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Can Collaborative Adaptive Management Improve Cattle Production in Multipaddock Grazing Systems?[☆]

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ABSTRACT

Collaborative adaptive management (CAM) is hypothesized to benefit management of rangeland ecosystems, but the presumed benefits have seldom been quantified, and never in a multipaddock rotational grazing system. Here, we evaluated average daily weight gain (ADG) of livestock (kg steer^{-1} d^{-1}) in four grazing management treatments during the summers of 2016–2018 in a semiarid shortgrass steppe. These four treatments had the same stocking rate but differed in stocking densities. The three lowest stocking densities were implemented using *nonadaptive* grazing management, while the highest stocking density was implemented using CAM by an 11-member Stakeholder Group. Three of the four treatments used multipaddock rotational grazing. Growing season precipitation varied from drought in 2016 to near average in 2017 and dry in 2018. During nondrought years, ADG under *nonadaptive* grazing declined linearly as stocking density increased from low to high. This relationship was not significant during drought (2016). CAM increased absolute livestock production by 0.13 to 0.19 kg steer^{-1} d^{-1} in nondrought years, or a 23–25% relative increase in ADG. This benefit of CAM arose from the Stakeholder Group's ability to rotate cattle in response to spatiotemporal heterogeneity across the landscape—i.e., the ability to graze the "right pastures at the right time." Multiplying the additional grazing season livestock gains achieved through CAM by the monetary value of gains (\$ kg^{-1}) resulted in an estimated additional gross revenue return from CAM of \$48.16 to \$55.54 per steer annually, as compared with revenues from *nonadaptive* multipaddock rotational grazing under nondrought conditions. These results indicate that CAM, supported with substantial and timely monitoring data, can minimize decreases in livestock production associated with high stocking densities used in multipaddock rotation systems. However, in this experimental context, the economic benefits of increased livestock production associated with CAM were likely insufficient to offset the substantial cost of this approach.

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Introduction

Collaborative adaptive management (CAM) is widely emphasized as a resource management approach that seeks to engage multiple stakeholders in a structured, deliberative, and experimental management process to achieve desired outcomes (Armitage et al. 2009; Booher and Innes 2013; Westgate et al. 2013). CAM integrates multiple interests and knowledge sources of diverse stakeholders to reduce uncertainty, accelerate learning, and foster stakeholders' shared understanding of complex ecosystem dynamics and responses to management actions. CAM aspires to increase provision of ecosystem services above what would be expected from less adaptive or collaborative approaches to ecosystem management. Despite the wide acceptance of CAM as an aspirational management strategy, its contributions to natural resources management and enhanced provision of ecosystem services have seldom been quantified (Westgate et al. 2013). Here we quantified the ability of CAM to offset the negative effects of increased stocking density on yearling cattle weight gains in a semiarid shortgrass steppe ecosystem.

Rangeland ecosystems are characterized by highly variable resource availability, which makes adaptive management essential but challenging (Derner and Augustine 2016). CAM is appropriate for these conditions because uncertainty is high and managers can modify system dynamics with various grazing strategies (Allen and Gunderson 2011; Fernández-Giménez et al. 2019). Rangeland managers frequently address the challenge of balancing forage supply with livestock demand by adaptively manipulating the timing, duration, and location of livestock grazing in relation to forage resources that vary spatially and temporally. An additional strategy is to increase the stocking density of grazing animals (number of animals • unit land area^{-1}) and adaptively rotate a larger herd of animals among multiple pastures (*sensu* paddocks), such that the larger herd spends shorter periods of time (e.g., several days to weeks) in each pasture. This approach is termed adaptive, multipaddock rotational grazing (Teague and Barnes 2017). The rate and pattern of herd rotation, as well as the number of pastures used in a given system, vary widely among regions and managers (Kachergis et al. 2014; Roche et al. 2015; Teague and Barnes 2017; Augustine et al. 2020).

Purported benefits of grazing at increased stocking density over shorter time frames include increased uniformity of forage utilization within a pasture (i.e., less selective grazing by animals), longer intervening periods of pasture rest (nongrazing), increased production of palatable forage species, and greater heterogeneity of vegetation structure among pastures (Teague et al. 2013). Syntheses of numerous experiments examining rotational grazing strategies based on fixed schedules (i.e., *nonadaptive* decision making) have not shown benefits of rotational grazing to forage or livestock production (Briske et al. 2008; Hawkins 2017). We recently compared livestock production under continuous, season-long grazing versus multipaddock rotational grazing implemented using an adaptive approach and found that cattle in the latter treatment gained 12−16% less weight each year (Augustine et al. 2020). However, these studies have not explored whether adaptive decision making implemented within a multipaddock rotational grazing system could enhance livestock gains when compared with a nonadaptive, multipaddock rotational approach. Furthermore, many rotational grazing studies test the effects of different stocking densities without holding stocking rate constant (Hart et al. 1998; Burboa-Cabrera et al. 2013). This lack of control in stocking rate may confound efforts to isolate the effects of stocking density on rotational grazing outcomes.

