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Research Note

Fall and spring grazing influence fire ignitability and initial spread in shrub steppe communities

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Abstract. The interaction between grazing and fire influences ecosystems around the world. However, little is known about the influence of grazing on fire, in particular ignition and initial spread and how it varies by grazing management differences. We investigated effects of fall (autumn) grazing, spring grazing and not grazing on fuel characteristics, fire ignition and initial spread during the wildfire season (July and August) at five shrub steppe sites in Oregon, USA. Both grazing treatments decreased fine fuel biomass, cover and height, and increased fuel moisture, and thereby decreased ignition and initial spread compared with the ungrazed treatment. However, effects differed between fall and spring grazing. The probability of initial spread was 6-fold greater in the fall-grazed compared with the spring-grazed treatment in August. This suggests that spring grazing may have a greater effect on fires than fall grazing, likely because fall grazing does not influence the current year's plant growth. Results of this study also highlight that the grazing–fire interaction will vary by grazing management. Grazing either the fall or spring before the wildfire season reduces the probability of fire propagation and, thus, grazing is a potential fuel management tool.

Additional keywords: fuel management, fuel moisture, grazing–fire interaction, grazing management, sagebrush, wildfire suppression.

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Introduction

Grazing, fire and their interaction affect ecological dynamics of wildlands globally (Fuhlendorf and Engle 2004; Kerby *et al.* 2007; Waldram *et al.* 2008). However, little is known about the influence of grazing on fires in many ecosystems, in particular its potential to be used as a fuel management tool. As area burned in wildfires is increasing in some regions and incidences of large wildfires occur more frequently (Krawchuk *et al.* 2009; Adams 2013; Doerr and Santín 2016), it is critical to understand the effects of grazing. This is especially imperative in ecosystems experiencing unprecedented change from increased wildfire frequency (D'Antonio and Vitousek 1992).

The increase in large wildfires has resulted in billions of dollars expended annually to suppress wildfires in the US (National Interagency Fire Center 2017). These costs will likely increase because larger and more frequent and severe wildfires are expected with climate change and increasing CO_2 levels (Fried *et al.* 2004; Fulé 2008; Yue *et al.* 2013). These effects have resulted in an increased need for fuel management (Daugherty and Snider 2003; Snider *et al.* 2006). However, it is challenging and potentially prohibitively expensive to apply fuel management across vast wildlands. Grazing by livestock is likely the most cost effective and practical treatment to apply across large landscapes scales to manage herbaceous fuels (Davies *et al.* 2015). Grazing can reduce fuel biomass, heights and continuity, and increase fuel moisture content (Blackmore and Vitousek 2000; Briggs *et al.* 2002; Davies *et al.* 2010, 2015). These grazing-induced alterations to fuels can result in less extreme fire behaviour, intensity and severity (van Langevelde *et al.* 2003; Kimuyu *et al.* 2014; Evans *et al.* 2015; Davies *et al.* 2016). However, the effects of grazing, through fuel modification on ignition and initial fire spread (from ignition to the next fuel source) are unknown.

Grazing effects have largely been confined to comparing one grazing management strategy with ungrazed areas. Grazing influence on fuel characteristics, fire ignition and initial spread, however, likely varies by grazing management. Effects of grazing on plant communities depend on grazing management (Davies *et al.* 2014); therefore, intuitively, grazing effects on fire vary by grazing management. However, the effects of different grazing management on fuel and fire characteristics have not be investigated. Many grazing management strategies exist; however, three grazing scenarios typically occur before the wildfire season: (1) ungrazed in the past and current growing season (ungrazed); (2) grazed in the fall of the prior year, but ungrazed in the current year (fall-grazed); and (3) ungrazed in the prior year, but grazed in the spring of the current year (spring-grazed).

The purpose of the present study was to evaluate effects of fall and spring grazing by cattle (*Bos taurus*) on fuel characteristics and probability of fire ignition and initial spread during the wildfire season. We hypothesised that: (1) both grazed treatments would increase fine fuel moisture, decrease fuel biomass, height, continuity and cover, and decrease fire ignition and initial spread probabilities compared with the ungrazed treatment, (2) that these effects would be greater in the spring- than fall-grazed treatment.

