Effects of targeted cattle grazing on fire behavior of cheatgrass-dominated rangeland in the northern Great Basin, USA

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Abstract. We evaluated the effectiveness of using targeted, or prescribed, cattle grazing to reduce the flame length and rate of spread of fires on cheatgrass (Bromus tectorum)-dominated rangeland in northern Nevada. Cattle removed 80–90\% of B. tectorum biomass during the boot (phenological) stage in grazed plots in May 2005. Grazed and ungrazed plots were burned in October 2005 to assess fire behavior characteristics. Targeted grazing reduced B. tectorum biomass and cover, which resulted in reductions in flame length and rate of spread. When the grazing treatments were repeated on the same plots in May 2006, B. tectorum biomass and cover were reduced to the point that fires did not carry in the grazed plots in October 2006. Fuel characteristics of the 2005 burns were used to parameterize dry-climate grass models in BEHAVE Plus, and simulation modeling indicates that targeted grazing in spring (May) will reduce the potential for catastrophic fires during the peak fire season (July–August) in the northern Great Basin.

Additional keywords: Bromus tectorum, fire modeling, flame length, fuel loading, rate of spread.

Introduction

Bromus tectorum (cheatgrass) is an invasive annual grass that originated in Eurasia and is now dominant on many rangelands in the western USA (Mack 1981). Invasion has set in motion a grass–fire cycle where B. tectorum provides the fine fuel necessary for the initiation and propagation of fire, and fire facilitates the spread of B. tectorum (D’Antonio and Vitousek 1992). Frequent fires preclude the establishment of native species, while B. tectorum recovers from seeds in an abundant soil seed bank (Young et al. 1969, 1987).

The 1995 Federal Wildland Fire Management Policy and Program Review report (updated, US Department of Interior 2001) encourages a more proactive approach to reduce the threat of catastrophic wildfires (fires with a fast-moving front, extending over a large area) on rangelands in the western USA. The report states that strategic landscape-scale fuel management will require the integration of a variety of treatment methods (fire, chemical, and biological), and recommends research and development on fuel reduction alternatives. Using prescribed fire to reduce fuel loads is effective but can be risky in areas that are dominated by fine fuels like the annual grass Bromus tectorum. In addition, prescribed fire only has an impact on seed input before seed-shatter when fuel moistures are still fairly high and thus burning is difficult (Rasmussen 1994; Brooks 2002). Herbicide treatments can reduce fuel build-up in B. tectorum-dominated landscapes, but they can be costly and have real or perceived effects on environmental quality (Vallentine 1989). Livestock grazing, primarily by sheep and goats, is recognized as an effective tool for fuel reduction in brush communities in Texas and California (Taylor 1994), and sheep grazing has been used for B. tectorum fuel reduction in Nevada (Davison 1996; Smith et al. 2000). Cattle have been used to reduce fuel loads of introduced perennial grasses in a seasonally dry tropical forest in Hawaii (Blackmore and Vitousek 2000). However, there is no information available on the use of cattle as fuel reduction agents on rangelands dominated by annual grasses, although they have been used to suppress B. tectorum before the seeding of desirable perennials (Vallentine and Stevens 1994).

To be effective, fuel reduction must keep pace with fuel accumulation (Pyne et al. 1996). In the northern Great Basin, biomass production for Bromus tectorum averages 500–600 kg ha\textsuperscript{−1}, and can range from 30 to >1500 kg ha\textsuperscript{−1}, depending on precipitation (Uresk et al. 1979). Unconsumed biomass is typically compressed to the soil surface by snow in the winter, adding fuel to the litter bed and increasing fuel connectivity. Fuel loading has a strong influence on flame length and rate of spread (Pyne et al. 1996), and without some type of fuel reduction in B. tectorum-dominated communities, fuel loads can get high enough to support fires within a few years.

