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Targeted Grazing in Southern Arizona: Using Cattle to Reduce Fine Fuel Loads☆,☆☆,★

Retta A. Bruegger [a,*], Leticia A. Varelas [b], Larry D. Howery [c], L. Allen Torell [d], Mitchell B. Stephenson [b], Derek W. Bailey [d]

[a] Former Graduate Student, School of Natural Resources and the Environment, University of Arizona, Tucson, AZ 85721, USA
[b] Former Graduate Students, New Mexico State University, Las Cruces, NM 88003, USA
[c] Professor, School of Natural Resources and the Environment, University of Arizona, Tucson, AZ 85721, USA
[d] Professors, New Mexico State University, Las Cruces, NM 88003, USA

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ABSTRACT

Managing the risk of wildfires is a growing concern in the western United States. Targeted grazing, or managing livestock grazing to achieve specific vegetation goals, is one possible tool to treat fuels, but few studies have evaluated its efficacy. The goal of this study was to test the effect of targeted grazing on herbaceous fuel loads and fire behavior by 1) implementing targeted grazing in a field experiment and 2) using a fire model (BehavePlus) to evaluate changes in fire behavior resulting from treatments. We applied targeted cattle grazing using low-stress herding and strategic placement of low-moisture block supplement on rugged rangelands in southwestern Arizona using a herd of 58 Red Angus cows and two bulls. Six of the cows were initially fitted with global positioning system collars. We tested two grazing treatments: 1) herding and supplement versus 2) no herding and no supplement on two pairs of study sites and replicated this for 2 years. Herding and supplement affected both the distribution of cattle and herbaceous fuel loads. Despite light utilization (26%) in treated sites, the BehavePlus fire model predicted that herding and supplement reduced fire rate of spread by more than 60% in grass communities and by more than 50% in grass/shrub communities. Fuel treatments dropped flame lengths below a 1.2-m critical threshold under the moderate fuel moisture scenario in grass communities and below a 2.4-m critical threshold in grass/shrub communities under both moderate and extreme fuel moisture scenarios. These results suggest that targeted grazing could reduce the potential cost of fighting fires in conditions similar to this study site. However, implementing this type of treatment on other sites will require careful calibration of animal numbers, supplement amounts, and length of herding periods relative to the specific context and goals.

Introduction

Effectively managing the risk of wildfire is a serious concern of state and federal land management agencies, local governments, and residents throughout the western United States. Urban growth into wildlands, decades of fire suppression, and invasion of exotic species have altered fire cycles in the western United States (D'Antonio and Vitousek, 1992; Agee and Skinner, 2005) and increased the risks to human life and property posed by wildfire. From 1987 to 2003, burned area of forested lands increased sixfold compared with area burned in the previous 16 yr (Schoennagel et al., 2009). Simultaneously, the wildland–urban interface (WUI) has expanded by 52% since 1970 and is expected to grow by another 10% by 2030 (Theobald and Romme, 2007). Arizona is among the top six states in which the WUI is expected to grow (Theobald and Romme, 2007). The combination of growth of human populations into the WUI and increased fire frequency in ecosystems throughout the western United States necessitates the development of tools to manage wildfire risk in ecologically, economically, and socially appropriate ways.

Since the Healthy Forests Restoration Act of 2003, fuel management has been the chosen method of managing fires (Stephens and Ruth, 2005; Keeley, 2006). Fuel management allows land managers to reach several firefighting objectives including reduced fire risk, reduced firefighting costs, reduced ecological impacts, and protection of WUI communities (Mell et al., 2010). Although there are many tools available to mitigate the risk of unwanted wildfires through fuel treatments (prescribed fire, herbicides, etc.), each carries trade-offs among cost, impacts, risks, feasibility, and public perception, all of which play a role in the acceptance of a risk-mitigation strategy (Cortner et al.,

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★ At the time of the research, the senior author was a research assistant, School of Natural Resources and the Environment, University of Arizona, Tucson, AZ 85721 USA.
* Correspondence: Retta Bruegger, CSU Extension, 2764 Compass Drive, #232, Grand Junction, CO 81506 USA.
E-mail address: retta.bruegger@colostate.edu (R.A. Bruegger).

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1990; Nader et al., 2007). For example, prescribed fire to manage fuel loads can escape and may affect air quality in nearby communities (Diamond et al., 2009), can be expensive to implement, or may not be desirable because of its impact on native plant species (Germano et al., 2001). Herbicides and mechanical control may negatively impact desirable vegetation, can be prohibitively expensive, and may be difficult to implement in rough terrain (Launchbaugh et al., 2006). Targeted livestock grazing may be one option for reducing fine fuels on extensive rangelands without the negative impacts and limitations from other options (Launchbaugh et al., 2008).

Targeted grazing is "the application of a specific kind of livestock at a determined season, duration, and intensity" to achieve objectives for wildlife habitat or ecosystem services (Launchbaugh et al., 2006). Critical components of a targeted grazing "prescription" are selecting the correct kind and number of livestock and combining this with the correct timing of grazing to address defined vegetation or landscape management objectives. As with every vegetation management tool, targeted grazing has unique costs and benefits (Frost and Launchbaugh, 2003). Under certain circumstances targeted grazing may be the most appropriate tool for vegetation management because it can be used in rough terrain, generally has greater public support, and may be more affordable compared with other methods (Nader et al., 2007). In one successful example, municipal governments successfully balanced multiple stakeholder and ecological values while using goats and sheep to reduce fuel loads near the WUI in Nevada and California (Davison, 1996; Taylor, 2006).

Although many studies examine fuel management in forested ecosystems (Covington, 2000; Agee and Skinner, 2005), few studies have considered alternative fuel management techniques on grasslands (Davies et al., 2010). Exotic grasses can invade ecosystems that have not evolved with fire, thus changing the habitat conditions required for native wildlife species (D'Antonio and Vitousek, 1992). In addition, fine fuels on lower-elevation grasslands and shrublands are easily ignited and serve as a conduit for igniting serious fires, which can spread to higher elevations and different vegetation types. For example, in 2005, exotic grasses and forbs served as an initial ignition source in lower elevations, which facilitated the expansion of Arizona's 100 362-ha Cave Creek Complex fire into higher elevations (CLIMAS, 2006).

