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Increasing weight of evidence that thinning and burning treatments help restore understory plant communities in ponderosa pine forests

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ABSTRACT

For more than a century ecosystems around the world have experienced an increase in the dominance of woody species. While the drivers of woody plant proliferation are complex, interactions between climate and land-use change are commonly invoked as primary contributing factors. In ponderosa pine forests of western North America, substantial increases in tree densities are impacting overall forest health and increasing the risk for severe wildfires and insect and disease outbreaks. Addressing this problem through the use of ecological restoration projects is widely advocated. Our objective was to quantify understory vegetation response five years after thinning and burning treatments in a southwestern ponderosa pine forest. We remeasured plant species richness and cover on thinned + burned, burned only, and untreated controls replicated four time in a BACI design. An untreated control (Untreated) was used for comparison of two alternative restoration treatments (1) thinning followed by prescribed fire (Thin + Burn) and (2) prescribed fire only (Burn-only). Understory species richness and total plant cover increased significantly in Thin + Burn compared to the Untreated and Burn-only treatments. Analysis of functional group composition revealed increases in species richness and cover was driven primarily by changes in annual–biennial forbs and graminoids. We then compared our results with those of three Long-term Ecological Restoration and Assessment Network (LEARN) sites. We found total and native plant cover showed evidence of a consistent response to Thin + Burn treatments across all sites. However, results suggest that understory response to restoration treatments is under strong environmental control. As a consequence the range of variability associated with understory responses should be expected to expand or contract depending on where treatments are implemented. Overall our findings add to a growing body of literature that restoration treatments combining mechanical thinning and prescribed fire are useful for increasing native understory abundance and diversity.

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1. Introduction

Increases in the abundance woody species into grasslands, forest openings, and savannahs is a global phenomenon that has received much attention in recent decades (Archer, 1989, 1995; Covington and Moore, 1994; Scheffer et al., 2001; Eldridge et al., 2011). Increases in the density of woody plants has been documented in the Chaco region of Argentina (Cabral et al., 2003), savannahs of Africa (Roques et al., 2001; Moleele et al., 2002), woodlands of Australia (Burrows et al., 1990; Bowman et al., 2001), and the arid and semiarid regions of North America (Van Auken, 2000). These transitions have led to drastic changes in landscape cover causing both socioeconomic (Moleele et al., 2002; Smit, 2004; Cabral et al., 2003) and environmental impacts (D'Odorico et al., 2010; Ratajczak et al., 2012). While reversing this trend represents an important challenge to scientists and natural resource practitioners, understanding the impact of alternative restoration techniques is required for making sound management decisions.

It is recognized that in many cases these are native species that were historically present at lower densities and are currently at densities outside of their natural range of variability (Archer, 1995). For that reason natural (or historical) range of variability concepts provide a relevant context within which to quantify key structural and functional conditions that can be used as a reference to guide restoration efforts, determine site potential, and evaluate targets. Natural variability represents the range of spatial and temporal conditions under which the ecological and evolutionary conditions of a system are sustained (Landres et al., 1999; Moore et al., 1999). Therefore quantifying the natural range of variability is not only fundamental to restoring ecological integrity but instrumental

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to assessing ecological changes and developing reference conditions that can be used to guide restoration projects (Covington et al., 1997; Landres et al., 1999; US Congress, 2003, Health Forest Restoration Act).

In ponderosa pine forests of the Southwest, the natural range of variability is widely accepted to represent conditions that existed prior to large-scale Euro-American settlement (i.e. presettlement) which began around 1870 (Larson and Churchill, 2012). Historically, frequent, low-severity surface fires were an integral component of ecological function (Fulé et al., 1997). Empirical evidence indicates that fire maintained a heterogeneous overstory structure characterized by individual trees and tree groups interspersed within a mosaic of grass, forb, and shrub dominated openings (Reynolds et al., 2013).

There is a general census that throughout their range, contemporary ponderosa pine forests exist outside of their natural range of variability making them increasingly susceptible to landscape-scale, high intensity wildfires. Early studies and historical accounts describe ponderosa pine forests as having open, park-like stands consisting of large trees interspersed among openings of a diverse and productive, grass-dominated understory (Beale, 1858; Woolsey, 1911; Pearson, 1923; Weaver, 1943; Cooper, 1960; White, 1985). These historical conditions were maintained primarily by frequent, low-intensity surface fires that acted to regulate the competitive balance between overstory and understory communities. Over the last 150+ years, a number of factors including grazing, logging, and fire suppression have combined to favor pine establishment at the expense of understory diversity and productivity. As a consequence contemporary forests often contain uncharacteristically high tree densities with closed canopies, lower light availability, and deeper forest floor litter and duff layers (Covington and Moore, 1994; Johnson, 1994; Vankat, 2011; Larson and Churchill, 2012). A major consequence of this has been the degradation of understory integrity, including declines in understory cover, productivity, and diversity. While often overlooked, the understory plant community is an integral component of structure and function in ponderosa pine ecosystems, influencing nutrient turnover rates, watershed function, wildlife habitat, and providing fuel for frequent surface fires (Allen et al., 2002; Kaye et al., 2005).