Targeted, or prescribed, cattle grazing at the most susceptible phenological stage (boot stage, i.e. inflorescence emergence from leaf sheath) can remove biomass, diminish subsequent regrowth, and reduce seed input of Bromus tectorum (Vallentine and Stevens 1994). By removing biomass, the fuel carry-over via the litter bed is drastically reduced. The purpose of the present project was to evaluate the effectiveness of using targeted cattle grazing to reduce the flame length and rate of spread of fires on B. tectorum-dominated rangelands in the northern Great Basin.
The study site is located in north-western Nevada, 20 km south-east of McDermitt (41°56.434′N, 117°47.099′W) within the Quinn River Management Area of the Bureau of Land Management Winnemucca Field Office. It is on a 5% slope with a western aspect at 1400-m elevation. Average annual precipitation is 228 mm, most of which falls as snow from November through March. Mean maximum (July) and minimum (January) temperatures are 17 and −1°C respectively. The site has 50–60% Bromus tectorum cover (standing cover at peak biomass in June). Other species include clasping pepperweed (Lepidium perfoliatum), tumble mustard (Sisymbrium altissimum), Scotch thistle (Onopordum acanthium), Sandberg bluegrass (Poa secunda), bulbous bluegrass (Poa bulbosa) and sixweek fescue (Vulpia octoflora). Islands of the native shrub big sagebrush (Artemisia tridentata spp. wyomingensis) are scattered throughout. The site is part of a 19 830-ha grazing allotment that is divided into 15 pastures and grazed in a rest–rotation–deferment system, where pastures are used early (1 March to 15 May), late (1 May to 31 August), deferred (1 July to 31 August), or in full (autumn) and winter (1 October to 28 February), or receive complete rest in alternating years (USDI-BLM 1998). This allotment consists of private and public land; the private lands are dominated by the B. tectorum community described above, whereas the public portion of this allotment is dominated by crested wheatgrass (Agropyron desertorum). Approximately 1500 cow–calf pairs are divided into four distinct herds, each of which is generally grazed in separate pastures throughout the grazing season. Historically, herbaceous forage utilization estimates have ranged between 20 and 40% for the pastures. The site has burned in 1972, 1985, 1994 and 1996 as the result of wildfires.

Soils are characteristic of the McConnel series (sandy-skeletal, mixed, mesic Xeric Haplocambids). These are deep soils formed with mixed rock particles and components of loess and volcanic ash over lacustrine deposits or gravelly alluvium fans extending into the Quinn River Valley (USDA-NRCS 1997). These soils correspond to Loamy, Claypan, and Droughty Loam ecological sites in the 200–350 mm precipitation zone (USDA-NRCS 1997).

Fuel treatments and experimental design

Four grazing–burning treatments, graze and no-burn (G/NB), graze and burn (G/B), no-graze and burn (NG/B), and a no-graze and no-burn control (NG/NB), were arranged in a 2 × 2 factorial design in a block, and replicated three times. Treatment plots were 60 × 60 m. Strips (10 m wide) were moved between treatments to reduce the potential of fire spread. The southern edge of each block had a 35-m-wide untreated Bromus tectorum ‘wick’ (50–60% cover) to carry fires into the treatment plots.

Although the present paper only addresses fire behavior, the overall study was designed to also assess the resulting seed-bank dynamics and aboveground community composition. Thus, we focus here on the two burn treatments (G/B and NG/B); the grazing-only and control treatments (G/NB and NG/NB) are presented to provide a clearer understanding of the overall study layout. The G/B and G/NB treatments were intensively grazed (equivalent of 83 cow–calf pairs ha⁻¹) during the boot stage (inflorescence emergence from the leaf sheath) of Bromus tectorum in early May 2005. The plots were grazed to 80–90% removal of aboveground biomass over a 32–40-h period. Cool temperatures and frequent precipitation promoted regrowth and additional germination of B. tectorum, so intensive grazing (same duration and stocking density) was repeated on G/B and G/NB treatments in late May (boot stage) to maintain 80–90% removal of aboveground biomass. The G/B and NG/B treatments were burned in mid-October 2005 to assess the effects of fuel reduction on flame length and rate of spread. The NG/NB control provided an estimate of aboveground biomass and species composition in the absence of grazing and burning. Grazing and burning treatments were repeated respectively in May and October 2006 for the seed-bank and community composition portion of the overall study. The 2006 grazing treatments also required two periods of grazing (boot stage), in response to cool, moist spring conditions.