In response to concerns over wildfire and the need for management tools, Bailey et al. (2008) called for the need to examine the practicality of using targeted grazing methods to address fuel-loading problems in various ecosystems with livestock distribution management techniques. Specifically, in our study area, the Coronado National Forest was concerned about fine-fuel loading due to Lehmann lovegrass (*Eragrostis lehmannniana* Nees), a warm-season, nonnative, perennial bunchgrass from South Africa. This experiment used 1) a field experiment with targeted grazing and 2) a fire model (BehavePlus; Andrews, 2009) to evaluate changes in fire behavior resulting from targeted grazing.

In the field experiment, we implemented targeted grazing by combining low stress herding (LSH) of cattle with strategic placement of low-moisture blocks (LMBs). We combined LSH and LMB because past research indicates that these two livestock distribution manipulation methods are more effective at increasing utilization than using either of these methods alone (Bailey, 2004; Bailey et al., 2008). Cattle were better suited to the objectives of this study compared with sheep and goats because they typically prefer grasses in greater proportions than other livestock species (Stuth, 1991), they are abundant in Arizona, and they are less likely to be affected by predation (Launchbaugh et al., 2006).

We used BehavePlus to evaluate changes in fire behavior resulting from the field experiment. Early work to translate the effects of cattle grazing into changes in fire behavior because of these impacts used McArthur's Fire Danger Meter, an early index predicting fire danger and suppression difficulty based on forage height and fire observations (Burrows, 1981). Van Wagtendonk (1996) used the fire growth simulation modeling system FARSITE to evaluate the effects of different fuel treatments. More recently, Diamond et al. (2009) determined that observed fire behavior was similar to estimated fire behavior using the fire simulation program BehavePlus on fuel treatment sites targeting cheatgrass (*Bromus tectorum* L.) with cattle grazing. Sophisticated fire prediction models like BehavePlus have made using computer models a sufficient and viable alternative to exploring the impacts of fuel treatments on fire behavior without the cost and risk of burning actual sites.

In evaluating the efficacy of using targeted cattle grazing and estimating its effect on fire behavior, we hypothesized that targeted grazing would 1) increase cattle distribution into previous unused areas, thus increasing utilization and, as a result, 2) decrease fire severity in these areas as modeled by BehavePlus.

Methods

The livestock handling and experiment procedures used in this study were approved by the University of Arizona Animal Care and Use Committee (Protocol 10–220).

Targeted Grazing Field Study

Study Area

Our study was conducted within the 3 000-ha Ranger Station pasture located on the Coronado National Forest in the Santa Rita Mountains of southern Arizona (lat 31°46′378″N, long 110°52′811″W). Elevation within the study pasture ranges from 1 200 m to 2 438 m. The terrain is rocky and very steep in some areas of the pasture and flat to gradually sloping in other areas. Annual precipitation varies between 230 mm and 510 mm (ESD MLRA 41). Average summer daily highs are 32—38°C, whereas winter highs (December and January) are 10—15°C.

The Ranger Station pasture is predominately a mesquite savanna. Dominant woody and herbaceous plant species are velvet mesquite (*Prosopis velutina* Woot.) and Lehmann lovegrass, respectively. Less dominant plant species include oak (*Quercus Emoryi* Torr.), catclaw acacia (*Acacia greggii* A.), fairy duster (*Calliandra eriophylla* Benth.), *Agave* spp., and a variety of native warm-season bunchgrasses such as sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), threeawns (*Aristida* spp.) and plains bristlegrass (*Setaria leucopila* K. Schum).

The primary perennial water sources for cattle are stock tanks at Benson Wells near the northwest region of the pasture (Fig. 1). Several ephemeral dry washes, springs, and one stock tank are also present in the pasture but contained no water during Year 1 (December 2010 to January 2011) of the study. During Year 2 (December 2011 to January 2012), five times the amount of winter rains compared with Year 1 resulted in numerous ephemeral springs and streams running throughout the pasture. In March 2010, before the initiation of the present study, we conducted an ocular use pattern mapping study by horseback, which indicated that most utilization occurred within 1.6 km of Benson Wells in the flatter areas of the pasture in areas with elevations that were less than 1400 m.

Selection of Study Sites

Two pairs of treatment and control study sites were systematically selected for a total of four study sites (see Fig. 1, Table 1). The primary criteria for selecting paired study sites (see Table 1) were that they 1) be approximately 1.6—2 ha in size; 2) contain similar terrain with roughly equivalent elevations, slopes, and aspects; 3) be located at least 1 km from Benson Wells; 4) have similar perennial grass production; and 5) show little or no evidence of previous use by cattle. Each target/control pair was located within 1.6 km of one another but separated by a rocky ridge that likely impeded travel by cows between the paired sites (see Fig. 1). Paired Study Sites 1 and 2 were located on an east-facing slope. Paired Study Sites 3 and 4 were located on west-facing slopes. Paired study sites were randomly assigned during the first year of the study as either a treated site (referred to as "target") or a control

