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Behavioral and Ecological Implications of Bunched, Rotational Cattle Grazing in East African Savanna Ecosystem☆

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ABSTRACT

Rangelands and the wildlife and livestock they support are critical to human livelihoods, but rangeland ecosystems increasingly suffer from overgrazing and degradation. Planned grazing, a strategy that commonly involves time-controlled rotations of high-density (bunched) groups of cattle across a pasture, is marketed as a method to enhance rangeland health and lessen livestock impacts. However, the behavioral mechanisms underlying any potential rangeland improvements resulting from rotational, high-density planned grazing have rarely been examined. To investigate these mechanisms, we compared planned grazing with conventional continuous grazing management in a savanna ecosystem in Kenya. We surveyed cattle grazing behavior, measured changes in vegetation characteristics through surveys conducted before and after cattle grazing, and measured native ungulate abundance following grazing using camera traps. Stocking rates were held constant across treatments, resulting in a commensurate decline in total foliar hits per pin (a proxy for vegetative biomass) across treatments. Planned grazing management altered cattle behavior and reduced grazing selectivity by restricting movements, causing cattle to walk more slowly while grazing and to take more bites per step. Vegetation survey results supported this finding: cattle in the planned grazing treatment ate significantly more *Pennisetum* grasses (typically avoided because of their unpalatability), creating the opportunity for regrowth of more palatable species after seasonal rains. We also documented significantly higher zebra presence in planned grazing plots after cattle grazing, likely due to increased relative abundance of more palatable grass species. This investigation of grazing behavior, and specifically decreased grazing selectivity as a mechanism underpinning the benefits of planned grazing, shows that when conducted at appropriate stocking densities, planned grazing has the potential to help mitigate rangeland degradation and improve rangeland sustainability for both livestock and wildlife in pastoral African savanna ecosystems.

Introduction

Rangelands cover approximately 25% of Earth's ice-free land and serve as important reservoirs of biodiversity and vital sources of income for pastoralist societies (Ramankutty et al., 2008; Thornton, 2010; Robinson et al., 2014; Searchinger et al., 2015). African savannas have historically supported high densities of wildlife alongside pastoral societies, providing a model for human-wildlife coexistence (Reid, 2012). However, cattle grazing can have a large negative environmental impact, especially at high densities, and is often blamed for rangeland degradation, forage quality and quantity reductions, and desertification (Savory, 1983; Fleischner, 1994; Steinfeld et al., 2006; Alkemade et al., 2013).

One proposed strategy to minimize grazing impacts and improve pasture quality without reducing cattle stocking rates involves time-controlled rotations of high-density intensive grazing (sometimes called *rotational grazing, cell grazing,* or *high-density, short-duration grazing*), here referred to as *planned grazing* (Hawkins, 2017). Holistic Planned Grazing™, a version of high-density rotational grazing that encourages a flexible approach to simultaneously managing financial, social, and environmental factors, is perhaps the highest profile alternative to continuous grazing (Savory, 1983; Butterfield et al., 2006). Holistic Planned Grazing™ in practice is context specific by design (Teague et al., 2013; Teague and Barnes, 2017), hindering systematic assessment and limiting our understanding of the mechanisms at work (Briske et al., 2008, 2011; Hawkins, 2017). In fact, recent meta-analyses have found no consistent difference in pasture

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quality or production between continuous grazing and planned grazing strategies, and positive results seem limited to areas of relatively high precipitation or are potentially confounded by stocking rates (Briske et al., 2008; Hawkins, 2017). As a result, planned grazing has been the subject of a persistent debate, with most published research indicating only limited potential benefits (Holechek et al., 1999, 2006; Briske et al., 2008; Carter et al., 2014; Fynn et al., 2017; Hawkins, 2017).

Despite heterogeneity in implementation, most planned grazing involves high-density rotational grazing dependent on forage availability (Hawkins et al., 2017; Teague and Barnes, 2017). In East Africa, high-density rotations are achieved by herders who actively bunch cattle into high-density groups (Hawkins, 2017; Odadi et al., 2017). Bunched cattle are grazed sequentially across the landscape for short time periods (determined by cattle number, pasture area, and management goals), allowing previously grazed areas to "rest" and regrow (Savory, 1983; Holechek et al., 1999; Butterfield et al., 2006; Briske et al., 2008; Hawkins et al., 2017; Odadi et al., 2017). Planned grazing involves multiple mechanisms that have been hypothesized (often with limited empirical support) to drive rangeland improvements, including soil disturbance, dung deposition, and periods of rest intended to mimic native ungulate grazing patterns (Butterfield et al., 2006; Briske et al., 2008; Hawkins, 2017). However, a fundamental and previously unexplored assumption of planned grazing is that bunched herds graze *less selectively*: when kept from roaming freely, cattle exert a uniform pressure across the pasture and consume less palatable species at relatively higher rates, thus enhancing the growth of more palatable and nutritious forage species (Odadi et al., 2017).