Management actions designed to mitigate these impacts are increasingly being advocated across western North America. Restoration objectives in ponderosa pine forests are commonly developed within an evidence-based framework designed to restore (1) overstory forest structure – age, size and spatial distribution of trees – to within its historical range of variability and (2) increase native understory plant cover and diversity (Fulé et al., 1997; Mast et al., 1999; Moore et al., 1999; Dodson and Peterson, 2010). Prescriptions appropriate for meeting these objectives use site-specific reference information to emulate key overstory characteristics. These include structural and compositional information obtained from both "legacy" and "latency" evidence (*sensu* White and Walker, 1997). Legacy information pertains to evidence such as remnant logs, stumps, and stags, while latency information is gained through dendrochronological techniques (Mast et al., 1999; Sánchez-Meador et al., 2010; Reynolds et al., 2013).

Alternative restoration techniques for meeting these objectives include mechanical thinning, prescribed fire, or a combination of the two. Empirical studies assessing treatment success have shown that a combination of mechanical thinning plus prescribed fire is most successful at meeting overstory restoration targets (Fulé et al., 2005; Korb et al., 2012). It is assumed that these management interventions restore the key feedback interactions between pattern and process under which these forests evolved, enhance ecological integrity, and increase resilience to disturbance (Fulé et al., 1997; Roccaforte et al., 2015). Yet consensus on meeting understory objectives remains mixed. For example, in a recent meta-analysis of 12 national Fire and Fire Surrogate (FFS) sites, Schwilk et al. (2009), found no consistent response of understory plant communities to mechanical thinning and burning treatments. A result that could be attributable to regional variation in disturbance history, climate, and anthropogenic activities. For example, in a recent study Ratajczak et al. (2012) found that across 13 grass-dominated ecosystems in North America, woody plant encroachment had a greater impact on diversity at sites with higher precipitation.

Although the natural range of variability in overstory structure and composition is readily obtained by reconstructing presettlement forest structure (Huffman et al., 2001), no such quantitative method is currently available for the understory plant community. Therefore, developing more specific restoration objectives for the understory plant community represents an under developed and challenging area of research (Laughlin et al., 2006).

Our current understanding of the range of understory variability in terms of cover, species composition, and diversity in the Southwest comes from studies using phytolith analysis, seed banks, relict sites or remnant grass patches and long-term permanent plots. Kerns et al. (2001) made comparisons between contemporary vegetation and surface soil phytolith assemblages to understand forest-grassland vegetation dynamics. Total above-ground understory community was composed of 70% grasses and shrubs. Overall the dominant species were C_3 grasses. Korb et al. (2005) examined the viable soil seed bank across a disturbance gradient. In general there was little correlation between below ground seed bank composition and above ground species composition. However sites that had received the lowest level of disturbance were dominated by late successional graminoid species. Gildar et al. (2004) examined understory reference conditions by comparing two relict sites (burned) to a nearby forest within which fire had been excluded since 1879 (unburned) on the North Rim of the Grand Canyon. Relict sites tended to have higher species richness, and total herbaceous cover, including both forbs and graminoids. While there was no difference in overstory characteristics between sites, relict sites tended to be more production.

Few studies provide long term data following restoration treatments; however this is valuable information for understanding variability and community dynamics. In one of the longest running restoration to date Laughlin et al. (2006) evaluated changes in remnant grass openings which they considered representative of the range of natural variability of herbaceous vegetation. Theses remnant grass openings were dominated by C_3 graminoids, followed by C_4 graminoids and legumes.

Collectively these studies provide information on a range of understory responses; however, they either lack a consistent response variable or the temporal resolution needed to accurately quantify variability of understory conditions. Historical and repeat photographs are an underutilized tool as well and can offer valuable insight into past vegetation structure, yet provide limited quantitative information on herbaceous species abundance or distributions (Egan and Howell, 2001).

Understory response to restoration takes place over time and monitoring over multiple years is required to determine changes in understory communities following treatments. With adequate temporal resolution, one approach to quantify a range of variability for understory response would be to combine data from multiple sites across a common ecosystem. A primary objective for understory plant response following ecological restoration treatments is to increase cover and diversity of native vegetation. In this study we evaluated whether this objective was met five years after alternative restoration treatments in the Mineral Ecosystem Management Area located on the Apache-Sitgreaves National Forest in east-central Arizona and part of Northern Arizona

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