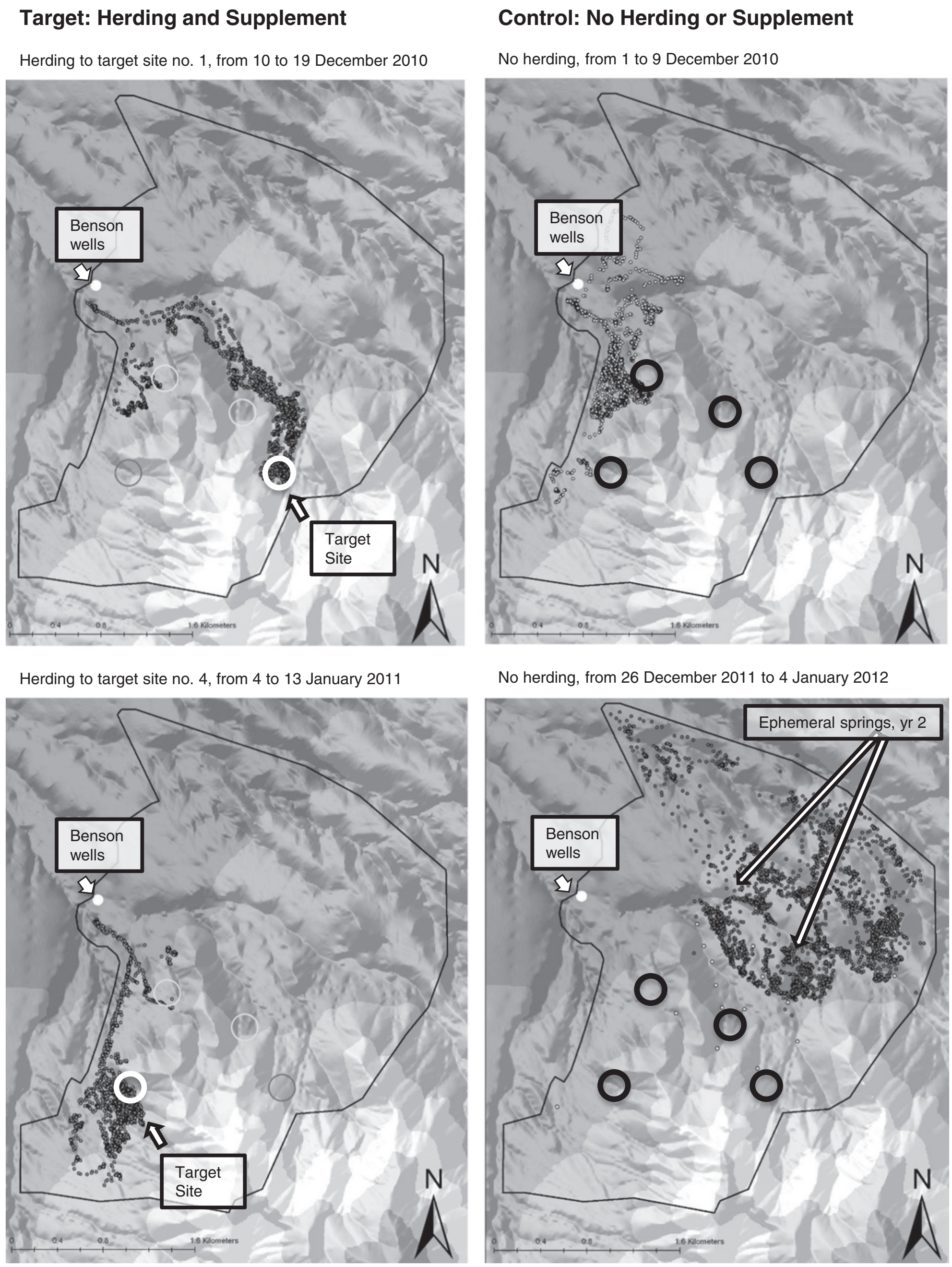

Figure 1. Locations of global positioning system (GPS)-collared cows from 2010 to 2012. Maps were generated using ArcGIS (version 10.0). Large circles denote locations of the four study sites. Small, dark circles are locations that were recorded on three to four GPS-collared cows every 10 min during TG (10 d of herding and supplement) and control periods (10 d of no herding and no supplement preceding target periods).

(i.e., $n = 2$ target sites and two control sites each year of the study). If a site was "treated," it means that cattle were actively herded (LSH) to the site and LMBs were located within the site for a 10-day period (see Fig. 1). A "control site" had no active herding to that site or supplement during that year of the study. During the second year of the study, target and control sites were switched within the pair so that each site was a control and target site once during the 2-year study. Although species composition varied somewhat between paired target and control sites, vegetation within all study sites was an oak/mesquite savanna with an herbaceous understory. Lehmann lovegrass dominated three of the

Table 1
Comparison of four study sites in the Ranger Station pasture in the Coronado National Forest in southeastern Arizona.

Study site	Average elevation (m)	Slope (°)	Lat	Long	Aspect	Distance to Benson Wells (km)	Distance to water (km)
1	1387	10	31°76'0201"N	110°86'1189"W	NE	3.5	2.25
2	1299	14	31°74'4212"N	110°86'900"W	N	2.4	1.71
3	1230	9	31°76'7322"N	110°87'2064"W	NW	1.2	0.96
4	1282	12	31°75'9951"N	110°87'5687"W	W	2.1	1.53

study sites (2, 3, and 4), while Study Site 1 contained significant quantities of native perennial grasses (e.g., sideoats grama and plains bristlegrass) in addition to Lehmann lovegrass.

Field Measurements within Study Sites

In fall of 2010, before cattle grazing, we established four, 100-m permanent transects within each of the four study sites. Randomization was constrained so that transects were at least 20 m from neighboring transects. We collected the following attributes in each study area: 1) live herbaceous standing crop, 2) standing dead biomass, 3) utilization, 4) stubble height, and 5) fecal material abundance. Cover and frequency were also collected. We collected data on the study sites approximately 1 month before herding began and again within 1 month after herding ended during both years of the study.

Standing Crop and Standing Dead Biomass

Standing crop was collected and analyzed using the actual weight method (Coulloudon et al., 1999a). We clipped six, 40 × 40 cm quadrats placed at random distances from end points and the center point of each transect for a total of 24 quadrat placements per study area. Clipped plant material was sorted into paper bags by functional groups (i.e., perennial grasses, perennial forbs, annual grasses and forbs, and standing dead) on-site and later dried at 60°C for 48 h and weighed. Shrubs were not included in the analyses because we did not expect cattle grazing to reduce shrub biomass.

Stubble Height and Utilization

Stubble height and utilization were collected for a 50-m segment along each of the four, 100-m transects at each site ($n = 200$ stubble height/utilization estimates). Height of the nearest perennial grass species (usually, Lehmann lovegrass) was recorded every meter along each transect. We generated a height-weight curve for Lehmann lovegrass according to the methodology described in Coulloudon et al. (1999b)) to estimate utilization by weight. When a native grass was observed, we used a species-specific US Forest Service utilization gauge (Aldon and Francis, 1984) to estimate utilization by weight. For Study Site 1, Lehmann lovegrass was a subordinate species component compared with native grasses. Therefore we developed two estimates of stubble height and utilization in Study Site 1, one for native grasses and one for Lehmann lovegrass.