Recent studies have investigated the implications of planned grazing for African rangelands (O'Connor et al., 2010; Lalampaa et al., 2016; Chamane et al., 2017; Odadi et al., 2017) yet have been limited by a lack of experimental investigation into underlying behavioral mechanisms (Hawkins et al., 2017). In an effort to fill this gap, we combine behavioral surveys with vegetation monitoring to investigate whether planned grazing management reduces grazing selectivity and the resulting implications for pasture health and productivity. Ours is the first experiment designed to explicitly investigate grazing selectivity as a mechanism linking bunched rotational grazing with potential rangeland improvements. Though our study's limited temporal and spatial scales preclude the assessment of long-term rangeland vegetation health implications (which requires longitudinal monitoring), our results provide important exploratory insights into the immediate behavioral effects and corresponding vegetation implications of a key component of planned grazing.

Methods

Study Area

Experimentation took place on 16 ha of black cotton soil savanna located at the Mpala Research Center in central Kenya (MRC; www.mpala.org) (Fig. 1). The study plots predominantly consisted of five native grasses—*Brachiaria lachnantha* (Hochst.) Stapf, *Pennisetum mezianum* Leeke, *Pennisetum* Peter, *Setaria sphacelata* (Shumach.), and *Themeda triandra* Forssk—in an *Acacia drepanolobium* Sjøstedt tree community.

Experimental Design

To compare the effects of planned grazing with continuous grazing, two groups of 25 randomly chosen steers of similar size and age were grazed in neighboring plots of savanna daily for 8 d (January 13 — 20, 2017). The study consisted of two replicates of 5 and 3 d, due to unpredicted time constraints. To account for this unbalanced design, replicates were analyzed separately; however, results are reported for the combined dataset unless replicate-specific results differed qualitatively in their significance. Stocking rate was determined on a replicate basis, maintaining the same grazing pressure across treatments (providing the same area of grassland per steer per d) to remove stocking rate as a confounding variable. Although the replicates differed in temporal and spatial extent, our design kept a constant impact per animal per d per ha and results confirm that cattle behavior did not differ between replicates (see Results). Mirroring typical rotational planned grazing management in Kenya, planned grazing cattle were rotated to a different 1-ha plot each day. Four herders were needed to actively bunch planned grazing cattle together, with cattle remaining closely beside one another and consistently < 1 m apart (see Fig. 1). Following conventional continuous grazing practices, continuous grazing cattle were given unrestricted access to roam freely in a single larger plot over multiple days, requiring only two herders to keep animals inside the treatment plot. Continuous grazing plots were 5 ha and 3 ha in Replicates 1 and 2, respectively, such that the stocking rate per d per ha was equivalent for each treatment in each replicate (see Fig. 1). Continuous grazing cattle were allowed to roam freely, ranging from right next to

