2015). Information that currently guides restoration of forest structure on the Front Range includes historical descriptions, repeat historical photographs, and dendrochronological reconstructions. Historical descriptions (Jack, 1900) and photographs (Veblen and Lorenz, 1991; Kaufmann et al., 2001; Fig. 1) can be important components of the historical forest narrative, but they lack quantitative data for informing silvicultural prescriptions. Previous dendrochronological reconstructions in the Colorado Front Range focused primarily on fire regimes using fire history and tree establishment data (Brown et al., 1999; Sherriff and Veblen, 2006; Schoennagel et al., 2011) without a direct comparison of current and historical forest structure metrics. Several studies have reported a substantial increase in forest density for lower montane ponderosa pine forests (Sherriff and Veblen, 2006;