The G/B and NG/B treatments were located at the southern end of all three blocks. The ignition point for all prescribed burns was a 35-m-wide Bromus tectorum wick, which allowed fires to reach peak behavior (flame length and rate of spread) before contacting the interface of the two burn treatments. Fire behavior was recorded using three video cameras. One camera was mobile, and moved with the flame front along the north–south axis of the burn. This camera recorded the rate of spread and flame length of the burn in the wick 10 m before reaching the G/B and N/GB treatments, at the interface of the wick and treatments, and at 5, 15, 35 and 55 m inside the treatment plots. Each of these points was marked with a 2-m Robel pole, which had alternating black and silver 10-cm bands. This allowed an accurate estimation of the flame length and rate of flame spread in the wick and treatments. The two additional cameras were placed 20 m beyond the plot boundary at the north-east and north-west corners of each plot. This allowed a different view of flame length and rate of spread. This was necessary because wildfire behavior is dependent on wind speed and direction, which can force smoke across the camera view, thus occluding filming.

The effects of targeted grazing on flame length and rate of spread were analyzed as a two-way factorial (grazing × distance) in a split-plot design with whole plots in blocks. Grazing is the treatment variable (G/B or G/NB) and distance is the distance between Robel poles. Grazing treatments were nested within blocks and distance was nested within grazing treatments. The significance of the relationship between grazing and distance, and flame length and rate of spread was tested using a mixed-model ANOVA ($P \leq 0.05$) (SAS Institute 2005).

Climatic and fuel variables were also recorded to enable an accurate prediction of fire behavior for the fuel type, fuel loading, fuel moisture, fuel bed depth and weather conditions. A portable weather station was on site at the time of the burn, recording air temperature, relative humidity, and wind speed and direction. To estimate fuel loads, we clipped the vegetation in five randomly located 0.5 × 0.5-m quadrats within each burn plot before burning. Vegetation was clipped at the soil surface, separated by species, weighed and then later dried at 60°C for 48 h. Fuel moisture was measured by comparing the wet weight with dry weight within the preburn biomass samples. To evaluate fuel continuity, percentage cover measurements were collected (after grazing,
before burning) using 10 sample points alternating along each of three permanent 30-m transects in each treatment plot. Cover (live plant canopy by species, litter, rock and soil surface) was measured in a 0.5 × 0.5-m quadrat at each sampling point. Litter depth was measured to the nearest mm when encountered in the cover survey. Fuel bed depth was measured at each Robel pole by assessing the plant height at which the pole width was obscured by standing biomass. The relationships between treatment and fuel load, fuel bed depth, litter depth and percentage cover were evaluated with a two-tailed *t*-test (*P* ≤ 0.05).

### Fire behavior modeling

As treatment plots were burned after the peak fire season, fire behavior was also analyzed using the BEHAVE Plus fire modeling system (Andrews et al. 2003). Fuel models were created by substituting fuel parameter (fuel load, surface area-to-volume ratio, fuel bed depth, heat content, extinction moisture) into the low-load, dry-climate grass (GR2 dynamic) fuel model for the G/B treatment and the high-load, dry-climate grass (GR7 dynamic) fuel model for the NG/B treatment (Scott and Burgan 2005). These models were selected owing to the similarity to actual fuel conditions within each treatment. The models were parameterized with the actual fuel and climatic conditions as the input variables. The models were then assessed based on the similarity of output (flame length, rate of spread) to actual fire behavior. Simulations were then run to determine fire behavior in the G/B and NG/B treatments under changing environmental conditions. The simulation conditions were based on actual values (October) for wind speed (3 km h\(^{-1}\)) and fuel moisture (6%) and those found at peak fire season (July–August) in 2005, i.e. fuel moisture (2%) and wind speed (20 km h\(^{-1}\)). It is important to note that models were based on the fuel loads and heights observed in October. At peak fire season, fuel loads and heights may be higher, and thus these models may under estimate fire behavior.

