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Collaborative restoration effects on forest structure in ponderosa pine-dominated forests of Colorado

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ABSTRACT

In response to large, severe wildfires in historically fire-adapted forests in the western US, policy initiatives, such as the USDA Forest Service's Collaborative Forest Landscape Restoration Program (CFLRP), seek to increase the pace and scale of ecological restoration. One required component of this program is collaborative adaptive management, in which monitoring data are used to iteratively evaluate and improve future management actions. Here, we assess the success of seven CFLRP treatments, implemented on 2,300 ha during the first three years of the Colorado Front Range Landscape Restoration Initiative (LRI) at achieving desired forest structure by comparing pre- and post-treatment conditions. We also compare post-treatment conditions with reconstructions of historical (ca. 1860) forest conditions to contextualize the magnitude of treatment effects. Restoration projects moved stands toward desired conditions by reducing basal area, tree density, and canopy cover and increasing average tree diameter, large gap cover, and abundance of small- to medium-sized tree groups. Post-treatment stands were similar to historical stands with respect to basal area of ponderosa pine; however, they had higher total tree density and fewer gaps than historical reference conditions, suggesting that restoration prescriptions may be improved with increased flexibility for density reduction of Douglas-fir and increased gap creation. This examination of early CFLRP treatment outcomes as they relate to desired conditions informs potential areas of adjustments to future treatments and provides baseline data to evaluate the evolution of treatments over the program's lifespan. We also identify and discuss several scientific, social, and logistical constraints to large-scale restoration success and make several recommendations to improve restoration outcomes.

1. Introduction

1.1. Background

A host of changes in land use, including grazing, logging, and fire suppression, have altered the structure and composition of many dry conifer forests of the western US over the past century, resulting in increased density in many of these forests compared to historical pre-settlement conditions (Allen et al., 2002). As a result, large, severe wildfires are increasingly affecting many ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) and other dry conifer forests of the western US with negative ecological and social consequences (Allen et al., 2002; Flannigan et al., 2013; Westerling et al., 2006). Forest restoration treatments in ponderosa pine typically focus on fuel reduction to mitigate these impacts (Covington and Moore, 1994). More recently, restoration treatment foci have expanded to address a comprehensive suite of ecological objectives such as increasing understory plant species diversity, improving wildlife habitat, enhancing landscape heterogeneity, and restoring historical fine-scale spatial patterns (Allen et al., 2002; Larson and Churchill, 2012). Large-scale US federal initiatives seek to increase extent of forest restoration on federal, state, and private lands (e.g., Charnley et al., 2011; Schultz et al., 2012). For

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example, the USDA Forest Service Collaborative Forest Landscape Restoration Program (CFLRP) is a restoration program supporting landscape-scale forest restoration and emphasizing collaborative and adaptive approaches to restoration (Schultz et al., 2012). This program emphasizes landscape-scale planning, stakeholder collaboration in the development of management goals, and an adaptive management process to monitor outcomes and provide flexibility to adjust future actions (Fernandez-Gimenez et al., 2008; Holling, 1978; Schultz et al., 2012).

Forest structure is a key component of a number of forest developmental processes. We define forest structure as composed of (1) forest density (e.g., basal area, tree density), (2) tree species composition (e.g., relative density), and (3) spatial arrangement (e.g., gap size or group size) (Franklin et al., 2002). Monitoring forest structure is a core component of adaptive management because these data are commonly collected, structural objectives are usually quantitatively defined in plans, and forest structure relates to many of the more difficult to measure restoration objectives such as decreased potential for crown fire and drought susceptibility (Fulé et al., 2012; Strahan et al., 2016). Management objectives of restoration treatments in ponderosa pine-dominated ecosystems generally focus on reducing tree density and restoring elements of composition and spatial pattern that historically characterized these stands prior to Euro-American settlement (e.g., spatial heterogeneity at multiple scales; Allen et al., 2002; Larson and Churchill, 2012). Forest spatial structure drives many forest processes such as resource availability (Boyden et al., 2012; Canham et al., 1990), regeneration dynamics (Chambers et al., 2016; Malone et al., 2018), and fire behavior (Buma, 2015; Cannon et al., 2017; Hessburg et al., 2005; Mitchell et al., 2009). Reconstructions of historical forest density, composition, and spatial patterns are often examined to infer historical range of variability of forest structure and as a reference to guide restoration efforts (Aplet and Keeton, 1999; Keane et al., 2009; Mast et al., 1999; Moore et al., 1999; Romme et al., 2003; Veblen, 2003; Waltz et al., 2003). Comparing restoration outcomes to desired conditions of restoration programs can identify areas of improvement in relevant terms for future prescription development. Comparing outcomes of restoration treatments to historical reference conditions can provide context for understanding the degree of change in forest structure accomplished by restoration treatments. Such comparisons highlight potential areas of adjustment of restoration treatment prescriptions to better achieve congruency with historical conditions; thus providing a critical linkage to a program of adaptive management (Aplet and Keeton, 1999; Keane et al., 2009). In addition, comparisons to historical data can promote consideration of restoration objectives in the context of future climatic scenarios, potentially with shifting species ranges and disturbance regimes (Aplet and Keeton, 1999; Keane et al., 2009). Here, we examine outcomes of one CFLRP landscape-scale program implemented in ponderosa pine forests of the Colorado Front Range to assess management objectives and to provide insights for implementing an adaptive management process in the context of large-scale forest restoration initiatives.

