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Historic fuel treatment effects on plant community dynamics following wildfire

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Abstract

Wildfire has substantially increased in sagebrush ecosystems resulting in degraded wildlife habitat, reduced forage, and altered fire regimes. Mechanical mowing, prescribed burning, and herbicide are fuel treatments aimed to reduce woody or herbaceous fuels; however, their long-term effect on plant community composition, as well as the response after wildfire, is unknown. We utilized data from three SageSTEP sites (<https://www.sagestep.org>) to examine plant community composition before and after fuel treatments, as well as after three sites had burned in a wildfire. After fuel treatments, reductions in sagebrush coincided with increased native perennial bunchgrass cover but also annual, invasive grass cover. Perennial forb increases were ephemeral after treatments. Immediately prior to wildfire, sites differed in species composition with control plots having the most shrubs and the prescribed fire plots having the most perennial grasses. After wildfire, shrubs were substantially reduced. Perennial grass cover generally increased, particularly in prescribed fire plots, although perennial grass responses were site dependent. Annual grass invasion varied by site and treatment after wildfire, and invasive forbs were dynamic post-wildfire. These results illustrate the need for long-term data to understand plant community dynamics after both fuel treatments and subsequent wildfire. Long-term monitoring of post-wildfire community trajectories will help deduce how strongly historical fuel treatments affect pre-wildfire composition and consequent post-wildfire recovery.

Introduction

Fuel reduction treatments are intended to reduce fuel loading of herbaceous and/or woody fuels. In sagebrush ecosystems in the western United States, woody fuels have increased due to increasing shrub density; herbaceous fuels have increased due to invasive annual grasses, primarily *Bromus tectorum* (cheatgrass). Cheatgrass recruits well after disturbance (West and Hasan 1985, Peterson 2005) and creates continuous, highly flammable fuels that aid fire spread (Brooks et al. 2004), which promotes further recruitment and increases fire risk (Link et al. 2006, Bradley et al. 2018). As a result, annual grass invasion has increased the size, frequency, and duration of wildfires in sagebrush ecosystems (Balch et al. 2013).

In addition to increasing fuel loads, annual grass invasion displaces native plants, which can in turn reduce biodiversity, forage quality, and wildlife habitat (DiTomaso 2000). Fuel treatments are intended to reduce fuel loads and fire risk in efforts to restore native plant communities. However, some fuel treatments may increase invasive species from physical disturbance and the reduction in native species (Potts and Stevens 2009, Freund et al. 2021, Pyke et al. 2022), which may inadvertently increase non-native dominance and further degrade an area. Additionally, fuel treatments may provide open niches for invasive species initially that are exacerbated when a wildfire occurs. We have little information about how fuel reduction treatments and subsequent wildfire interact to alter the post-fire trajectory of ecosystem succession. Considering that fire return intervals have decreased substantially in sagebrush ecosystems (Baker 2006), it is imperative we understand how prior fuel treatments affect post-wildfire plant community responses. While we assume that fuel treatments reduce risk to ecosystems that burn in wildfire, it is possible that the dual disturbances of fuel treatments and subsequent wildfire have negative impacts.

Using data from long-term fuel treatment experiments that burned in wildfires, we examined plant successional trajectories following fuel treatments and wildfire. Three sagebrush shrubland sites in the Sagebrush Steppe Treatment Evaluation Project (SageSTEP) burned in wildfires approximately ten years after fuel treatments were implemented. We present ten years of post-fuel treatment data along with 3-4 years of post-wildfire data on plant functional group responses in control, tebuthiuron, prescribed fire, and mowing plots.

Methods

Experimental Design

The Sagebrush Steppe Treatment Evaluation Project (SageSTEP) is a long-term plot network with 19 sites across six states and a range of environmental conditions in the Intermountain West, USA. Fuel treatments in shrublands were implemented from 2006-2009. Prescribed fire treatments were applied in late summer and early fall with the intention of consuming most woody vegetation. Herbicide treatments included tebuthiuron (Spike 20P; 1.68 kg/ha) and imazapic (Plateau; 22.2% acid equivalent), which were applied to reduce woody and herbaceous fuels, respectively. Mowing treatments were applied to reduce shrub cover by 50%. Annual vegetation, fuels, soil, and climate data have been collected for all treatments at all SageSTEP sites (McIver and Brunson 2014, Pyke et al. 2014, Freund et al. 2020). Three of the original shrubland sites, characterized by Wyoming big sagebrush and invasive annual grasses have burned in recent wildfires: Owyhee, Nevada (2018); Moses Coulee, Washington (2019); and Rock Creek, Oregon (2020).

Field data were collected from April to June each year during the peak growing season in the year prior to treatment, annually post-treatment, and for 3-4 years post-wildfire. Treatment plots contained between 12 and 22 sampling subplots; all subplots were 30 x 33 m in size. Plant cover was measured on five-30 meter transects using the line-point intercept method with 300 points per subplot. We looked at foliar cover across four functional groups (perennial grass, annual grass, annual forb, and shrub) to assess the effect of fuel treatments on the post-wildfire plant community. Full field sampling protocols are available in Stebleton and Bunting 2009, Bourne and Bunting 2011, and Wozniak and Strand 2019.

