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Original Research

Pretreatment Tree Dominance and Conifer Removal Treatments Affect Plant Succession in Sagebrush Communities[☆]

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ABSTRACT

In sagebrush (*Artemisia tridentata* Nutt.) ecosystems, expansion and infilling of conifers decreases the abundance of understory perennial vegetation and lowers ecosystem resilience and resistance of the once shrub grass − dominated state. We prescribed burned or cut juniper (*Juniperus* spp. L.) and pinyon (*Pinus* spp. L.) trees at 10 sites across the western United States. We measured vegetation cover and density on untreated and treated plots 3 and 6 yr after treatment across a gradient of pretreatment tree dominance as quantified by the tree dominance index (TDI); (tree cover)/(tree + shrub + tall grass cover). We analyzed plant responses by functional group using mixed-model analysis of covariance, with TDI treated as a covariate. As tree cover increased and TDI exceeded 0.5, shrub cover declined to < 25% of the maximum on untreated plots. Although total shrub cover recovered on burned plots to untreated percentages 6 yr after treatment, sagebrush cover was still 1.1 − 0.6% on burned plots compared with 13.9 − 0.5% on untreated plots across the range of 0 − 1 TDI. Tall grass cover increased to 25.4 − 9.4% for burn plots and 24.3 − 22.4% on cut plots from 0 − 1 TDI 6 yr after treatment. Cheatgrass (*Bromus tectorum* L.) increased on prescribed fire and on cut treatments, especially at higher pretreatment TDI. However, ratios of cheatgrass to tall grass cover were much lower on cut than burn plots. To retain the shrub, especially sagebrush, components on a site and increase ecosystem resilience and resistance through increases in tall grasses, we recommend treating at low to mid TDI using mechanical methods, such as cutting or mastication. Effects of fire and mechanical treatments implemented at different phases of tree dominance create different successional trajectories that could be incorporated into state-and-transition-models to guide management decisions.

Introduction

Since the late 1800s, semiarid lands around the world have been experiencing increasing cover of woody vegetation (Archer et al., 1995; Miller and Tausch, 2001; Archer and Predick, 2014). In many areas of the western United States, juniper (*Juniperus* spp. L.) and pinyon pine (*Pinus* spp. L.) are expanding and infilling in rangelands at an unprecedented rate (Miller et al., 2000; Brockway et al., 2002; Miller et al., 2008; Floyd and Romme, 2012; O'Connor et al., 2013). In sagebrush (*Artemisia tridentata* Nutt.) ecosystems, dominance of juniper and pinyon alters fire regimes, increases soil erosion, decreases shrub and herbaceous cover, and diminishes habitat for certain wildlife species (Burkhardt and Tisdale, 1976; Tausch and West, 1995; Miller et al., 2000; Miller and Tausch, 2001; Bates et al., 2005; Ansley et al., 2006; Pierson et al., 2007; Baruch-Mordo et al., 2013; Roundy et al., 2014a; Roundy et al., 2016). Increased canopy fuel loads (Young et al., 2015) and decreased understory cover (Roundy et al., 2014a) as trees expand and infill can increase fire severity followed by annual weed dominance, increased fire frequency, and loss of ecosystem services.

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Drivers for woodland expansion include increases in atmospheric CO_2, altered fire regimes due to fire suppression, and a reduction in fine fuels caused by livestock grazing (Miller and Wigand, 1994; Archer and Predick, 2014). Over the past several thousand years, pinyon and juniper ranges have expanded and contracted in response to changing climatic conditions (Miller and Wigand, 1994; Miller and Tausch, 2001). However, in the past 150 yr, woodland expansion has exceeded rates recorded for the previous 5 000 yr (Miller and Tausch, 2001; Miller et al., 2008). Increased woodland area burned in the past 30 yr has been associated with changes in climate and increases in invasive grasses (Board et al., 2017).

Tree removal is commonly used to restore structure and function to these communities (Brockway et al., 2002; O'Connor et al., 2013; Stephens et al., 2016). However, successional trajectories following disturbance are dependent on disturbance severity and residual species abundance, composition, and resulting structure on a site (Bates et al., 2005; Briske et al., 2008; Bates et al., 2013; Miller et al., 2014a, 2014b; Roundy et al., 2014a). As tree cover increases, both shrub and herbaceous cover decrease, with relative decreases depending on species composition and ecological site characteristics (Tausch and West, 1995; Roundy et al., 2014a; Bybee et al., 2016). After tree removal, if shrub and herbaceous cover have already declined, missing components of the community may be replaced by invasive species, especially on warmer and drier sites (Young et al., 2013a, 2013b, 2014; Chambers et al., 2014a, 2014b; Miller et al., 2014a). For this reason, pretreatment tree dominance plays a vital role in steering the successional trajectories of these ecosystems following disturbance (Miller et al., 2000; Archer et al., 2011; Miller et al., 2014a; Roundy et al., 2014a). Successional trajectories that appear similar in the short-term (1-5 yr) may diverge when monitored over the long term (5-11 yr). Thus, long-term monitoring is necessary to determine the outcome of these treatments.