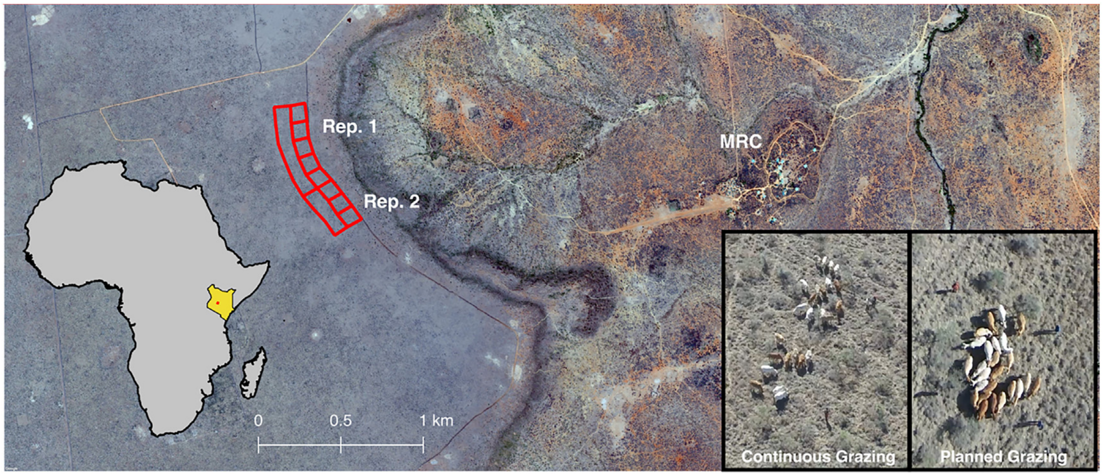

Figure 1. The Mpala Research Centre and Conservancy (MRC) in Laikipia, Kenya. Experimental setup is shown in red, marking replicates 1 and 2. The general locations of Kenya (yellow) and the study site (red dot) are shown on the African continent inset on the left. The inset at right includes an aerial view of the two grazing management strategies used in this study: planned grazing (right) and continuous grazing (left). Inset image taken by Daniel I. Rubenstein using an aerial drone, aerial imagery provided by Google, and map produced in QGIS version 2.18.9, Quantum GIS Development Team 2017.

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each other to > 100 m apart (see Fig. 1). The spatial distribution of continuous grazing cattle was consistent between replicates despite differing areas of continuous grazing plots.

Plots were placed sequentially north to south along the western side of a low-traffic unpaved road, with planned grazing plots beside continuous grazing plots (see Fig. 1). Plot locations were chosen by Mpala Ranch Manager Mike Littlewood and behavioral ecologist Daniel I. Rubenstein (Princeton University) to provide adequate forage during the experiment. Initially, plots did not statistically differ in grass species composition or total foliar hits per pin, indicating an absence of spatial autocorrelation (see Results). Cattle grazed between 7:30 a.m. and 4:30 p.m. were taken to water at 12:30 pm (along roads to prevent grazing) and were housed overnight in a predator-free metal boma (corral).

Vegetation Surveys

Vegetation surveys of grassland species composition and foliar hits per pin were conducted immediately before and after cattle grazed in each plot. Following Odadi et al. (2017), vegetation surveys involved placing a 1-m metal pin perpendicularly to the ground at each meter along a 25-m transect, recording each grass and forb species touching the pin, the number of leaves and stems, and the number of seeds. Twenty evenly spaced transects were surveyed in each 1-ha unit. Foliar hits per pin is the sum of leaf, stem, and seed numbers for forbs and grasses recorded at each pin hit. Foliar hits per pin are positively correlated with vegetation biomass ($R^2 = 0.88$; Sensening et al., 2010) and has previously been used as a proxy for biomass (Odadi et al., 2013; Odadi and Rubenstein, 2015).

Cattle Behavior Surveys

Six focal cattle in each treatment were randomly chosen for repeated behavior surveys of 1) time use allocation, 2) bite and step frequency, and 3) grazing velocity. Distance traveled by focal cattle each day was determined using i-gotU GT-120 GPS tracking devices (Mobile Action Technology, Inc., Taiwan), which recorded positions every 15 s (Schieltz et al., 2017).

We surveyed cattle behavior three times daily: morning (8:00 − 9:30 a.m.), midday (10:00 − 11:30 a.m.), and afternoon (2:30 − 4:00 p.m.). Time allocation surveys recorded behaviors at 2-min intervals for 20 min (yielding proportions of time spent grazing, walking, standing, browsing, lying, or grooming; $N = 288$), and grazing behavior surveys recorded bite and step frequencies and average velocities for each focal individual during 2 − 5 grazing bouts (defined as continuous periods of grazing with head at grass level, following Odadi and Rubenstein, 2015). From this we calculated the bite/step ratio (number of bites taken per step; $N = 688$) and the average grazing velocity (m traveled per min; $N = 236$). Bite/step ratios serve as a measure of grazing selectivity: low values indicate more selective grazing, as cattle take fewer bites per step in search of preferred items.

Wildlife Surveys

To determine the immediate effects of grazing treatments on wildlife, we set up motion-activated cameras in Replicate 1 for 7 d following the grazing treatment. Two cameras, one facing north and one south, were placed in the middle of each 1-ha unit (2 cameras in each planned grazing plot and 10 in the larger continuous grazing plot, spaced similarly). Wildlife occurrence was noted for eight species, Grevy's zebra *(Equus grevyi)*, plains zebra *(Equus quagga)*, cape buffalo *(Syncerus caffer)*, reticulated giraffe *(Giraffa camelopardalis)*, elephant *(Loxodonta africana)*, spotted hyena *(Crocuta crocuta)*, impala *(Aepyceros melampus)*, and Thomson's gazelle *(Eudorcas thomsonii)*, along with the time of sighting (day or night) and whether the individual was grazing or walking.

