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Effectiveness and durability of common fuel treatments in sagebrush-dominated rangelands

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Abstract

Increased wildfire size and frequency pose major challenges to rangeland conservation. A common strategy for mitigating fire risk in sagebrush-dominated rangelands is to use fuel treatments that alter the amount and structure of burnable material, resulting in lower fire intensity, and creating access points for fire suppression resources. For fuel treatments to be practical in management, durability (lasting effectiveness) is critical. We present 15 years of data on fuel accumulation and resultant modeled fire behavior through time in prescribed fire, mechanical, herbicide, and control plots using data from the Sagebrush Steppe Treatment Evaluation Project (SageSTEP). In shrub-dominated plots ('shrubland network'), fire and mechanical treatments reduced fuel beds by up to 49%, resulting in modeled flame lengths that were significantly lower than untreated control plots. In sagebrush systems experiencing conifer expansion ('woodland network'), however, treatments increased surface fire spread rate by 15-21 times that of untreated areas due to increased herbaceous fuels. However, treatments also completely removed the risk of canopy fire spread. By 15 years post-treatment, durability was limited in shrubland systems, though prescribed fire and mechanical treatments continued to perform better than herbicide or untreated control treatments through year 10. In woodland plots, the infilling and growth of trees began to limit durability by post-treatment year 15. An improved understanding of fuel treatment effectiveness and durability will allow natural resource managers to evaluate tradeoffs and synergies in conserving rangeland ecosystems and reducing the potential for fast spreading and high intensity wildfire.

Introduction

Fire regimes in sagebrush-dominated ecosystems historically were typified by long periods without fire, facilitating a patchwork of late successional sagebrush canopy with intermittent native bunchgrass prairies in recently burned areas. In the last century, much of the sagebrush steppe has become degraded by invasive annual grasses, conifer encroachment, human land use and ignitions, climate change, and altered fire regimes (Balch et al., 2013). Cheatgrass (*Bromus tectorum*) is an invasive annual that is particularly problematic, as it recruits well after disturbance (Peterson, 2005; West and Hassan, 1985) and creates continuous, highly flammable fuels that aid fire spread (Brooks and Pyke, 2000), which further promotes invasive recruitment and increases fire risk (Bradley et al., 2018; Link et al., 2006). Similarly, higher elevation sagebrush ecosystems are at risk from increases in pinyon and juniper trees, which outcompete the shrub and grass understory, often reducing surface fuels but increasing the risk of high severity crown fires. Land managers implement fuel treatments to reduce or redistribute burnable material in hopes of decreasing fire intensity and burn severity (Reinhardt et al., 2008). In annual grass-invaded sagebrush, herbicide, mowing, and prescribed fire treatments can reduce fuel loads and reduce subsequent wildfire risk (Ellsworth et al., 2022). For areas with increased shrub and tree fuel, treatments such as prescribed fire (Davies and Dean, 2019) and conifer reduction (Dittel et al., 2018) may break up continuous woody cover, decreasing the spread of invasive species, reducing flammable fuel loads, and providing access points for fire suppression (Davies and Dean, 2019; McIver et al., 2010).

Long-term experimental data provide information on the effects of fuel treatments on vegetation change and fuel accumulation; however, modelling allows us to leverage that data to estimate potential fire behaviour. Here we used the long-term treatment plots in the SageSTEP network (McIver et al., 2010) to 1) understand how fuel treatment type affects fuel accumulation in shrublands and woodlands 2) understand the durability of treatments over long time periods; and 3) develop management recommendations for retreatment intervals that maximize restoration and conservation of sagebrush ecosystems while mitigating fire risk.

Methods

The SageSTEP network spans an elevation range of 262-2500 m and a precipitation range of 164-458 mm providing an opportunity to examine responses to fuel treatments across climatic and productivity gradients (McIver and Brunson, 2014). At each of 19 sites, woody fuel treatments were applied across the entire area of each treatment plot (prescribed fire, mechanical, herbicide, or untreated control). Prescribed fires were intended to remove all woody vegetation. Mechanical treatments in shrubland network plots consisted of mowing shrubs to remove approximately half of the canopy. Mechanical treatments in woodland network plots consisted of cutting and dropping all trees. Herbicide treatments were done in the shrubland network plots only; Tebuthiuron, an herbicide that targets broadleaf plants, was applied to remove approximately half of the shrub canopy. Pre-treatment data were collected, and treatments were applied in year 0 and post-treatment data were collected in years 1, 2, 3, 6, 10, and 15 following treatments. Tree height and woody and herbaceous plant biomass and cover data were collected by species at each sampling event and were used to create custom fuel models for each site at each sample year.