Materials and methods

Study area

Five study sites were located ~50–56 km west of Burns, Oregon, USA (latitude 43°29′N, longitude 119°43′W). Climate is cool and wet in the winter and hot and dry during the summer. Wildfire season occurs during the summer, with most wildfires occurring in July and August. Study sites were Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle and A. Young)–bunchgrass communities with an understorey dominated by native bunchgrasses. Shrub cover averaged 21% across study sites. Dominant bunchgrasses were Thurber needlegrass (*Achnatherum thurberianum* (Piper) Barkworth) and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve). Average distance between study sites was 3 km. Elevation at study sites ranged from 1402 to 1469 m with slopes between 0 and 20%. Crop year precipitation (1 Oct–30 Sept) was 90 and 86% of the 30-year average in 2014–15 and 2015–16 respectively. These shrub steppe communities are estimated to have historically burned every 50–100+ years (Mensing *et al.* 2006).

Experimental design

We used a randomised complete block design with five sites (blocks) and three treatments. Treatments were randomly assigned to 50 × 50-m plots in each block. Plots had a 5-m buffer between them to reduce edge effects. Treatments were: ungrazed, fall-grazed and spring-grazed. Grazing treatments were applied with five heifers (365 to 450 kg) that grazed plots until 40 to 50% of the available forage was consumed based on the method described in Anderson and Curreir (1973). The fall- and spring-grazing treatments occurred in late September of 2015 and in late May–early June of 2016 respectively. The ungrazed treatment was not grazed in 2015 and 2016.

Probability of ignition, bunchgrass burning and initial fire spread were measured during the wildfire season on 19 July 2016 and 24 August 2016. Relative humidity averaged 27 and 22%, wind speed ranged from 1.2 to 13.5 km h^{-1} and 1.8 to 13.2 km h^{-1}, and air temperature averaged 24 and 24°C during the July and August trials respectively. Fire ignitions were applied to all three treatments in each block within a 30-min time interval. Order of ignition among treatments in each block was randomly assigned during trials.

Measurements

Probability of ignition was determined along two randomly located 1-m transects in each treatment replicate. Every 10 cm along each transect, a lighter was lit and held on for 2 s. Ignition was considered successful if, after extinguishing the lighter, flames continued for ≥2 s. Probability of ignition was determined by the number of successful ignitions divided by total number of attempts. During ignition attempts, the lighter was positioned at a 45° angle with the tip positioned 1 cm off the soil or fuel surface with the flame adjustment at the highest setting. All ignition attempts were performed from the upwind side. Two bunchgrasses were selected at random on each sampling date in each treatment replicate and ignited with the lighter using the above procedure. Ignition occurred on the upwind side of the bunchgrass. A bunchgrass was considered burned if the entire crown was burned (i.e. black). Initial spread was considered successful if flames from the ignited bunchgrass ignited another fuel source.

Herbaceous and shrub fuel moisture were measured before ignition attempts in each treatment. Herbaceous fuel was harvested from five randomly located 0.2-m^2 quadrats. Shrub fuel moisture was measured by harvesting one 7–10-cm branch from five randomly selected shrubs. Harvested biomass was weighed in the field, oven-dried, and reweighed to determine moisture content. Fuel moisture was calculated as a percentage of dry weight.

In July, cover and continuity of herbaceous and shrub fuels were measured using four 20-m transects randomly placed within each treatment replicate. Herbaceous and shrub cover was determined by the line-intercept method (Canfield 1941). Continuity was the length of continuous herbaceous and shrub cover along each transect. Bunchgrass height was measured on 50 randomly selected plants in late July in each treatment replicate. The tallest current year's growth and prior years' growth were measured on each bunchgrass. Fine fuel biomass was collected in late July by harvesting 10 randomly located 1-m^2 quadrats in each treatment replicate. Collected biomass was oven-dried and then weighed.

Statistical analysis

Repeated-measures analysis of variance using the PROC MIXED procedure in *SAS*, ver. 9.4, was used to compare the response of repeatedly measured variables to treatments. Sampling date was the repeated variable, treatment was considered a fixed variable, and block and block-by-treatment interactions were treated as random variables in the models. The appropriated covariance structure was selected based on Akaike's Information Criterion (Littell *et al.* 1996). Non-repeatedly measured variables were analysed using analysis of variance using the PROC MIXED procedure in *SAS*, ver. 9.4. Data that did not meet assumptions of analysis of variance were square-root or log-transformed. Figures and text present non-transformed (i.e. original) data. Means were separated using the Fisher's Least Significant Difference method ($\alpha = 0.05$) and reported with standard errors.

Results

Probability of ignition differed among treatments and varied by date (Fig. 1; $P < 0.001$ and 0.021). Ignition probability was 170 to 220% greater in the ungrazed compared with the fall- and spring-grazed treatments ($P = 0.001$ and <0.001), but did not differ between grazed treatments ($P = 0.284$). Probability of perennial bunchgrass burning varied among treatments (Fig. 1; $P = 0.037$), but did not differ between dates ($P = 0.448$).