### Results

#### Fuel treatments and prescribed burns

Targeted grazing in May 2005 led to significant reductions in total biomass (*P* < 0.001) and *Bromus tectorum* cover (*P* < 0.001) in the G/B plots before the implementation of prescribed burns in October 2005. When compared with the NG/B treatment, the G/B treatment had less than half the amount of total biomass, two-thirds the amount of *B. tectorum* cover, similar litter cover, half the litter depth, one-third the fuel bed depth and twice the amount of soil cover (Table 1).

During the prescribed burns in October 2005, air temperature was 25 ± 6°C and relative humidity was 21 ± 8%, resulting in a fuel moisture of 6 ± 2%. Wind speed was 3 ± 3 km h\(^{-1}\) and direction was variable. Grazing resulted in significant reductions in flame length between the G/B and NG/B treatments (*F* = 140.39; *P* < 0.001) and across distance within the G/B treatment plots (*F* = 18.25; *P* < 0.001) (Fig. 1). In the wick and at the wick–treatment interface, flame lengths were indistinguishable for the two treatments (*F* = 0.46; *P* = 0.801). As the flame front reached the 5-m point inside the treatments, flame behavior.

### Table 1. Mean values (± s.e.) for plants, litter and soil cover, *Bromus tectorum* and total plant biomass and fuel characteristics, including fuel load, litter depth and fuel bed depth for GB (graze and burn) and NGB (no-graze and burn) treatments in 2005 and 2006

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>2005</th>
<th>GB</th>
<th>NGB</th>
<th>2006</th>
<th>GB</th>
<th>NGB</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>B. tectorum</em> cover (%)</td>
<td>32 ± 4.3</td>
<td>16 ± 4</td>
<td>52 ± 4.3</td>
<td>51 ± 4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Poa secunda</em> cover (%)</td>
<td>1 ± 1.3</td>
<td>10 ± 1.1</td>
<td>7 ± 1.3</td>
<td>11 ± 1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forbs cover (%)</td>
<td>24 ± 1.8</td>
<td>6 ± 1.5</td>
<td>16 ± 1.8</td>
<td>3 ± 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Litter cover (%)</td>
<td>10 ± 3.7</td>
<td>18 ± 3.7</td>
<td>10 ± 3.7</td>
<td>9 ± 3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil cover (%)</td>
<td>30 ± 4.4</td>
<td>45 ± 4.2</td>
<td>15 ± 4.4</td>
<td>17 ± 4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>B. tectorum</em> biomass (kg ha(^{-1}))</td>
<td>340 ± 47</td>
<td>34 ± 43</td>
<td>896 ± 47</td>
<td>101 ± 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total biomass (kg ha(^{-1})) (July)</td>
<td>550 ± 36</td>
<td>63 ± 36</td>
<td>1225 ± 36</td>
<td>122 ± 33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel load (kg ha(^{-1})) (October)</td>
<td>445 ± 84</td>
<td>150 ± 53</td>
<td>1503 ± 227</td>
<td>260 ± 72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Litter depth (cm)</td>
<td>1 ± 0.1</td>
<td>0.8 ± 0.1</td>
<td>2 ± 3</td>
<td>0.6 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel bed depth (cm)</td>
<td>20 ± 1.1</td>
<td>10 ± 0.7</td>
<td>60 ± 21</td>
<td>40 ± 13</td>
<td></td>
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</tr>
</tbody>
</table>

Cover and biomass measurements taken in July; fuel load litter depth and fuel bed depth taken just before burning in October.
The impact of targeted grazing on fire behavior

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Fig. 2. Mean rate of spread for treatments GB (graze and burn), NGB (no-graze and burn) at Robel pole distances inside treatment plots during prescribed burn in October 2005. Distance begins at 0 m at the wick–treatment interface. There were no significant differences at \( P < 0.05 \). The significance of the relationship between grazing and distance, and rate of spread was tested using a mixed-model ANOVA and Fisher’s least significant difference (l.s.d.) \(( P \leq 0.05)\).