Statistical Analysis

All statistical analyses were conducted using R (version 3.4.2, R Core Team, 2017; RStudio Team, 2016). Model assumptions of residual normality and homoscedasticity were assessed graphically (using histograms, residual vs. fitted values plots, and quantile-quantile plots), informing subsequent data transformations and model choices. We included nested random effects in the mixed-effects models to account for pseudoreplication in vegetation survey and cattle behavior data collection.

Preliminary statistical analyses were conducted on raw foliar hits per pin data using Mann-Whitney tests to determine whether initial total foliar hits per pin per hectare overall and for each grass species individually differed across grazing treatments. Linear mixed-effects models (LMMs, R package *lme4*; Bates et al., 2017) were then used to test the effect of grazing treatment on total foliar hits per pin and foliar hits per pin for each grass species. Time of measurement (before or after grazing treatment), grazing treatment, and the random effect of hectare plot were included as variables in the models. The interaction between time of measurement (before or after grazing treatment) and grazing treatment (planned grazing or continuous grazing) was used to determine if the decrease in foliar hits per pin differed significantly between grazing treatments. P values on LMMs were calculated using R package *lmerTest* (Kuznetsova et al., 2017).

Four cattle behavior response variables (time spent grazing, time spent walking, bite/step ratios, and grazing velocities) were investigated using linear and generalized linear mixed-effects models (LMMs and GLMMs, respectively). These mixed-effects models varied only in the model distribution assumed, and all included treatment and time (morning, midday, or afternoon) as fixed effects and replicate, day, and cattle ID as nested random effects. The proportions of time cattle spent grazing ($N = 288$; six focal cattle in each of two treatments, surveyed three times daily for 8 d) and walking ($N = 288$) were each modeled using a GLMM assuming a binomial distribution (R package *lme4;* Bates et al., 2017). Bite/step ratios (in bites taken per 100 steps; $N = 688$) were modeled using a GLMM assuming a negative binomial distribution (R package *glmmTMB;* Magnusson et al., 2017). Cattle grazing velocity (in m/min; $N = 236$) were modeled with an LMM assuming a normal distribution (R package *lme4;* Bates et al., 2017). Differences between distances walked by cattle in each treatment were determined with an LMM using treatment as the main effect, day as an additional explanatory variable, and cattle ID as a random effect.

When analyzing camera trap data, we fit two GLMMs assuming a poisson distribution to determine if grazing treatment significantly affected the total number of individuals or the total number of zebras present in the plots at night. These GLMMs included treatment and day as fixed and random effects, respectively.

Results

Vegetation Surveys

Initial total foliar hits per pin did not differ significantly between plots assigned to planned grazing and continuous grazing treatments (Mann-Whitney: $W = 40$, $P = 0.44$). Foliar hits per pin per ha (mean ± SE) were distributed among the focal species as follows: *B. lachnantha* (11.72% ± 0.85%), *P. mezianum* (9.58% ± 0.85%), *P. stramineum* (2.79% ± 0.33%), *S. sphacelata* (65.65% ± 3.34%), and *T. triandra* (10.44% ± 2.23%). Initial foliar hits per pin did not differ between planned grazing and continuous grazing treatments for the majority of species (Mann-Whitney: *P. mezianum*—$W = 19.5$, $P = 0.21$; *P. stramineum*—$W = 18$, $P = 0.27$; *S. sphacelata*—$W = 41$, $P = 0.38$; *T. triandra*—$W = 25$; $P = 0.51$). *B. lachnantha*, however, had significantly higher initial foliar hits per pin per ha in continuous grazing plots (Mann-Whitney: $W = 57$, $P = 0.007$).

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Table 1
Vegetation models and results
Total (1) and species-specific (2-5) effects of grazing treatment on foliar hits per pin. All models are linear mixed-effects models, including Time (before or after grazing), Treatment, and the interaction of Time and Treatment as fixed effects, with Plot as a random effect. Although the interaction term was significant at the 0.10 level, separate analyses for each replicate showed that *T. triandra* biomass (3) decreases did not differ by grazing treatment.