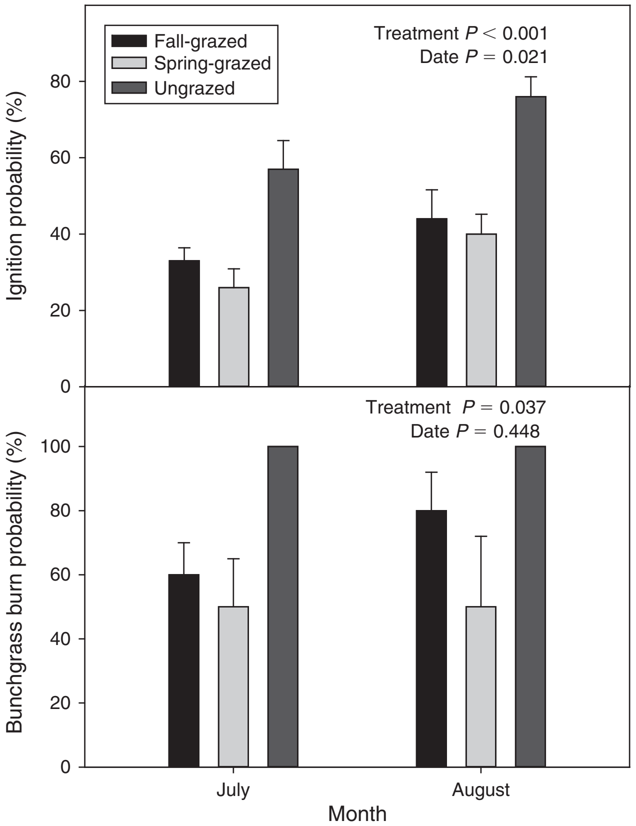

Fig. 1. Ignition (top) and bunchgrass burn (bottom) probability (mean + s.e.) expressed as a percentage in July and August among treatments. Fall-grazed, grazed in the prior fall; Spring-grazed, ungrazed in the fall prior, but grazed in the spring before sampling; Ungrazed, not grazed in the prior fall or the spring before sampling.

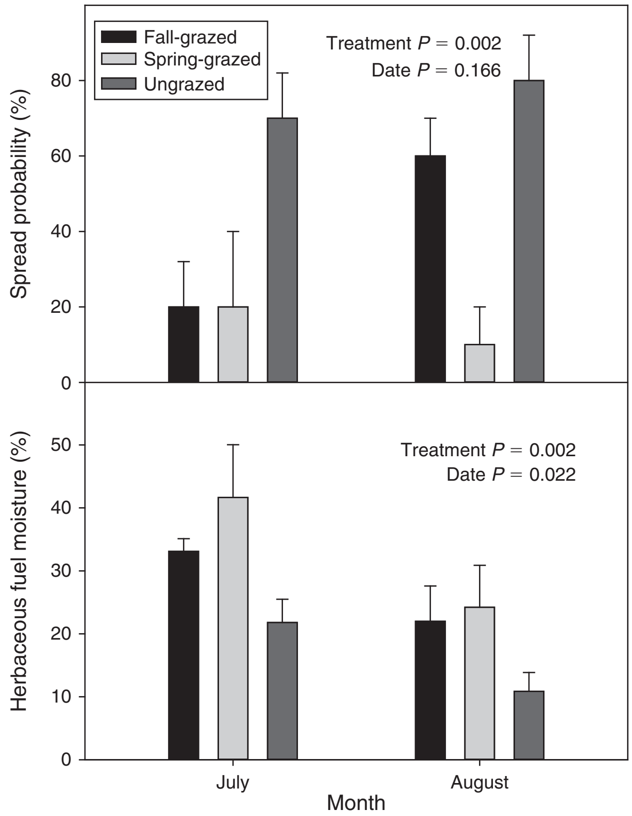

Fig. 2. Fire spread probability (top) and herbaceous fuel moisture (bottom) (mean + s.e.) expressed as a percentage in July and August among treatments. Fuel moisture was calculated as a percentage of dry weight. Fall-grazed, grazed in the prior fall; Spring-grazed, ungrazed in the fall prior, but grazed in the spring before sampling; Ungrazed, not grazed in the prior fall or the spring before sampling.