Fig. 3. Simulated flame length for treatments GB (graze and burn), NGB (no-graze and burn) based on actual prescribed burn conditions (6% fuel moisture and 3 km h\(^{-1}\) wind) and peak fire season conditions (2% fuel moisture and 20 km h\(^{-1}\) wind) during July–August 2005.

Fig. 4. Simulated rate of spread for treatments GB (graze and burn), NGB (no-graze and burn) based on actual prescribed burn conditions (6% fuel moisture and 3 km h\(^{-1}\) wind) and peak fire season conditions (2% fuel moisture and 20 km h\(^{-1}\) wind) during July–August 2005.

Flame lengths in the G/B treatment \((0.5 \pm 0.1 \text{ m})\) were one-fourth as long as those in the NG/B treatment \((2.3 \pm 0.0 \text{ m})\). By the 15-m point, flame lengths in the G/B treatment \((0.25 \pm 0.1 \text{ m})\) were one-eighth as long as those in the NG/B treatment \((2.3 \pm 0.2 \text{ m})\). Grazing, however, did not lead to significant changes in rate of spread between the G/B and NG/B treatments \(( F = 3.46; P = 0.069)\) (Fig. 2). After the fire encountered the wick–treatment interface, the rate of spread did not exceed 7 m min\(^{-1}\) for either treatment.

A second targeted grazing period within the same treatment blocks in May 2006 led to significant reductions in total fuel biomass \(( P < 0.001)\), Bromus tectorum cover \(( P < 0.001)\) and fuel bed depth \(( P < 0.001)\) in the G/B treatment before the October 2006 prescribed burns. When compared with the NG/B treatment, the G/B treatment had half the amount of total biomass, less than one-third the amount of B. tectorum cover, similar litter cover and depth, and one-fourth the fuel bed depth (Table 1).

During the prescribed burns in October 2006, air temperature was \(22 \pm 10^\circ\text{C}\) and relative humidity was \(18 \pm 12\%\), resulting in a fuel moisture of \(6 \pm 2\%\). Wind speed was \(3 \pm 3 \text{ km h}^{-1}\) and direction was variable. Grazing resulted in complete extinction of the prescribed burn. As the flame front reached the wick–treatment interface, the fire slowed drastically and only carried up to 5 m in several areas of the G/B treatment before complete extinction. The NG/B treatment in 2006 had flame lengths \(( F = 0.54; P = 0.751)\) and rates of spread \(( F = 0.81; P = 0.691)\) similar to those for the G/B treatment in 2005.

Fire behavior modeling

Simulations using the BEHAVE Plus low- and high-load dry-climate grass models provided estimations of fire behavior under differing environmental conditions. The actual fuel moisture \((6\%)\) during the prescribed burns in October 2005 was well above peak fire condition (July–August) fuel moisture \((2\%\)\), and the actual wind speed \((3 \text{ km h}^{-1})\) during the prescribed burns was well below peak fire condition wind speed \((20 \text{ km h}^{-1})\). Under prescribed burn conditions, the low-load dry-climate grass model accurately estimated flame lengths for the G/B treatment \((\text{actual} = 0.2 \text{ m}, \text{modeled} = 0.2 \text{ m})\), and the high-load dry-climate grass model also accurately estimated flame lengths for the NG/B treatment \((\text{actual} = 2.0 \text{ m}, \text{modeled} = 2.2 \text{ m})\). Under peak fire conditions, predicted mean flame lengths \((0.6 \text{ m})\) in the G/B treatment were one-eighth as long as those predicted in the NG/B treatment \((4.8 \text{ m})\) (Fig. 3). The mean actual and modeled rates of spread were similar for the G/B treatment.
The G/B treatment in 2006 was incapable of supporting a fire (Vitousek 1992). Bromus tectorum-dominated sites in the northern Great Basin (Smith et al. 2000) are burned, B. tectorum-dominated sites are characterized by high levels of fine fuel deposition, creating a contiguous and volatile fuel bed (McAdoo et al. 2007a). When sites such as these are burned, B. tectorum communities will continue to dominate (Young et al. 1987). However, targeted grazing of annual grasses at the boot stage can suppress seed production and plant yield (Young et al. 1987; Mosley and Roselle 2006; McAdoo et al. 2007b), and lead to a decrease in fuel biomass and connectivity, thus moderating fire behavior (Taylor 1994).