	Response variable: Total and species specific foliar hits per pin				
	All species	*B. lachnantha*	*T. triandra*	*Pennisetum spp.*	*S. sphacelata*
	(1)	(2)	(3)	(4)	(5)
Intercept	3.12***	2.22***	2.23***	2.28***	2.81***
	t = 24.20	t = 17.24	t = 17.27	t = 18.36	t = 19.56
	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001
	df = 17.1	df = 25.2	df = 39.6	df = 31.5	df = 17.5
Time	1.32***	0.77***	0.71***	0.73***	1.28***
	t = 16.48	t = 5.68	t = 4.35	t = 4.99	t = 13.74
	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001
	df = 622	df = 548.4	df = 437.1	df = 673.4	df = 617
Treatment	-0.11	-0.17	-0.34	-0.27	-0.04
	t = -0.63	t = -0.91	t = -1.85	t = -1.51	t = -0.22
	p = 0.54	p = 0.37	p = 0.07	p = 0.14	p = 0.83
	df = 17.1	df = 26.3	df = 40.7	df = 34.3	df = 17.5
Time*Treatment	-0.17	0.06	0.44	0.46*	-0.22
	t = -1.51	t = 0.32	t = 1.91	t = 2.16	t = -1.63
	p = 0.14	p = 0.76	p = 0.06	p = 0.04	p = 0.11
	df = 622	df = 550.2	df = 442.4	df = 679.6	df = 617
Observations	640	566	453	685	635

Note: *p<0.05; **p<0.01; ***p<0.001.

Cattle grazing significantly decreased total foliar hits per pin, and this decrease did not significantly differ in magnitude across grazing treatments (Table 1). This trend held in species-specific analyses, except for *Pennisetum* spp., whose foliar hits per pin decreased significantly more in planned grazing treatment plots (see Table 1).

Cattle Behavior Surveys

Replicates were initially analyzed individually in order to capture any potential differences in cattle grazing behavior due to the experimental design; however, the replicates did not differ qualitatively in their significance, so results are presented for combined replicates. Cattle in both treatments spent the majority of their time grazing (84.56% ± 1.32%; mean ± SE) (Table 2). Cattle spent only a small proportion of their time walking, and planned grazing cattle spent significantly less time walking (3.48% ± 0.52%) than continuous grazing cattle (7.60% ± 0.89%) (see Table 2). Cattle in both treatments spent significantly less time grazing and less time walking during midday (see Table 2), when cattle typically ruminate.

Bite/step ratios—a measure of grazing selectivity for which high values indicate less selective grazing—were significantly higher for planned grazing cattle (5.25 ± 0.20 bites/step) than for continuous grazing cattle (2.65 ± 0.20 bites/step) and did not differ based on time of day (see Table 2). Planned grazing cattle grazed at significantly lower linear velocities (3.77 ± 0.13 m per min [mpm]) than continuous grazing cattle (7.28 ± 0.31 mpm) during typical grazing bouts (see Table 2). Cattle across both treatments grazed at significantly slower velocities at midday, when cattle typically ruminate (see Table 2). Continuous grazing cattle walked significantly farther in the plots each day (5.01 km ± 0.10, mean ± SE) than planned grazing cattle (3.59 km ± 0.08) (LMM: Treatment—$t = -11.53$, $P < 0.001$).

Wildlife Surveys

Significantly more zebras were counted in planned grazing plots than continuous grazing plots at night after cattle had grazed the plots (GLMM: Treatment—$z = 2.19$, $P = 0.03$). Zebra individuals, *E. grevyi* and *E. burchelli,* made up 87% of the animal occurrences recorded;

Table 2
Behavior models and results
Model results investigating the effect of Treatment (planned grazing) and Time (of day) on cattle behavior: proportions of time spent grazing (1) and walking (2), bite/step ratios (3), and grazing velocities (4). All models included Treatment and Time (morning, midday, or afternoon) as fixed effects and replicate, day, and cattle ID as nested random effects. Time spent grazing (1) and walking (2) were modeled using a generalized linear mixed-effects model (GLMM) assuming a binomial distribution, bite/step ratios were modeled using a GLMM assuming a negative binomial distribution, and velocities were modeled using a linear mixed-effects model (LMM).