Statistics

All statistical analysis was performed using R (R Core Team 2024). Total foliar cover data was used across all sites for all functional groups to assess temporal and treatment effects before and after wildfire. Using the glmmTMB (Mollie et al. 2017) package in R, Beta Generalized Linear Mixed Models (Beta GLMMs) were used to model plant community resilience. To meet the distribution requirements of Beta GLMMs, total foliar cover values were scaled for each functional group at each site to range between 0 and 1 by

normalizing each functional group's cover value relative to the total cover within each plot. To ensure reliable model performance, the data was filtered to include only those plots where the scaled foliar cover values were greater than 0 and less than 1. In the model, total foliar cover was considered the response variable; treatment, year, and their interaction were considered fixed factors; and plot number was used to account for variability and manage repeated measures within the same plot. A beta distribution with a 'logit' link function was used to appropriately model the proportional response variable. To ensure model fit and reliability, the DHARMA (Hartig 2024) package in R was used to visually inspect residual versus predictor plots and quantile (Q-Q plot) residuals. The model was run for each functional group for each site using the same predictors and response variable. Percent changes were calculated by comparing estimated marginal means of treatments relative to control values, and statistical significance (p-values) was determined through pairwise contrasts (using emmeans), with significance at $\alpha = 0.05$.

Results

At Owyhee post-wildfire (2019-2023), perennial grass cover was not significantly affected by any fuel treatment compared to control (all $p > 0.05$). Annual grass often substantially increased, such as by 260% in tebuthiuron (2019), but these increases lacked statistical significance. In prescribed fire, annual forb cover decreased by 46% in 2022 ($p=0.021$) and increased by 24% in 2023 ($p=0.035$) relative to control; annual forb responses were otherwise varied with no significant trends. Shrub cover in mowing and prescribed fire was generally lower than in control, but not significant, except in 2021 when shrub cover in mowing plots was 80% lower than in control ($p=0.014$).

At Moses Coulee post-wildfire, perennial grass consistently exhibited large and statistically significant increases in all three treatments relative to control. In 2021, perennial grass cover increased by 124–455% ($p \leq 0.001$) depending on the treatment, remained elevated in 2022 (90–209%, $p \leq 0.001$), and continued to be high in 2023 (85–303%, $p \leq 0.002$). Annual grass notably increased in the first-year post-wildfire (2021) in tebuthiuron (93%, $p=0.016$) and prescribed fire (97%, $p=0.011$) plots, though subsequent years yielded smaller or non-significant changes. Annual forb responses were not significant aside from a large decrease in prescribed fire plots in 2022 (73%, $p=0.001$). Shrub cover effects were more limited, with significant reductions observed in 2023 under tebuthiuron (79%, $p=0.004$) and prescribed fire (69%, $p=0.049$).

At Rock Creek post-wildfire, perennial grass cover rose by 91–95% across treatments relative to control ($p \leq 0.004$) in 2020, with similar increases (75–113%, $p \leq 0.018$) in 2021. In 2022, prescribed fire produced a significant increase in perennial grass cover (47%, $p=0.026$). However, by 2023, all treatments again yielded significant perennial grass increases relative to control (60–68%, $p \leq 0.004$). In 2022, annual grass cover in prescribed fire plots was 413% greater than in control ($p=0.012$). However, in 2023, annual grass cover did not significantly differ between treatments and control. Annual forb changes were variable, highlighted by a notable 170% increase in prescribed fire relative to control in 2022 ($p=0.001$), with few differences between treatments and control in 2023. Changes in shrub cover relative to control were minimal and lacked statistical significance across all treatments and years.

Discussion

The variability in plant functional group responses to different fuel treatments across the three sites underscores the importance of tailoring post-wildfire management strategies to specific ecological contexts. While previous studies (Chambers et al. 2021, Ellsworth et al. 2022) found that prescribed fire can facilitate herbaceous recovery in sagebrush ecosystems, our findings further demonstrate increases in perennial grasses under prescribed fire. This consistency, especially compared to more variable outcomes under mowing and tebuthiuron, suggests that prescribed fire's broad-spectrum effectiveness is robust across

environmental settings and temporal scales. In contrast, the modest or non-significant changes in perennial grass at Owyhee and the inconsistent responses of annual grasses and forbs to mowing and tebuthiuron highlight that these other treatments may only be beneficial under certain pre-fire conditions or site-specific biotic and abiotic factors.

This work enhances our understanding of how fuel treatments interact with local conditions to shape vegetation trajectories. Although shrubs are predictably reduced post-fire due to their fire intolerance, our results indicate that whether gaps left by shrubs are filled by perennial grasses, annual forbs, or annual grasses depends heavily on the chosen treatment and the site's inherent resiliencies or vulnerabilities. This aligns with ecological principles suggesting that community recovery is contingent on environmental gradients, seed sources, and disturbance histories. While managers may find prescribed fire a consistently reliable tool to promote perennial grasses, the more context-dependent results from mowing and tebuthiuron caution against a one-size-fits-all approach. Thus, it is important to integrate local site assessments—soils, climate, seedbank composition, and pre-fire vegetation—before deploying fuel treatments.

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