Perennial bunchgrasses were 200% more likely to burn in the ungrazed than the spring-grazed treatments ($P = 0.013$). Bunchgrass burn probability did not differ between the ungrazed and fall-grazed treatments or the fall- and spring-grazed treatments ($P = 0.092$ and 0.238). Likelihood of initial spread differed among treatments (Fig. 2; $P = 0.002$), but did not vary between dates ($P = 0.166$). Spread probability was greater in the ungrazed than in the fall- and spring-grazed treatments ($P = 0.030$ and <0.001) and greater in the fall-grazed compared with the spring-grazed treatment ($P = 0.022$). The probability of spread was 8 times greater in the ungrazed compared with the spring-grazed treatment in August. The interaction between date and treatment was not significant for ignition, bunchgrass burn probability or initial spread ($P > 0.05$).

Herbaceous fuel moisture varied among treatments and by date (Fig. 2; $P = 0.002$ and 0.022). Herbaceous fuel moisture was 1.6 to 1.9-fold and 2.0 to 2.2-fold greater in the grazed treatments compared with the ungrazed treatment in July and August respectively ($P = 0.004$ and <0.001). Grazed treatments did not differ in herbaceous fuel moisture ($P = 0.250$). Sagebrush moisture did not differ among treatments (data not shown; $P = 0.590$), but was 1.7 times greater in July than in August (data not shown; $P < 0.001$).

Herbaceous fuel cover varied among treatments (Fig. 3; $P = 0.014$) with it being 140 and 170% greater in the ungrazed compared with the fall-grazed and spring-grazed treatments respectively ($P = 0.021$ and 0.006). Herbaceous fuel cover did not differ between grazed treatments ($P = 0.414$). Continuity of herbaceous fuel varied among treatments (Fig. 3; $P = 0.050$). Herbaceous fuel continuity length was 1.5-fold greater in the ungrazed than spring-grazed treatment ($P = 0.018$), but did not differ between the ungrazed and fall-grazed treatments ($P = 0.170$) or grazed treatments ($P = 0.183$). Shrub cover and continuity did not vary among treatments (data not shown; $P = 0.288$ and 0.936). The height of perennial bunchgrass current year's growth varied among treatments ($P < 0.001$). Perennial bunchgrass current year's growth height was less in the spring-grazed (16 ± 2 cm) compared with the fall-grazed (38 ± 3 cm) and ungrazed (45 ± 4 cm) treatments ($P < 0.001$), but did not differ between the fall-grazed and ungrazed treatments ($P = 0.193$). Height of bunchgrass prior years' growth varied among treatments ($P = 0.001$). It was greater in the ungrazed (18 ± 4 cm) treatment compared with the fall- (6 ± 1 cm) and spring-grazed (5 ± 2 cm) treatments ($P = 0.001$ and <0.001), but did not differ between grazed treatments ($P = 0.693$). Fine fuel biomass varied by treatment

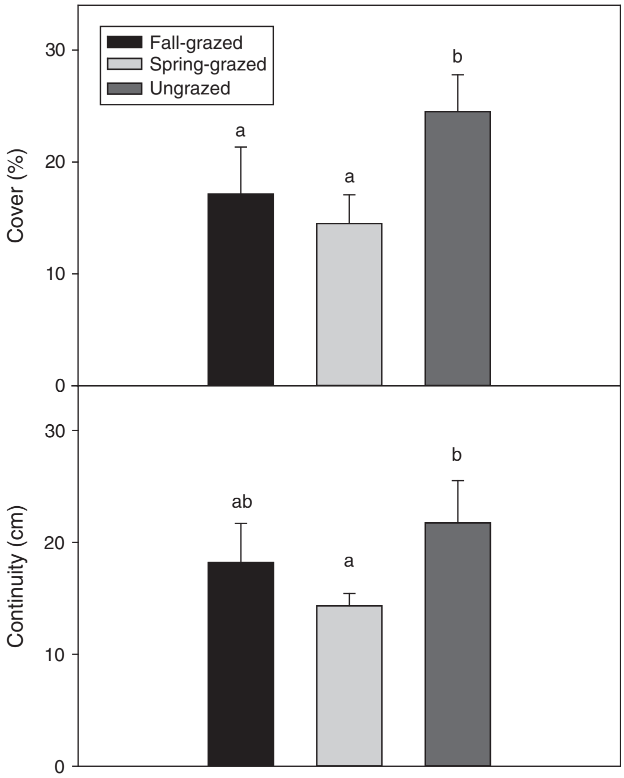

Fig. 3. Herbaceous cover (top) and continuity (bottom) (mean + s.e) among treatments in July. Continuity is the average length of continuous herbaceous fuel without a gap measured with the line-intercept method. Fall-grazed, grazed in the prior fall; Spring-grazed, ungrazed in the fall prior, but grazed in the spring before sampling; Ungrazed, not grazed in the prior fall or the spring before sampling. Lower-case letters represent significant differences among treatments ($P \leq 0.05$).

