Forest Ecology and Management 406 (2017) 228–241

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Efficacy of variable density thinning and prescribed fire for restoring forest heterogeneity to mixed-conifer forest in the central Sierra Nevada, CA

Eric E. Knapp[a,*], Jamie M. Lydersen[b], Malcolm P. North[b], Brandon M. Collins[c]

[a] USDA Forest Service, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding, CA 96002, USA
[b] USDA Forest Service, Pacific Southwest Research Station, 1731 Research Park Drive, Davis, CA 95618, USA
[c] Center for Fire Research and Outreach, University of California, Berkeley, CA 94720, USA

ARTICLE INFO

Keywords:
Frequent-fire forest
Prescribed fire
Restoration
Silviculture
Spatial structure

ABSTRACT

Frequent-fire forests were historically characterized by lower tree density, a higher proportion of pine species, and greater within-stand spatial variability, compared to many contemporary forests where fire has been excluded. As a result, such forests are now increasingly unstable, prone to uncharacteristically severe wildfire or high levels of tree mortality in times of drought stress. While reducing tree density might help to restore resilience, thinning treatments are frequently seen as conflicting with management for other resources such as wildlife habitat, in part because standard thinning prescriptions don't typically produce the degree of within-stand heterogeneity found in historical forests. In this study, we compare stand structures and heterogeneity produced by two different mechanical thinning treatments and in an unthinned control, all with or without prescribed fire as a follow-up treatment. The "high variability" thinning treatment was designed to produce the spatial variability once found in frequent fire forests and was based on historical data from nearby old-growth stands, while the "low variability" thinning treatment retained a similar number of trees but at a relatively even crown spacing. Stand averages and degree of variation for common forest metrics were calculated and values compared to a historical old-growth reference stand. Both thinning treatments reduced tree density and basal area, and shifted species composition towards historical values. Thinning treatments contained a deficit of trees in both the smallest (< 25 cm) and largest (> 80 cm) size classes, relative to historical conditions. The high variability thinning treatment increased forest structure variation more than the low variability thinning treatment for most measures and retained a broader distribution of canopy closure values across the treatment units. While prescribed fire also reduced stand density and increased the amount of within-stand heterogeneity (when delayed mortality was included), the magnitude was much less than that produced by thinning. Prescribed fire did not significantly reduce basal area or alter the species composition. Prescribed burning did significantly reduce surface fuel loads, while thinning alone had no effect for most fuel classes. Our results show that high variability thinning coupled with prescribed burning resulted in a forest better aligned with the conditions present in historical frequent-fire forests, which were known to be more resilient to both wildfire and drought.

1. Introduction

Frequent fire historically shaped the density and structure of many western U. S. forests (Leiberg, 1902; Show and Kotok, 1924). Patchy tree mortality and spatially aggregated regeneration produced a spatially heterogeneous fuel bed, leading to variable fire effects when burned (Weaver, 1943; Cooper, 1960; Larson and Churchill, 2012). In patches of tree mortality with heavier fuels, fire exposed mineral soil and created areas conducive to regeneration (White, 1985). Subsequent fires thinned or locally removed regenerating seedlings and saplings where fuels had accumulated, but more open patches where fuels were lighter were more likely to escape burning (Show and Kotok, 1924). Seedlings growing in the open and not under the canopy of larger trees also attain a fire resistant size more quickly (Cooper, 1960). This interaction of fire and regeneration dynamics resulted in a fine-scaled matrix of mature trees, gaps, and groups of seedlings and saplings (Larson and Churchill, 2012), which also promoted a diverse herbaceous and shrub understory (Knapp et al., 2013).

Early forest examiners noted the relatively open structure of forest stands and predicted that more trees could be grown if fire were kept

* Corresponding author.
E-mail addresses: eknapp@fs.fed.us (E.E. Knapp), jmlydersen@fs.fed.us (J.M. Lydersen), mnorth@fs.fed.us (M.P. North), bcollins@berkeley.edu (B.M. Collins).

http://dx.doi.org/10.1016/j.foreco.2017.08.028
Received 9 June 2017; Received in revised form 16 August 2017; Accepted 17 August 2017
0378-1127/ Published by Elsevier B.V.

out (Leiberg, 1902). With the advent of fire exclusion policies, seedlings and saplings once thinned by fire rapidly established, filling gaps and crowding out understory vegetation (Cooper, 1960). Forests that evolved with frequent fire are now commonly much denser than they were historically (Moore et al., 2004; Scholl and Taylor, 2010; Collins et al., 2011; Knapp et al., 2013). In addition, shade-intolerant and fire-resistant species have declined in abundance in many fire-adapted mixed-conifer stands, replaced by more shade-tolerant and fire-sensitive species.

Early timber harvesting removed many of the largest trees (Knapp et al., 2013), and infilling of gaps produced a more homogeneous forest structure, both vertically and horizontally (Larson and Churchill, 2012; Lydersen et al., 2013). Accumulated fuels in the absence of fire along with fuel continuity resulting from increasing forest homogeneity have contributed to a higher probability of stand replacing wildfire. Due to competition for resources, higher tree densities are also associated with reduced tree vigor, increasing the likelihood of loss through bark beetle mortality (Ferrell et al., 1994; Fettig et al., 2007).

While mechanical thinning is one obvious tool for reversing tree densification and mitigating the risk of stand replacing fire or heightened tree mortality, the structural changes associated with thinning can have undesirable impacts on other resources. Maintaining habitat for wildlife species that prefer dense, multi-layered stands is often a competing objective (Lehmkuhl et al., 2007; Scheller et al., 2011). This conflict between thinning to reduce tree densities and conserving closed-canopy habitat for wildlife has been accentuated by conventional thinning approaches adapted for fire hazard reduction (Agee and Skinner, 2005). More nuanced thinning approaches that seek to enhance and restore heterogeneity may be one means of balancing these seemingly competing objectives (North et al., 2009).