Fecal Material Abundance

Before and after herding, the number and relative size (rank 1–5) of fecal pats were recorded along four, 10 × 100 m belt transects which bisected each vegetation transect using the methodology described by Tate et al. (2000). We categorized fecal pats as cattle or deer, although deer pellets were infrequent and are not discussed further. For each size rank of cattle fecal pats, we harvested, dried, and weighed reference fecal pats. The dry weight of fecal material abundance per unit area was calculated on the basis of the number of fecal pats within each size rank class within the study site (Tate et al., 2000).

Frequency and Cover

Frequency and cover data were collected before herding along five 50-m transects that ran perpendicular to each permanent transect. Frequency and basal cover were recorded in two hundred 40 × 40 cm plots per study site using the step point intercept described in Coulloudon et al. (1999a).

Cattle Herd, Supplement, and Global Positioning System Collars

The purebred Red Angus cattle herd used in this study consisted of 58 cow-calf pairs and two bulls from the Santa Rita Ranch. The herd was trained to consume LMB protein supplement by placing 226.7 kg of Crystalyx (Crystalyx Brand Supplements, Mankato, Minnesota, USA) near Benson Wells for 2 wk before turnout in early November. Crystalyx LMB has been used in numerous studies of cattle distribution (Bailey and Welling, 2007; Bailey et al., 2008). The type of LMB that we used within the study was 25% Beef, which contains 25.0% crude protein, 4% crude fat, 2.5% crude fiber, and various trace minerals such as calcium (1.5−2%), magnesium (1%), potassium (2.0%), iodine (17 ppm), and copper (500 pmm). By the end of the 2-wk training period, cattle had consumed nearly all of the LMB.

About 1 wk before turnout in Year 1, we put Lotek global positioning system (GPS) 3300 collars (Lotek Wireless, Newmarket, Canada) on 6 of the 58 cows. Collared cows were randomly selected. In Year 2, GPS collars were placed on 5 of the 58 cows. In both years of the study, collared animals were turned out into the Ranger Station pasture with the entire herd (n ~ 60 animal units [AUs]) in mid-November and subsequently removed from the pasture in late January. Collar signals were tested periodically during the study (Bailey et al., 2008). In both years of the study, a few collars did not work or stopped working during the study period, so GPS tracking data were only used from three cows during the Year 1 and four cows during Year 2. Collars recorded the GPS location of cattle every 10 min during the entire study period. We used ArcGIS 10.0 (ESRI, 2011) to determine the elevation, slope, distance to water, and distance from treated site (i.e., target site) and control sites of GPS tracked cattle during herding versus nonherding periods (Bailey et al., 2008).

Implementing Herding and Supplement Treatments

Before herding began, the herd was allowed to graze freely in the Ranger Station pasture for 35 days in Year 1 and 25 days in Year 2, at a stocking rate of 17 ha•AUM^{-1} (Animal Unit Month). In Year 1, herding was delayed for 10 days because one of the horses we planned to use for herding was ill. A few hours before implementing a treatment (i.e., herding cows to a study site where LMB was present), we packed about 250 kg of LMB into the study site by a team of mules. Only one study site contained LMB at the beginning of a herding period while control sites and the other target site contained none. The LMB was randomly scattered near the center of the target study site between the two middle permanent transects.

Each year, we "treated" two sites by herding and supplementation ("target sites"), and two sites were controls (see Fig. 1). In Year 1 cattle were allowed to roam freely for 10 d, herded to Study Site 1 (where LMB was placed on the first day of that herding period) every other day for 10 d, allowed to roam free again for 10 d, and then herded to Study Site 3 every other day for 10 d. We waited until early afternoon to begin herding because cows generally come to water in the morning, so afternoon herding makes it 1) easier to gather cattle and 2) more likely that cattle would stay at target sites because they would have already accessed water and would not have to leave sites once herded (Bailey et al., 2008). During Year 1, 20−40% of the herd was typically found at or near Benson Wells during early afternoon (see Fig. 1), which facilitated gathering and herding to the target site. During each herding day, two to five horseback riders or walkers also rode or walked the pasture and herded other cows to the target site using LSH techniques (Cote, 2004; Hibbard, 2012). Once cattle arrived at the target site, herders waited until they began consuming LMB and then counted the number of adult animals present.

Experimental Design and Statistical Analysis

Spatial (Target) and Temporal (TG) Comparisons

We compared sites spatially (referred to as target vs. control sites) and temporally (referred to as TG vs. control) in order to distinguish between 1) the impact of treatments on vegetation in sites that were treated (target sites) versus untreated (control sites) and 2) the impact on a site before and after LSH and LMB were in a target site (TG) versus periods of time when there was no herding or supplement (control).

Analysis Methods

Data were analyzed using a 2 × 2 Latin Square design with treatment (target vs. control sites) and herding period (preherding vs. postherding) as factors and years ($n = 2$) and pairs ($n = 2$) as blocks, using a MIXED model procedure in SAS (SAS Institute, 2008). Similar experimental designs have been used in cattle distribution field studies (Bailey et al., 2008). The impact of low-stress herding and LMB was measured on the following dependent variables in the spatial analyses (target vs. control sites): standing crop of all perennial grasses (kg·ha^{-1}), standing crop of all perennial grass plus standing dead biomass (kg·ha^{-1}), utilization (%) and stubble height (cm) of Lehmann lovegrass, and fecal material abundance (kg·ha^{-1}). Collared cow locations collected before and during herding periods (temporal analyses = TG) were analyzed for 1) use of slope, 2) elevation, 3) distance from Benson Wells, 4) distance from ephemeral water, 5) distance traveled, and 6) time cattle spent within target and control sites during herding and nonherding periods. Frequency and cover data (%) were arcsine transformed for normality (Gotelli and Ellison, 2004) and analyzed for differences between years and between study sites using one-way analysis of variance. Observations on numbers of cattle herded and numbers of cattle at target sites during herding periods were analyzed using a Student's *t*-test. All dependent variable data met analysis of variance assumptions. Means were considered different at $P < 0.10$.