($P = 0.004$) and was greater in the ungrazed (703 ± 94 kg ha^{-1}) compared with the fall- (365 ± 31 kg ha^{-1}) and spring-grazed (242 ± 72 kg ha^{-1}) treatments respectively ($P = 0.039$ and 0.001) and greater in the fall- than the spring-grazed treatment ($P = 0.048$).

Discussion

Both grazing strategies modified fuels in ways that reduce fire behaviour severity. Similarly, others have found grazing reduced fuel biomass, heights and continuity, and increased moisture content (Blackmore and Vitousek 2000; Briggs *et al.* 2002; Davies *et al.* 2010, 2015). In agreement with prior research (Davies *et al.* 2010, 2015), we found that grazing by cattle did not appear to influence shrubs. Though both grazing treatments influenced fine fuels, spring grazing decreased fine fuel height and biomass during the wildfire season more than fall grazing. Herbaceous fuel continuity also appeared to be influenced more by spring grazing compared with fall grazing as it was less in the spring-grazed treatment than the ungrazed treatment, but did not differ between the fall-grazed and ungrazed treatment. Fall grazing had less effect on fuels than spring grazing because fall grazing did not influence current year's herbaceous vegetation. Therefore, the cumulative effect of spring grazing on fire is expected to be greater than the effect of fall grazing when fires occur within the normal wildfire season.

Grazing effects on fine fuel characteristics decreased fire ignition probability and initial behaviour. Reduced fuel amounts and greater fuel moisture also decreased wildfire ignition and spread in other ecosystems (Rorig and Ferguson 1999; Littell *et al.* 2009; Prestemon *et al.* 2013). The effects of grazing on fire spread varied by management strategy, with initial spread being less in the spring- compared with the fall-grazed treatment. This difference between grazing management strategies was most evident in August, when the fall-grazed treatment was 6-fold more likely to have initial fire spread than the spring-grazed treatment (Fig. 2). Thus, spring grazing, compared with fall grazing, is more likely to induce changes in fuels that reduce the likelihood of wildfire, even though both treatments were associated with reduced ignition potential and initial fire spread.

Effects varied by grazing management strategy, highlighting the importance of understanding the complexity of grazing and the grazing–fire relationship and not treating grazing as a simply grazed or ungrazed. We only evaluated differences in timing of one grazing event; however, effects on fire likely vary by a host of factors including defoliation level and frequency, herbivore type, grazing history, plant community and site characteristics, and interactions among these factors. A better understanding of how grazing management influences fuels and subsequent wildfires across a broad range of plant community and site characteristics is needed to improve management. This is particularly important because of increasing frequency and size of wildfires (Fulé 2008; Krawchuk *et al.* 2009; Adams 2013) and escalating cost of suppression (Calkin *et al.* 2005; National Interagency Fire Center 2017).

Grazing and fire occur across the majority of wildlands around the globe; therefore, our results suggest grazing is likely influencing the probability of initial ignition and spread of fires globally. Grazing, for example, has been demonstrated to reduce fire temperature and severity in Africa (van Langevelde *et al.* 2003; Kimuyu *et al.* 2014) and, similarly, in the United States (Davies *et al.* 2016). Thus, our results suggest that grazing has the potential to be managed to decrease the probability of wildfire propagation in many fire-prone ecosystems. Using livestock grazing to manage herbaceous fuels may be especially valuable in ecosystems that are experiencing a positive feedback between exotic grasses and fire. For example, exotic grass–fire cycles have developed in parts of Australia, tropical America and western North America (D'Antonio and Vitousek 1992).

A challenge with using grazing to manage fuels is that improper grazing can negatively affect plant communities (Daubenmire 1940; Mack and Thompson 1982; Reisner *et al.* 2013). Strategic application of grazing is needed to manage fuels, minimise undesired effects and achieve a broad range of management goals in fire-prone ecosystems. Fuel management will probably not be crucial every year, allowing for diverse management applications to maintain a wide array of ecosystem services. Fuel management is likely most beneficial after high-herbaceous-production years. Big wildfire years often occur after a year or two of above-average plant production (Knapp 1998; Westerling *et al.* 2003; Littell *et al.* 2009). Grazing effects, however, vary by fuel characteristics, especially those fuels not influenced by grazing and fire weather (Strand *et al.* 2014; Schachtschneider 2016). Nevertheless, grazing is a tool that can decrease the probability of wildfire propagation.

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