State-and-transition-models (STMs) are useful tools for making land management decisions that improve ecosystem conditions (Bestelmeyer et al., 2003; Stringham et al., 2003; Bestelmeyer et al., 2004; Briske et al., 2008; Bagchi et al., 2013; Chambers et al., 2014a, 2014b; Miller et al., 2014a). The development of STMs requires an understanding of underlying ecological site characteristics, ecosystem processes, ecological thresholds, and successional trajectories relative to pretreatment site conditions and the treatment method employed (Chambers et al., 2014a, 2014b; Miller et al., 2014b; Roundy et al., 2014a). Generalized STMs for sagebrush ecosystems have not specified effects of different tree reduction treatments (Chambers et al., 2014b; Miller et al., 2014a). If prescribed fire and mechanical treatments implemented at different phases of tree dominance lead to different successional trajectories and vegetation states, then inclusion of this information in state-and-transition models could better guide land management.

Ecosystem resistance is a system's ability to maintain its current state when exposed to disturbance or stress (Briske et al., 2008; Chambers et al., 2014a, 2014b). However, resistance to annual grass invasion and dominance is of most importance to sagebrush ecosystems because that dominance poses the greatest risk to the system. Exotic annual bromes, such as cheatgrass, can alter fire regimes, soil nitrogen pools, soil microbial communities, and hydrologic conditions leading to degraded site conditions (Brooks et al., 2004; Blank and Morgan, 2012; Bagchi et al., 2013; Reisner et al., 2013; Rau et al., 2008, 2014; Chambers et al., 2014a, 2014b). The major concern is that after disturbance the system passes through a biotic threshold where annual grass dominance results in more frequent and larger fires (Balch et al., 2013), which then requires major intervention by use of herbicides and seeding to restore the system.

Effects of prescribed fire compared with mechanical tree reduction on annual grass resistance depend on initial site conditions and differential treatment effects on perennial shrubs and grasses, seedbanks, and resource availability (Pyke et al., 2010; Bates et al., 2013; Miller et al., 2013; Roundy et al., 2014a). Comparison of these treatments in relation to pretreatment tree dominance is necessary to determine how to best reinforce a restoration trajectory (Briske et al., 2008) toward a desirable state and resist a trajectory to an undesirable state (weed dominance). Deep-rooted perennial (tall) grasses are especially important in limiting cheatgrass invasion and dominance (Chambers et al., 2007; Blank and Morgan, 2012; Reisner et al., 2013; Miller et al., 2014a). Perennial grasses increase resistance to cheatgrass invasion by limiting the availability of gaps for establishment and reducing water and nutrient availability (Blank and Morgan, 2012; Reisner et al., 2013).

Compared with prescribed fire, mechanical treatments may result in greater resistance to cheatgrass dominance primarily through retention of shrubs and increases in tall grasses (Miller et al., 2014a, 2014b; Roundy et al., 2014a; Bybee et al., 2016). Sites with high tree dominance are more likely to experience increases in cheatgrass cover after tree reduction due to lower perennial herbaceous and shrub cover and thus higher availability of resources (Bates et al., 2013; Roundy et al., 2014a, 2014b).

Objectives

Our study was a follow-up to the region-wide SageSTEP woodland experiment (McIver and Brunson, 2014) in which effects of tree reduction were reported by Miller et al. (2014b) and Roundy et al. (2014a). Our objective was to determine how successional trajectories have changed from 3 to 6 yr post treatment to better predict how tree-expansion communities will ultimately respond to no-removal or tree-removal treatments. We hypothesized that compared with no treatment and prescribed fire, tree reduction by cutting at low to mid tree dominance will result in a community most similar to the pre-expansion community. This is because 1) on untreated plots, perennial understory cover will continue to decrease with increasing pretreatment tree dominance, 2) on burn treatments cheatgrass cover will continue to increase and shrub cover will remain low, 3) on cut treatments, perennial herbaceous and shrub cover will continue to increase, and 4) on both burn and cut treatments, perennial plant recovery will be highest and cheatgrass cover lowest when treatments are implemented at low to mid tree dominance.

Methods

Study Region and Sites

This study included 10 conifer-expansion or wooded shrubland sites (Romme et al., 2009) located across the Great Basin region (Fig. 1, Table 1): four western juniper (*Juniperus occidentalis* Hook.) sites in Oregon and northern California, three single-leaf pinyon (*Pinus monophylla* Torr. & Frém.)—Utah juniper (*Juniperus osteosperma* Engelm.) sites in central and eastern Nevada, one Utah juniper site in Utah, and two Colorado pinyon (*Pinus edulis* Engelm.)—Utah juniper sites in Utah (McIver et al., 2010; Miller et al., 2014b; Roundy et al., 2014a, 2014b). These sites all contain big sagebrush (*Artemisia tridentata* spp. L.) communities on loamy soils (Roundy et al., 2014b). This current study did not include data from the Stansbury, Utah site originally included in the Miller et al. (2014b) and Roundy et al. (2014a) analyses because that site burned in a wildfire 3 yr after treatment. Elevation, soils, and climate vary widely among sites and across the study region. Sites and environmental conditions were described in detail by McIver et al. (2010), McIver and Brunson (2014), Miller et al. (2014b), and Roundy et al. (2014a, 2014b). The wide distribution of our study sites allows us to determine regional responses to treatments.

Experimental Design and Treatments

We used a randomized complete block design with study sites as the blocks. Within each block, we assigned a cutting treatment (cut), a prescribed fire treatment (burn), and an untreated control to three plots