Fire Model

We used the BehavePlus (Andrews, 2009) computer simulation fire model program to determine the effect of targeted cattle grazing and the subsequent reduction in fine fuels on fire behavior. We used the model to estimate two fire behavior characteristics: fire rate of spread (m·min^{-1}) and flame length (m). The BehavePlus system is an upgrade of the original BEHAVE program and provides for better in-depth analysis of multiple aspects of fire behavior including rate of spread, flame length, and spotting and by allowing users to alter different aspects of fire conditions. The model is limited to calculations at a single point of time and space and does not include a spatial or temporal scale. However, BehavePlus can evaluate the changes in fire behavior resulting from fuel treatments. We used standing crop of herbaceous species on target sites (pretreatment and post treatment) from the field experiment to calculate the reduction of fine fuel loads resulting from targeted grazing.

Fuel Models

Within BehavePlus, there are two available groups of fuel models for predicting fire behavior: the original 13 fuel models described by Rothermal (1983) and Albini (1976) and the 40 fuel models created and discussed by Scott and Burgan (2005). BehavePlus users have the option to use the fuel loads described by these models or manually change the fuel loads to represent the vegetation present. We conducted analyses on fire behavior using fuel models as a basis and accounting for specific changes to herbaceous fuel loads to represent grazing treatments on target sites.

We evaluated two fuel parameters with the targeted grazing data in fire simulations: fuel bed depth and live herbaceous fuel load. Fuel parameters represented vegetation estimates of pregrazing and postgrazing conditions of the targeted grazing study sites. Fuel bed depth was based on stubble height of Lehmann lovegrass because this species made up the majority of fine fuels at the project site. We combined biomass data from all perennial grasses for fire behavior analyses because native grasses contribute similarly to ungrazed fuel loads compared with Lehmann lovegrass in this system (McDonald and McPherson, 2011). Values used in the BehavePlus model reflected changes in live herbaceous fuel loads in this study and ranged from 750 kg·ha^{-1} to 1550 kg·ha^{-1}, at 50 kg·ha^{-1} intervals. Fuel bed depth ranged from 30 cm to 75 cm, at 5-cm intervals.

Fuel Moisture Levels

Fuel moisture levels are also an integral part of fire model inputs. We developed two fuel moisture scenarios for the study area: moderate and extreme. Fire Family Plus (Main et al., 1990) was used to determine fuel moisture scenarios for the study area at the 75th (moderate) and 97th (extreme) percentile fire weather conditions during peak fire season for the study area (April 1 through July 15). These percentiles represent weather conditions that occur 25% and 3% of a given time period, respectively. Weather data were based on the Saguaro weather station (Station number 021202, about 60 km from the study site). Table 2 summarizes the fuel moisture assumptions used for the different fuel moisture scenarios considered.

Table 2
Fuel moisture scenarios using weather data from the Saguaro Weather Station (Station number 021202).

Fire condition	Weather percentile	1-h fuels	10-h fuels	100-h fuels	Live herbaceous	Live woody
Moderate	75th Percentile	2.01	2.73	3.97	30	60
Extreme	97th Percentile	1.51	2.12	3.83	30	60

Wind Speeds and Other Assumptions

Other assumptions that remained constant in the models were wind speed and 1-h and 10-h fuel loads. Fuel load classes are determined by timelag, or the time it takes for two-thirds of the fuel to react to precipitation (USFS, 2007). In grass vegetation communities, there were no shrub species. In grass/shrub vegetation communities, shrubs are assumed to be 0.3048 m tall. In the BehavePlus fire model, wind speed is entered as wind speed at midflame height, which is often referred to as eye-level wind. For all simulations, midflame wind speed was held constant at 8 km·hr^{-1} for all simulations. Fuel treatments were evaluated at a constant 5% slope.

Results

Targeted Grazing Field Study

Time required to herd cattle to a target site ranged from 4.5 h at the beginning of first herding period to around 2 h by the end of each herding period. Cattle became much easier to gather and herd with each subsequent herding event. We herded (i.e., gathered and actively moved to sites) similar numbers of cows during Year 1 (23 cows $\pm$ 6) as Year 2 (23 cows $\pm$ 3), but cattle tended to disperse more throughout the pasture during Year 2 and did not congregate at lower elevations or near Benson Wells due to the presence of ephemeral springs. Upon the first herding event of each period, we found zero cows at each site. However, after herding began during Year 1 we found an average of 29 $\pm$ 4 cows at target sites that had stayed or returned without herding, compared with only 4 $\pm$ 2 cows during Year 2. Thus the total average number of animals, including those that were herded to or found at target sites during herding days, was about 44 cows, or about 76% of the herd in Year 1, and 26 cows, or about 45% of the herd in Year 2. These observations are corroborated by collared cows, which spent 11 $\pm$ 6 h·visit^{-1} in target sites during Year 1 compared with 7 h·visit^{-1} $\pm$ 0.5 h in Year 2, although these differences were not significant ($P < 0.59$).

Collared cows spent more time in ($P < 0.02$) and within 100 m ($P < 0.004$) of TG sites during herding periods than during nonherding periods (see Figs. 1 and 2). During herding periods, collared cows were located in TG sites 22% of the time and within 100 m of TG sites 34% of the time compared with < 1% of the time during nonherding periods. During both herding and nonherding periods, collared cows were located in control sites ≤ 3% of the time and within 100 m of control sites 11% of the time during nonherding periods.

Average elevation, slope, and distance to water sources (permanent and ephemeral) of collared cows were not different between herding and nonherding periods. However, collared cows traveled about 998 $\pm$ 117.5 m more per day ($P < 0.01$) during herding periods compared with nonherding periods.