	Time Grazing	Time Walking	Bite/Step ratio	Velocity
	(1)	(2)	(3)	(4)
Intercept	2.64***	-2.61***	5.56***	7.58***
	z = 9.77	z = -6.30	z = 69.47	t = 21.86
	p < 0.001	p < 0.001	p < 0.001	p < 0.001
Treatment	0.26	-0.89***	0.72***	-3.45***
	z = 1.07	z = -4.35	z = 9.06	t = -9.52
	p = 0.29	p < 0.001	p < 0.001	p < 0.001
Time: midday	-1.62***	-0.54**	−0.04	-1.12**
	z = -12.10	z = -2.79	z = −0.56	t = -3.06
	p < 0.001	p = 0.01	p = 0.57	p = 0.01
Time: afternoon	0.13	-0.35	−0.13	0.03
	z = 0.81	z = -1.91	z = −1.82	t = 0.08
	p = 0.42	p = 0.06	p = 0.07	p = 0.94
Residual df	281	281	680	228
Observations	288	288	688	236

Note: *p<0.05; **p<0.01; ***p<0.001.

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there were not enough data to conduct separate analyses for other species. However, the data show a similar trend when nighttime occurrence data from all species were combined (GLMM: Treatment—$z = 1.72$, $P = 0.09$).

Discussion

Our experiment shows that planned grazing changes cattle behavior, causing cattle to graze less selectively, with significant effects on the vegetation community and wildlife responses. Despite its limited spatial and temporal scope, we believe that our results provide a preliminary understanding of the behavioral mechanisms that may lead to rangeland improvements under planned grazing. Planned grazing cattle were restricted to grazing in their immediate vicinity, evidenced by their significantly lower velocities and higher bite/step ratios compared with continuous grazing cattle. Vegetation survey results support this finding, with planned grazing cattle eating significantly more *Pennisetum* grasses, which when mature or senescent are typically avoided due to their “wiry” structure and unpalatable nature (Odadi et al., 2013). It seems likely that when bunched together in the planned grazing treatment, cattle were unable to selectively avoid eating the *Pennisetum* grasses. We hypothesize that it was increased removal of these unpalatable grass species that increased zebra presence in planned grazing plots post treatment (Rubenstein and Hack, 2004; Odadi et al., 2017). The long-term impacts of these two grazing methods on rangeland vegetation will need to be assessed through seasonal and interannual vegetation monitoring. We expect that increased consumption of *Pennisetum* spp. in planned grazing plots will increase palatable grass species following seasonal rains, attracting more wildlife in the short and long terms (Odadi et al., 2011; Schieltz and Rubenstein, 2016).

Though planned grazing changed cattle grazing selectivity, importantly there was no significant difference in grazing time or amount between the two treatments. Despite no measurable effect on forage quantity, work on the nutritional content of these savanna grasses is necessary to determine whether planned grazing significantly affected forage quality, which could affect long-term weight gain and cattle health. Past work by Odadi et al. (2017) found that planned grazing management significantly increased cattle weight gain. In our study continuous grazing cattle spent significantly more time walking than planned grazing cattle, which could indicate increased energetic expenditure by continuous grazing cattle and may explain the differential weight gain found by Odadi et al. (2017).

The unequal herder effort required to implement these two cattle grazing methods must also be considered. Four herders were needed to keep 25 cattle bunched for the planned grazing treatment, while the same number of cattle required only two herders for the continuous grazing treatment. From the cattle ranch owner’s perspective, the planned grazing approach comes with the cost of hiring more herders and its financial benefits (improved rangeland health and sustainability and cattle weight gain) will need to outweigh these costs to encourage switching from conventional continuous grazing. Moreover, keeping cattle actively bunched together requires greater diligence from herders, posing another potential barrier to adopting the planned grazing approach.

Implications

The results presented here indicate that rotations of intensive grazing by bunched cattle, common attributes of planned grazing management strategies, change cattle behavior and lead to less selective grazing, as indicated by slower grazing velocities and increased bite/step ratios. This behavioral change resulted in a relatively larger decline in less palatable grass species (*Pennisetum* spp.) than under continuous grazing, without changing the total biomass of vegetation grazed by the cattle. Before these results are used to alter management policy, the long-term effects of this behavioral change should be monitored. Although this effect has the potential to improve rangeland health and sustainability, we recommend long-term measurements of species egrowth and abundances to confirm the role of decreased grazing selectivity as a mechanism driving improvements in rangeland vegetation quality. Although the potential benefits of bunched rotational grazing are large, it is critical for rangeland managers to focus on landscape-appropriate grazing strategies and stocking intensities, rather than relying on rotational planned grazing as a “one-size-fits-all” solution.

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