Targeted grazing reduced the total fuel load and percentage cover of Bromus tectorum in the G/B treatment. These reductions in the fuel load, B. tectorum percentage cover, and fuel bed depth, and the increase in bare soil, resulted in a reduction in fuel connectivity. Although the existing litter cover did not significantly change with grazing, the removal of B. tectorum plants and cattle hoof action led to an increase in bare soil, creating a patchy litter bed (soil patches 0.1–1 m diameter) that still allowed fire to spread through the G/B treatment but resulted in islands of unburned vegetation.

Targeted sheep grazing and herbicide application are also capable of altering the fuel characteristics of Bromus tectorum-dominated sites in the northern Great Basin (Smith et al. 2000; Kury et al. 2002). Smith et al. (2000) used 90 sheep ha$^{-1}$ to reduce herbaceous fuel loads and create a 60-m-wide fuel break along a portion of the urban–wildland interface surrounding Carson City, Nevada. The plant community was dominated by B. tectorum, with interspersed crested wheatgrass (Agropyron desertorum) and Poa secunda. Intensive sheep grazing reduced biomass by 73%, litter by 60% and fuel bed depth by 75%. These findings are similar to ours, in terms of biomass reduction and fuel bed depth; however, litter reduction appears to be higher with the use of sheep. Similarly, Kury et al. (2002) used varying levels of herbicide Plateau (imazapic) to suppress B. tectorum south of Kuna, Idaho. Their site was similar to ours in terms of climatic conditions and species composition, being dominated by B. tectorum with low levels of P. secunda. The use of 437 mL ha$^{-1}$ of herbicide resulted in maximum B. tectorum suppression, reducing B. tectorum biomass by 80–90%, as did our G/B treatment.

Unlike these previous studies (Smith et al. 2000; Kury et al. 2002), our study evaluated the fire behavior of fuel reduction treatments with prescribed burning. As the fuel loads and fuel connectivity were reduced in the G/B treatment, flame lengths were reduced to one-eighth of those in the NG/B treatment. The decrease in flame length resulted in a reduction of fuel preheating adjacent to the flame front (Pyne et al. 1996). Although a 2-m flame length, as in the NG/B treatment, is capable of preheating fuels up to 2 m ahead of the flame front, a 0.25-m flame length, as in the G/B treatment, is only capable of preheating directly adjacent fuels. The low and erratic wind speeds during the prescribed burn resulted in vertical flame lengths; thus, only directly adjacent fuels were preheated, and rates of spread between the G/B and NG/B treatments were not significantly different (Pyne et al. 1996).

Even though we were able to evaluate fire behavior of grazed and non-grazed treatments with prescribed burning, the lack of fire suppression personnel during the peak fire season (July–August) did not allow us to burn until October in 2005 and 2006. However, the October burns did provide baseline data for fire behavior modeling under different fuel and climatic conditions. The simulations based on October 2005 fuel and climatic conditions mirrored the actual fire behavior during the prescribed burn. Given the high degree of similarity between actual and modeled fire behavior under October conditions, the models have high inferential value for peak fire conditions in July and August. Modeling of fire behavior based on our simulations indicates that at lower fuel moisture (2%) and higher wind speed (20 km h$^{-1}$), flame lengths up to 4.5 m play a significant role in preheating fuels. At high wind speeds in grasslands, flame lengths can become near horizontal (Pyne et al. 1996). Under peak fire conditions, a fire in the NG/B treatment could spread at up to 231 m min$^{-1}$, whereas a fire in the G/B treatment is only capable of spreading at up to 12.4 m min$^{-1}$. The combination of a high fuel load, high Bromus tectorum cover and a contiguous litter bed, as in the NG/B treatment, results in a high rate of spread. While litter cover is similar between the two treatments, litter depth is much lower and bare soil is greater in the G/B treatment, owing to the reduced cover of B. tectorum. This shallow and less contiguous litter cover, along with a lower fuel bed depth, reduces the potential for fast-moving fires in the G/B treatment.