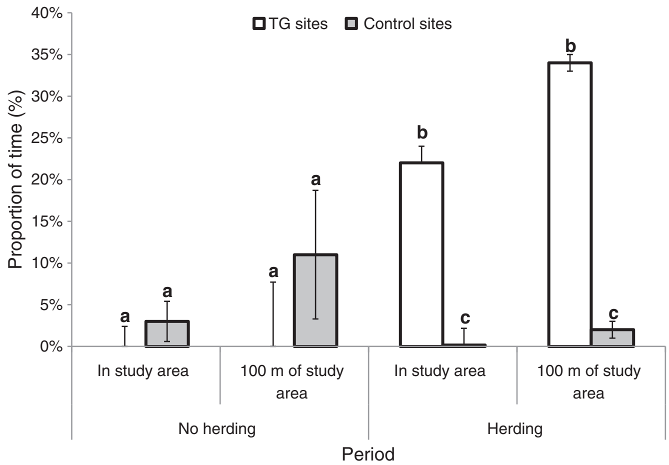

Figure 2. Proportion of locations (mean ± SE) that GPS-collared cows were in or within 100 m of target or control sites during TG and control periods. Cows were herded to target sites every other day for 10 d and were not herded during control periods. Different letters indicate significant differences between the means.

The quantity of perennial grass standing crop after the study was less than before the study, and the quantity of perennial grass in target sites was less than in the control sites (Table 3). However, no interaction between period (pregrazing and postgrazing) and treatment (target and control sites) was detected. The combination of perennial grass and standing dead was less at the end of the study than at the beginning of the study, but no differences in target compared with control sites were detected. No interaction of period and treatment was detected for perennial grass and standing dead standing crop (see Table 3).

Utilization (%) of Lehmann lovegrass increased between preherding and postherding in both target and control sites (see Table 3); however, this effect was greater in target sites than in control sites. For Study Site 1, where native grasses made up a larger portion of the species composition, stubble height and utilization measurements on native grasses and Lehmann lovegrass data were not different. Thus only Lehmann lovegrass utilization and stubble height estimates were included in our vegetation analyses.

Mean stubble height of Lehmann lovegrass decreased between preherding and postherding in both target and control sites (see Table 3). This effect was again greater in target sites than in control sites. Interaction effects between treatment and period were detected for both utilization and stubble height.

Fecal material increased in abundance between preherding and postherding periods. Fecal abundance at target sites increased more than control sites (see Table 3).

Frequency of major plant functional groups did not change ($P > 0.10$) between Years 1 and 2. Percent basal cover of perennial grasses and gravel was also similar ($P > 0.10$) across sites.

Fire Model

In the grassland vegetation model, the BehavePlus fire model predicted that rate of spread was reduced by ≥60% in both fuel moisture scenarios following the targeted grazing treatments on the TG sites (see Fig. 4). In addition, flame lengths were reduced to below a critical 1.2-m threshold for the moderate fuel moisture scenario and below a 2.4-m threshold for the extreme fuel moisture scenario (Fig. 3). In the grass/shrub vegetation model, fire rate of spread was reduced by ≥ 50% and flame lengths were reduced to below a 2.4-m threshold in both fuel moisture scenarios (Fig. 4).

Discussion

Applying Targeted Grazing in a Field Setting

Cattle Effects in Target vs. Control Sites

Targeted grazing, applied via LSH and LMB, successfully increased use in target sites compared with controls by threefold (see Table 3). Targeted grazing also increased cattle distribution into terrain that was steeper, more rugged, and farther from water than the more gentle terrain that cattle had historically used, according to a use pattern mapping study conducted in March 2010 by the coauthors of this paper. During herding, cattle greatly increased the amount of time they spent within 100 m of target sites (see Fig. 2) and spent almost no time in control sites. Forage utilization, standing crop, stubble height, and fecal material abundance data also indicated that cattle used target areas more than control areas during LSH and LMB placement. As in other studies (Pollak, 2007; Bailey et al., 2008; Stephenson, 2014), the combination of LSH and strategic LMB placement increased grazing distribution. Supplements are most attractive to cattle when natural

Table 3
Mean (SE) values for standing crop of perennial grasses, standing crop with standing dead of perennial grasses, utilization, stubble height, and fecal material abundance. Dependent variables were measured before (pre-) and after (post-) cows grazed Ranger Station Pasture during a 2-year study (2010/11—2011/12). Fixed effects were treatment (target vs. control sites), period (preherding vs. postherding periods), and the treatment by period interaction and years ($n = 2$), which was used as a blocking factor.

	Factors			Significance of fixed effects		
Attribute	Treatment	Period	Means (SE)	Treatment	Period	Treatment Period
Standing crop of perennial grasses, (kg·ha^{-1})	Target sites	Pre	911 (57)	0.03	0.02	0.42
		Post	421 (53)			
	Control sites	Pre	913 (175)			
		Post	641 (57)			
Standing crop with standing dead of perennial grasses, (kg·ha^{-1})	Target sites	Pre	1498 (188)	0.51	0.07	0.16
		Post	817 (76)			
	Control sites	Pre	1257 (254)			
		Post	1154 (74)			
Utilization, (%)	Target sites	Pre	0.1 (0.1)	0.08	<0.01	0.04
		Post	26.4 (3.5)			
	Control sites	Pre	1.6 (1.3)			
		Post	10.8 (4.7)			
Stubble height, (cm)	Target sites	Pre	71.3 (2.1)	0.15	<0.01	0.05
		Post	35.0 (2.4)			
	Control sites	Pre	70.0 (2.9)			
		Post	51.9 (6.5)			
Fecal material abundance, (kg·ha^{-1})	Target sites	Pre	17.6 (6.7)	0.12	<0.01	<0.01
		Post	82.8 (12.6)			
	Control sites	Pre	25.8 (10.4)			
		Post	32.5 (7.5)			