1.2. Colorado Front Range Landscape Restoration Initiative (LRI)

The Front Range Roundtable, a multi-stakeholder collaborative group in Colorado, identified 162,000 ha of ponderosa pine-dominated forests as priority areas where ecological restoration and fire risk mitigation needs overlapped (Cheng et al., 2015; FRFTPR, 2006). This collaborative group was selected as a CFLRP grant recipient in federal fiscal year 2010 to implement the Colorado Front Range Landscape Restoration Initiative (LRI) with a treatment goal of 13,000 ha implemented over a 10-year period. The program has funded implementation of restoration treatments across the Arapaho and Roosevelt National Forests and the Pike and San Isabel National Forests. To address the complex restoration objectives, diverse stakeholders, and large geographic extent of the LRI, the group collaboratively developed desired conditions (Dickinson and SHSFRR, 2014), a monitoring plan (Addington et al., 2018; Barrett et al., 2017; Clement and Brown, 2011), and an adaptive management plan to assess program outcomes (Aplet et al., 2014).

Although the history of fire and forest establishment is relatively well-studied in Front Range forests (Brown et al., 2015, 1999; Donnegan et al., 2001; Ehle and Baker, 2003; Kaufmann et al., 2000; Schoennagel et al., 2011; Sherriff and Veblen, 2007; Williams and Baker, 2012), limited quantitative data on historical forest density, composition, and spatial pattern were available at a geographic extent appropriate for informing decisions about stand-scale desired conditions. Thus, a general set of qualitative desired conditions of the LRI was developed based on a synthesis of scientific literature on fire history and forest establishment, supplemented with historical descriptions and photographs (Jack, 1900; Kaufmann et al., 2001; Veblen and Lorenz, 1991), management guidelines from southwestern US ponderosa pine systems (Reynolds et al., 2013), and the expertise of collaborating scientists and practitioners. The desired conditions of the LRI pertaining to stand-scale forest structure include the following (Addington et al., 2018; Dickinson and SHSFRR, 2014):

- Low-density forest patches and openings should predominate on lower productivity or drier sites and lower elevations; higher density patches should predominate on higher productivity or wetter sites, and higher elevations.
- Lower productivity sites should be highly dominated by ponderosa pine; higher productivity sites should have greater species diversity with higher Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) abundance and other species present to varying degrees.
- All stands should contain a mosaic of openings, groups of trees, and isolated trees; on lower productivity sites, openings and isolated trees should occur more frequently; on higher productivity sites, larger tree groups should occur more frequently.

Previous studies have documented aspects of some LRI restoration treatments. Underhill et al. (2014) found that early treatments reduced tree density and increased canopy openness. Briggs et al. (2017) found that treatments altered forest structure in accordance with desired conditions, although not all metrics of spatial heterogeneity increased; these authors also documented no increase in exotic understory plants and no decreased use by certain wildlife species. Dickinson et al. (2016) used remote sensing techniques to map forest canopy and openings and found that LRI treatments reduced canopy cover and increased some metrics of spatial heterogeneity. At the time of these studies, detailed information on historical forest structure was not available, making it difficult to contextualize the magnitude of changes in forest density, composition, and spatial pattern of restoration treatments.

1.3. Research objectives

Here, we analyze pre- and post-treatment data from early (2010–2013) restoration treatments of the Colorado Front Range LRI to a) assess whether they achieved desired conditions, and b) compare treatment outcomes to recently available reconstructions of historical (1860) conditions (Battaglia et al., 2018a; Brown et al., 2015). Because detailed historical data were not available for reference at the time the LRI drafted their initial desired conditions, our presentation of the differences between post-treatment and historical conditions should not be viewed as evaluative or judgmental of individuals or institutions. Rather, they provide valuable insights towards understanding the effectiveness of past restoration treatments and improving the effectiveness of future implementation. Comparisons between treatment outcomes and historical data advance the adaptive management process of the LRI and more generally provide insights into constraints of the adaptive management process in the context of large-scale forest restoration initiatives.