Simulations based on the 2006 G/B fuel conditions (resulting from targeted grazing in May 2005 and 2006, and prescribed burning in October 2005) indicate that even under peak fire conditions, a flame front would not carry in this treatment. The simulation models indicate that under peak fire conditions, the 2006 NG/B treatment will support a burn with low flame lengths and slowed rate of spread, as observed in the 2005 G/B treatment. Although this is the first study to evaluate Bromus tectorum fuel reduction with grazing and the consequences for fire behavior, others have used modeling and observed estimates to evaluate fire behavior for other fuel reduction treatments (Smith et al. 2000; Kury et al. 2002). Although the Plateau-treated site in Idaho was not burned, fire behavior was modeled using a short-grass prairie model in BEHAVE Plus (Kury et al. 2002). The resulting simulations of fire behavior indicated that flame lengths in the herbicide treatment would not exceed 0.5 m, whereas the untreated control would exceed 4 m. The model also estimated rates of spread not exceeding 12 m min$^{-1}$ in the herbicide treatment and up to 231 m min$^{-1}$ in the control. Running our
own parameters in the same model indicated that these are slight overestimations of fire behavior. Thus, the treatment effects on modeled fire behavior in the herbicide study were very similar to those in our study. The fuel break created with targeted sheep grazing along the urban–wildland interface surrounding Carson City, Nevada (Smith et al. 2000) did burn in a wildfire event (C. K. Chapman, Utah State University, pers. comm., 2007). Observed estimates during the burn indicate that the grazing treatment suppressed flame lengths from above 2 m to below 1 m and slowed the rate of spread by three-quarters. While the model used by Kury et al. (2002) may have been inappropriate, and the estimates of fire behavior by C. K. Chapman (pers. comm., 2007) were not modeled, they demonstrate a similar change in fire behavior (flame length and rate of spread) associated with similar types of B. tectorum fuel-reduction treatments.

Simulation modeling has also been used to evaluate the potential for livestock grazing to modify fuel loads and fire behavior in perennial plant communities. In Hawaii, introduced African pasture grasses have spread into open-canopied, seasonally dry tropical forests, increasing fire frequency and promoting the conversion of forest to grassland (Blackmore and Vitousek 2000). Cattle grazing was used to reduce biomass and canopy height of kikuyu grass (Pennisetum clandestinum) by 70 and 77% respectively. BEHAVE modeling indicated that under dry and windy conditions (7% fuel moisture and winds of 12 km h\(^{-1}\)), fires in grazed kikuyu grass would be much less intense (0.7-m flame length, covering 1.4 ha after 1 h) than in ungrazed kikuyu grass (3.0-m flame length, covering >75 ha after 1 h). Along the Idaho–Nevada border in the northern Great Basin, the Murphy Wildland Fire Complex burned over 260,000 ha of rangeland in July 2007. A post-fire evaluation team observed completely burned areas, patchily burned mosaics and abrupt contrasts in burn severity within the complex, and indicated that some of the burned mosaics and abrupt contrasts could be attributed to differences in livestock utilization levels before the fire (Lauchnbaugh et al. 2008). Fire modeling using BEHAVE Plus examined how varying the amounts of current-year and residual herbaceous biomass would affect fire behavior in sagebrush communities (Artemisia tridentata) and seeded grasslands (crested wheatgrass (Agropyron cristatum)) under environmental and fuel-moisture conditions. Simulation results revealed that moderate grazing in grasslands could reduce the rate of spread and fireline intensity to a greater extent than in shrublands, particularly under less extreme fire conditions (fuel moisture >12%, wind speeds <16 km h\(^{-1}\)). When burning conditions became extreme (<12% fuel moisture, wind speeds >24 km h\(^{-1}\)), moderate grazing had limited or negligible effects on fire behavior in both vegetation types. A moderate level of utilization is a standard grazing management prescription for most semiarid rangelands in the western USA; therefore, reducing herbaceous biomass to levels that would strongly influence fire behavior under extreme fire conditions would require reductions that would potentially degrade shrub and grassland communities, and compromise sustained livestock production (Lauchnbaugh et al. 2008). In contrast, more intensive grazing could be used to drastically reduce fuel loads in Bromus tectorum-dominated communities that are already degraded and lacking in desirable perennial herbaceous species, and not considered sustainable sources of livestock forage.