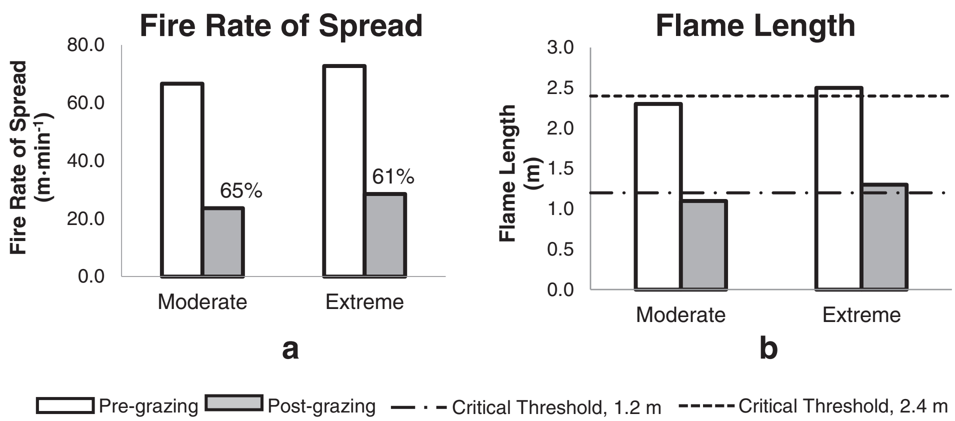

Figure 3. Impacts of targeted grazing on fire behavior on rate of spread (**a**) and flame length (**b**) in grassland vegetation communities. **a,** Numbers above bars indicate percent *decrease* in fire rate of spread.

forage is dry or old and lacking in nutrients (Launchbaugh et al., 2006). Crude protein (nitrogen) and other nutrients provided by LMB when rangeland vegetation is dormant can also increase cattle intake of low-quality forages (Titgemeyer et al., 2004). We found this to be true in the present study as cows consumed virtually all of the available LMB and significantly increased time spent in target sites compared with when there was no herding to or LMB in these same sites (see Fig. 2). Bailey et al. (2008) in Montana, and Pollak (2007) in New Mexico found that upland forage utilization in and near target sites was greater than corresponding control sites when a combination of strategic LMB placement and low-stress herding was applied. Stephenson (2014) found that forage utilization increased by 15% in target areas, although corresponding control areas increased by only 6% in a companion study on New Mexico rangelands evaluating the potential of focusing cattle grazing with LSH and strategic LMB placement. Other authors have had positive results applying herding without strategic supplement to increase cattle distribution (Butler, 2000; Cote, 2004). Our results, in concert with other studies, suggest that LSH and LMB can be effective tools to increase cattle distribution into previously unused or underused areas.

Influence of LSH and LMB on Cattle Behavior and Distribution

Cattle became accustomed to LSH, LMB, and repeated use of these tools. For example, time required to herd cattle to target sites averaged over twice as long during the first day of herding compared with the last day. This is consistent with animal behavior principles, as livestock can be trained to perform management-related tasks if the desired action does not cause excessive stress (Smith, 1998; Grandin, 2000; Hibbard, 2012). Cattle in our study likely became accustomed to the LSH routine with each subsequent herding event and to finding the LMB "reward" located in the target sites. This was remarkable given the rugged terrain and thorny vegetation that herders and cows routinely traversed along the way to target areas. Once cows were introduced to a target site containing LMB, they created new trails and used them to navigate to and from target sites as has been observed in other studies (Bailey, 2005). After the first herding day, cow-calf pairs were occasionally observed moving to target sites from these new trails on their own volition without herding. We occasionally missed collared cows during our herding activities, but GPS data confirmed that collared cows moved to the target site on their own later during the same day. Herd dynamics and social learning likely contributed to the behavioral patterns we observed in our study (Launchbaugh and Howery, 2005). Cows apparently remembered target sites that had previously contained LMB for a year. Collared cows returned to Study Site 4, which had previously contained LMB in Year 1 within several days after they returned to Ranger Station pasture in Year 2. Both domestic and wild ungulates have been shown to have long-term memory for high-quality food locations (Bailey and Sims, 1998; Launchbaugh and Howery, 2005).

Field Setting Considerations in Applying Targeted Grazing

Any application of targeted grazing in the field will have to contend with unpredictable factors such as weather, which influences the precision at which a treatment can be applied. In our study, differences in environmental factors between years could account for consistent disparities in 1) the average number of cows that were already observed at target sites before herding began (10 vs. 4 cows during Years 1 and 2, respectively); 2) average number of visits to target sites by collared

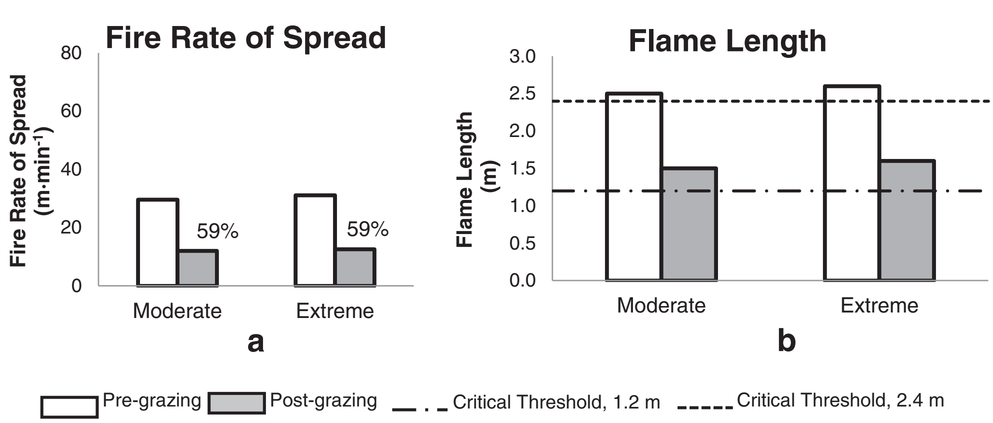

Figure 4. Impacts of targeted grazing on fire rate of spread (**a**) and flame length (**b**) in grass/shrub vegetation communities. **a,** Numbers above bars indicate percent *decrease* in fire rate of spread.

cows during herding periods (7 vs. 4 visits during Years 1 and 2, respectively); and 3) average time spent/visit in target sites by collared cows during herding periods (11.4 h vs. 7 h during Years 1 and 2, respectively).