Early observers in unharvested or "virgin" forests associated with frequent fire consistently noted that trees were grouped or clustered, as opposed to regularly spaced (Dunning, 1923; Cooper, 1961), and uneven aged, or "at best even-aged by small groups" (Show and Kotok, 1924). Historical data and stand reconstructions indicate that conifer-dominated forests throughout the western US appear to have shared a similar structure, with widely spaced individual trees, groups of trees, and canopy openings organized at 0.1–0.3 ha spatial scales (Larson and Churchill, 2012). This "patchy and broken" structure contributed to the relative immunity of historical forests to crown fire (Show and Kotok, 1924). Because surface fuels are a product of overstory structure and composition (Lydersen et al., 2015), variability in overstory conditions presumably led to surface fuel discontinuity, which likely limited spread of higher intensity fire (Miller and Urban, 2000). Given the environmental stress forest ecosystems are likely to experience under a changing climate, heterogeneity may be particularly important in shaping stand resilience to wildfire and other disturbances (Drever et al., 2006; Stephens et al., 2010).

Conceptual frameworks for managing for greater complexity have been described in different forest types (North et al., 2009, Franklin and Johnson, 2012, Reynolds et al., 2013). Silvicultural prescriptions have been developed for restoring heterogeneity based on historical stand structure data (Harrod et al., 1999; Churchill et al., 2013), or with the goal of simultaneously enhancing forest structural attributes for wildlife species and reducing wildfire hazard (Reynolds et al., 1992; Long and Smith, 2000; Graham and Jain, 2005). However, implementation of forest restoration treatments designed to enhance heterogeneity has been slow (Puettmann et al. (2015). This is partially because contemporary silvicultural approaches are generally still rooted in conventional timber-focused practices, which often seek to maximize individual tree growth (Puettmann et al. 2009). On federally managed forest lands in areas of the western U.S. that historically experienced frequent fire, tree spacing guidelines once employed to maximize growth have to some extent been re-purposed for restoration and fire hazard reduction treatments. Such treatments typically rely on average stand structure metrics (density, basal area) as targets, or employ uniform crown spacing guidelines, which tend to generate relatively homogenous stand conditions. Most available evidence suggests that such homogeneity did not exist in these forest types historically (Sánchez Meador et al., 2011; Larson and Churchill, 2012; Lydersen et al., 2013; Clyatt et al., 2016).

Notable examples of thinning with the overarching goal of generating heterogeneity applied at experimental or operational scales do exist. In Douglas-fir forests of the Pacific Northwest, Carey (2003) tested a variable thinning on stands divided up into 40 m grid cells, with the goal of multi-resource management and enhancing habitat for a diversity of species. Methods for restoring spatial structure of tree groups, individuals and openings with thinning based on historical reference data, provided in Churchill et al. (2013), are being evaluated in Washington State. In the southwestern U.S., variable thinning prescriptions are now being implemented at landscape scales (Reynolds et al., 2013).

In this study, we compare forest structure (density, basal area, diameter distribution, species composition) and heterogeneity (coefficient of variation for structural variables, variation in canopy closure) of an unthinned control against two thinning approaches – one designed to restore the within stand spatial complexity that historically was generated by frequent fire, and one designed to reduce stand density leaving a relatively regular crown spacing. Half of the units were followed by prescribed burning, allowing an evaluation of the heterogeneity produced by burning alone, as well as thinning and burning. We also compare the structures produced by treatment against a historical reference, obtained from plots stem mapped prior to any logging in 1929 (Knapp et al., 2013).

2. Methods

2.1. Study area

The approximately 100 ha study area is located within the Stanislaus-Tuolumne Experimental Forest, on the Stanislaus National Forest, near Pinecrest, CA (Fig. 1). The mixed conifer forest at the study elevation (1740 to 1900 m) is composed of white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), ponderosa pine (*P. ponderosa*), Jeffrey pine (*P. jeffreyi*), and black oak (*Quercus kelloggii*), in order of abundance. Climate is Mediterranean, with the majority of the annual precipitation occurring during fall, winter, and spring. Up to 75% of precipitation fell as snow at this elevation in the past (Kittredge, 1953). Tree growth is rapid due to high site productivity, with deep and well-drained loam to gravelly loam soils (Wintoner-Inville families complex) derived from granite or weathered from tuff breccia. The last fire occurred in 1889 but fire was historically frequent in the study area, with a median return interval of 6 years (Knapp et al., 2013). The study area was selectively logged in 1928 and 1929, removing most of the larger trees. The forest that developed after logging and under fire exclusion contained a greater abundance of white fir and incense cedar, and less pine than the historical forest. At the time our study was initiated the forest density was 240% and basal area 29% greater than historical old-growth forests at this site in the 1920s (Knapp et al., 2013). With the lack of fire, surface fuels were also likely considerably elevated relative to historical conditions. Other than removal of roadside hazard trees, no additional management action had occurred in the decades prior to the study.

2.2. Treatments

Two prescribed burning treatments (burned, unburned) were randomly assigned to larger units and three thinning treatments (high variability "HighV" thin, low variability "LowV" thin, and unthinned control) were subsequently randomly assigned to the three units within each burn unit in a nested experimental design. The six total treatments were replicated four times, resulting in 24 units, each approximately