In summary, targeted cattle grazing of Bromus tectorum at the boot stage has the potential to moderate the flame length and rate of spread of wildfires. This grazing treatment reduced percentage cover of B. tectorum, fuel bed depth and fuel loading, and thus the flame length and rate of spread. By basing our simulations on the actual burning of the treatments, we provide a high degree of inference to peak fire season estimates. These simulations of fire behavior indicate a decrease in predicted wildland fire behavior (flame length and rate of spread) under peak fire conditions. These findings constitute an initial step in reducing the threat of catastrophic wildfires on B. tectorum-dominated rangelands in the northern Great Basin.

Management implications

The reduction of wildfire flame lengths and rates of spread through targeted grazing leads to a need for fewer fire suppression resources. Flame lengths above 1 m, as observed in the NG/B treatment, require the use of indirect attack methods. Flame lengths near 0.25 m, as observed in the G/B treatment, can be managed via direct attack (Pyne et al. 1996). Fewer fire resources reduce the cost of suppression, and release resources for higher-severity wildfires.

Although a single targeted grazing event, as in May 2005, has the potential to slow a wildfire, the combination of grazing and burning, followed by a second targeted grazing event, as in May 2006, has the potential to stop a wildfire. The reduction in fuel load, fuel bed depth and Bromus tectorum cover along with an increase in bare soil accomplished with a graze–burn–graze treatment appears to virtually eliminate the spread of a wildfire. Under extreme fire conditions (>20 km h\(^{-1}\) wind speeds at low fuel moisture), this treatment will likely not carry a fire but fire spotting across the treatment may occur.

Targeted grazing of Bromus tectorum at the boot stage is capable of reducing flame length and rates of spread, but how should grazing be implemented? Grazing management limits the application of this method in space and time. The temporal window for B. tectorum treatment is narrow, between the short boot stage and soft dough stage (2–3 weeks in spring), and the treatment must be repeated within that window (Mosley and Roselle 2006). The spatial extent of this grazing treatment is limited both by the time of grazing and the management goals for the grazers (McAdoo et al. 2007b). Given these temporal and spatial constraints, we recommend that the two-thirds of a hectare G/B treatment plot size used in the present study can be scaled up in two ways: as a strip or as a large block. A strip 100 m wide could be used as a brown-strip fire break around desirable plant communities or simply to supplement current fire breaks such as roads (McAdoo et al. 2007b). The maintenance of Bureau of Land Management green strips (primarily Agropyron desertorum) in Idaho is reliant on livestock to reduce fuel loads (Davison 1996). Targeted grazing of large blocks and strips could be used as the initial step in the revegetation of B. tectorum-dominated sites (Miller 2006). Grazing B. tectorum may allow native or non-native desirable plants to be seeded into the site following the grazing treatment and establish with reduced competitive pressure from B. tectorum (Svejcar 1990). Targeted grazing of B. tectorum-dominated sites can be applied as a first step in breaking the cheatgrass–fire cycle via removal of fire disturbance. However, caution must be
used in applying this level of biomass removal in a community that retains some native or desirable plant species. The use of this grazing treatment should therefore be limited to degraded rangeland with little or no native perennial plant cover.

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References


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