To estimate the impact that fuel treatments had on fire behaviour over the 15 year study period, we parameterized the fire behaviour modelling system Fuel Characteristic Classification System (FCCS) in the Fuel and Fire Tool (FFT) (Prichard et al., 2013) with these custom fuel models. Slope assumptions for each model run were based on the average % slope (range 0-10%) (McIver and Brunson, 2014) and wind speed assumptions were based on the 80th percentile wind speed over the summer (June-September) from the nearest remote automated weather station for the study years.

Environmental scenarios were chosen to represent the range of fuel moisture expected as vegetation phenology progresses from the active growing season (fully green scenario; D2L4 scenario in FFT), through partially curing stages (1/3 cured and 2/3 cured scenarios; D2L3 and D2L2, respectively), to late in the summer, when fuels are completely dry and risk of high intensity fire is greatest (fully-cured scenario;

D2L1). Model outputs chosen to characterize fire behavior included rate of spread (ROS; m min^{-1}), flame length (FL; m), and reaction intensity (RI; the rate of heat release per unit area of the flaming front; kW m^{-2} min^{-1}) (Byram, 1959). Linear mixed models were also used to test for differences in the rate of spread, flame length, and reaction intensity (response variables) as a function of environmental scenario (*i.e.* fuel moisture conditions), treatment, and time since treatment.

Results

In the shrubland network, reduction of woody fuels and subsequent release of the herbaceous understory from shrub competition resulted in changes in modelled fire behaviour metrics (rate of spread, flame length, reaction intensity) that differed by shrub fuel treatment. Prescribed fire plots had the greatest reductions (49%) in modelled fire behaviour metrics, as this treatment was the only one to remove a large portion of the total fuel load from the sites. Shrub and downed woody fuel remained present but was sparse throughout the fifteen years after prescribed fire, while herbaceous fuel increased. The increases in herbaceous fuel in this study were primarily driven by perennial deep-rooted grasses through year six. In years 10- 15, perennial cover returned to levels seen in the control and there was a concomitant increase in annual grasses. The increase in herbaceous fuel likely increased fuel continuity assuring rapid fire spread, while the reduction of woody and shrub fuels decreased flame length. The reduction in reaction intensity with prescribed fire was short-lived. We anticipated a reduction in modelled flame length due to the mow treatment, but we found that mowing was nearly as effective as prescribed fire at reducing reaction intensity and fire rate of spread. However, the reduction in modelled fire spread and reaction intensity lessened in year 3 onward, whereas reduced modelled flame lengths were maintained for at least 10 years, with variability in sites. Herbicide treatments did not alter fuel loads or modelled fire behaviour.

In the woodland network, prescribed fire reduced shrub fuel but substantially increased herbaceous fuel, while mechanical tree reduction resulted in both increased live shrub fuel and downed wood. These changes in vegetation structure and fuel loads modified predicted fire behaviour such that fuel treatments increased surface fire behaviour for the first fifteen years post-treatment. By year fifteen, however, all treatments prevented crown fire spread, which was possible in control plots in later years of the study due to increased density of small pinyon and juniper trees. These findings demonstrate a significant management trade-off between short-term increases in surface fire behaviour for restoration of shrubland plant communities and long-term reductions in the potential for crown fire spread.

Discussion and Conclusion

Fuel treatments are commonly applied in sagebrush ecosystems to reduce fire risk associated with annual grass invasion and conifer encroachment. These fuel treatments can have significant effects on vegetation communities and fuel loads, thus affecting future fire behaviour. While these treatments may provide useful tools for managers, we need to better understand the durability and long-term effects of fuel treatments on vegetation and fuels, particularly along productivity and climatic gradients. As there are proposed fuel breaks for 11,000 miles in the Intermountain West, USA, it is imperative we understand the short- and long-term implications of these fuel treatments in current and future climate conditions. While there are important site-specific results to consider, we commonly saw woody fuel treatments in the shrubland network that remained durable through years 10 to 15 post-treatment. In the woodland network, in contrast, regeneration of young trees limits the efficacy of treatments in the long term. We recommend that site-specific regeneration dynamics be closely monitored, and manual removal of small trees be done at 5 year intervals to preserve treatment integrity.

The efficacy and spatial arrangement of fuel treatments, as well as initial site conditions are highly influential on potential for access and fire suppression, as well as for protecting valuable natural resources. Treatment effectiveness may depend on weather conditions for prescribed burning, appropriate use of machinery, and adequate herbicide application. Additionally, practitioners should consider the broader landscape to strategically place treatments where they are readily accessible by fire personnel and take advantage of existing roads, prevailing wind direction, and local topography to best protect valued resources. Repeated treatments will need to be considered when initial treatment begins to lose effectiveness, as we begin to see in the later years of this study. Finally, understanding pretreatment condition and inherent site characteristics, such as resilience to disturbance and ability to resist invasion, can help guide placement of treatments and estimate the likelihood that the fuel treatments will be ultimately beneficial rather than contribute to further degradation (Chambers et al., 2019, 2014; Shinneman et al., 2019).

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