In addition, in a field setting, utilization levels using LSH and LMB may be lower than intended given stocking rate estimates. For example, adjusted stocking rates for our approximate 1.82-ha study sites averaged 3.8 AUM·ha^{-1} assuming an average of 35 (AUs) (about 58% of the herd) occupied target sites for 10 days. This stocking rate would have been more than sufficient to achieve > 100% use on Lehmann lovegrass within target sites that produced an average of 911 kg·ha^{-1} (see Table 3) if cattle: 1) had been confined to the target sites and 2) had consumed a diet consisting exclusively of Lehmann lovegrass within the target sites. In reality, animals had free access to the entire pasture, consumed unknown amounts of rangeland forages that were available both inside and outside of target sites, and consumed an average of 0.71 kg of LMB·d. Moreover, livestock use of target sites decreased dramatically during nonherding periods when no LMB was present. This resulted in light utilization (mean = 26%) in target sites when applying the 60 AUs that were available as part of a US Forest Service federal grazing permit, which is lower than another study (Diamond et al., 2009) in which 80−90% utilization levels were achieved by increasing grazing pressure with an electric fence. Our observations and experience on the present study underscore that, as with other management actions on range, successful implementation of targeted grazing requires site specific knowledge, flexibility, and adaptive actions in response to weather and other factors, in addition to knowledge of animal nutrition and grazing behavior (Macon, 2014).

Impacts of Targeted Grazing on Fire Behavior

Our results from the fire model suggest that targeted grazing could reduce the potential cost of fighting fires on both grasslands and grass/shrub habitats in conditions similar to our study sites, even though average utilization was 26% in target sites. On the basis of our pretreatment and post-treatment vegetation data, the BehavePlus fire behavior model predicted that targeted grazing could reduce the rate of spread by ≥ 50% in both fuel moisture conditions for both grass and grass/shrub communities. The targeted grazing treatment in grasslands resulted in a reduction of flame lengths below 1.2 m in moderate conditions, creating conditions where it was feasible for hand crews to fight fires. Firefighting policy dictates that hand crews (i.e., lower cost) are allowed to fight fires when flames are < 1.2 m (Andrews and Rothermel, 1981). The model predicted that targeted grazing could reduce flame lengths below 2.4 m in under extreme fuel moisture conditions for the grass community and for both fuel moisture conditions in the grass/shrub communities. Machinery can be used to fight fires with flames up to 2.4 m, but only indirect firefighting is allowed when flames exceed 2.4 m (e.g., aircraft, higher cost).

Targeted grazing may impact fuel continuity in addition to amount. A similar study (Diamond et al., 2009) found that litter cover did not change with grazing; however, cattle grazing increased the amount of bare ground during the 2-year study, a finding that was also reported in a targeted grazing study in Spain (Ruiz–Mirazo and Robles, 2012). Although targeted grazing may reduce fuel continuity, BehavePlus assumes only continuous fuel loads; therefore our analyses presented here cannot test these potential impacts. Results from Varelas (2012) using FlamMap (Finney, 2006) showed that while the overall severity of the fire was reduced in moderate conditions, targeted grazing treatments alone were not sufficient to stop the fire. Despite this, our results support other findings on the value of grazing as a potential tool to reduce fire characteristics on rangelands (Strand et al., 2014). Diamond et al. (2009) concluded that the higher amount of bare ground and lower amounts of biomass in the grazed and burned areas 1) resulted in a lower-severity burn and therefore 2) created islands of unburned vegetation, leading to 3) improved wildlife habitat and 4) accelerated recovery of native vegetation after burning. In our study, a projected lower-severity fire would make future wildfires less expensive and dangerous to address and potentially increase the rate of recovery following burns.

As in all applications of all fuel treatments, timing is critical to achieve intended results and our results are not meant to be prescriptive. Our experiment tested targeted grazing on dormant fuels not during the active fire season. This means that given an early monsoon, more fuels could accumulate before a wildfire (peak wildfire season in this area is April 1 to July 15). Dormant season grazing is likely not appropriate in all cases; however, Davies et al. (2015) found that grazing on dormant vegetation may reduce fire risk, even if new growth occurs before the next fire season. For example, in the sagebrush steppe, sites that experienced dormant season grazing were unlikely to burn before August, compared with ungrazed sites, in which fuel moisture levels were low enough to burn by June (Davies et al., 2015). Although dormant season grazing does not address all types of fire risk, it may shorten the window of time in which a fire is likely to occur.

Implications

The use of LSH with strategic placement of LMB in our study was effective in moving livestock to previously ungrazed Lehmann lovegrass areas without the use of expensive rangeland improvements such as fences or additional water. The BehavePlus fire model provided strong evidence that the removal of biomass following the application of targeted grazing reduced flame lengths and thereby would have reduced the cost of fighting a potential wildfire most in grassland vegetation types in two fire conditions. Targeted grazing treatment did influence fire behavior in grass/shrub communities, but its effects were limited. Although it is a promising tool for altering fire behavior, targeted grazing will be most effective in grass communities under moderate weather conditions.

Our study also reveals management implications for future targeted grazing studies or applications. Namely, successful applications of targeted grazing must consider context and objectives, including the timing of fuel treatments relative to peak fire season and phenology. As observed in our study, targeted grazing using LSH and LMB is applied in a field setting where factors like precipitation, cattle behavior, and other public-land users cannot be completely controlled. Herding and supplementation do not confine animals to sites nor require that they *only* consume the targeted vegetation species, so actual utilization may be less than predicted given the AUs, as we found in our study. To achieve higher use rates on Lehmann lovegrass and potentially greater fire management results, one or more of the following tactics could be implemented: 1) increase stocking rates (Ruiz-Mirazo and Belen Robles, 2012), 2) increase the amount of supplement placed in target sites, 3) extend herding periods to target sites and/or use electric fence to increase grazing pressure (Diamond et al., 2009). Applying targeted grazing is both an art and a science, and managers will need to respond on a context-dependent and adaptive basis to carefully calibrate animal numbers, supplement amounts, and length of herding periods to achieve desired objectives, while balancing other ecosystem services.

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