In this study, we quantified 1) the influence of stocking density (holding stocking rate constant) on average daily gains of livestock *nonadaptively* managed and 2) the contributions of CAM to livestock production at the highest stocking density, relative to *nonadaptive* grazing, when both were implemented in a multipaddock, rotational grazing framework over a 3-yr period (2016−2018). This represents the first experimental investigation of the contributions of CAM to livestock production in a multipaddock rotational grazing system where stocking density was increased but stocking rate was held constant.

Methods

Definitions: Stocking Density versus Stocking Rate, Adaptive versus Nonadaptive Management

In cases where rotational grazing strategies involve an increase in stocking density, weight gain per grazing animal tends to decrease. This outcome has been repeatedly demonstrated in rangelands (Gutman et al. 1990; McCollum et al. 1990; Olson et al. 2002; Harmoney and Jaeger 2011), including the shortgrass steppe (Augustine et al. 2020). Yet two issues have limited scientific efforts to isolate the effects of stocking density on livestock production.

First, studies and management trials often confound stocking density (number of animals per unit of land at a given point in time) and stocking rate (number of animals grazed per total amount of land over some duration of time, e.g., season or year). Confounding can occur when experimental designs increase stocking density by reducing pasture area for the same number of animals, or when the pasture area remains unchanged but the number of grazing animals is increased while reducing the length of the grazing season by some predetermined amount of time (Hart et al. 1998; Burboa-Cabrera et al. 2013).

Second, managers who increase stock densities and rotate cattle among pastures often also employ adaptive management when designing rotation sequences and decision triggers for herd movement. Therefore ranch-scale responses of forage and livestock production to changes in stocking densities are often confounded with the degree to which managers monitor changing conditions and modify management actions (Teague et al. 2013; Hawkins 2017; Augustine et al. 2020). Consequently, past experimental grazing research might not have demonstrated the purported benefits of rotational grazing because the adaptive decision making of an experienced manager had been *excluded* (Briske et al. 2011).

Collaborative Adaptive Rangeland Management and the Stakeholder Group

This study involves the Collaborative Adaptive Rangeland Management experiment (CARM, https://www.ars.usda.gov/plains-area/fort-collins-co/center-for-agricultural-resources-research/rangeland-resources-systems-research/docs/range/adaptive-grazing-management/research/), located in the semiarid shortgrass steppe rangeland ecosystem of the western Great Plains (Wilmer et al. 2018; Fernández-Giménez et al. 2019). The CARM experiment includes an 11-member Stakeholder Group comprising ranchers, nongovernment conservation organization representatives, and state/federal land managers. This Stakeholder Group adopted a CAM grazing strategy that resulted in a 10-fold increase in stocking density compared with traditional rangeland management (TRM, season-long, *nonadaptive*) in this ecosystem. Stocking rate between the CAM and TRM grazing management strategies did not differ within a year, but it could differ between years.

The Stakeholder Group used adaptive decision making, at both annual and seasonal scales, to manage a rangeland ecosystem for multiple objectives, including the provision of wildlife habitat, vegetation composition and structure, ranch profitability and economic sustainability, and learning. The Stakeholder Group's

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Table 1
Characteristics of grazing management treatments. Quantitative stocking densities for the traditional rangeland management treatment represent the mean of 10 pastures.

Grazing treatment	Adaptive	Seasonality	Qualitative stocking density (2016–2018)	Quantitative stocking density (yearling steers 130 ha^{-1})			Quantitative stocking rate (AUM ha^{-1})		
				2016	2017	2018	2016	2017	2018
Traditional rangeland management (TRM)	No	Season-long	Low	23.4	24.4	28.0	0.67	0.70	0.81
Prescriptive-medium (PM)	No	Rotational	Medium	88	92	106	0.67	0.70	0.81
Prescriptive-high (PH)	No	Rotational	High	128	134	154	0.67	0.70	0.81
Collaborative adaptive management (CAM)	Yes	Rotational	Very high	234	244	280	0.67	0.70	0.81

AUM indicates animal unit month, or one 454-kg animal for 1 mo.

adaptive decisions were informed by biophysical and ecological monitoring data collected and analyzed by the research team, as well as by livestock condition and behavior data documented by technicians (Wilmer et al. 2018; Fernández-Giménez et al. 2019). Monitoring data that stakeholders used to make decisions included precipitation across different pastures; vegetation composition, structure, productivity, diversity, and residual biomass; wildlife habitat conditions and populations of key grassland bird species; and livestock gains, diet quality, and behaviors, such as “pushing fences.”

The Stakeholder Group used consensus-seeking decision making with the fallback of a supermajority (75%) vote to make decisions (Wilmer et al. 2018). Stakeholders received weekly email updates during each grazing season to support within-season decisions on livestock movements. They met in person every quarter to review monitoring data and seasonal weather and climate outlooks, discuss progress toward each objective, and make annual decisions on stocking rates, pasture grazing sequences, and identification of pastures for planned full-season rest. Social scientists on the research team facilitated semistructured discussions and consensus-building activities through which stakeholders explored their diverse mental models of rangelands, interpreted data as a group, proposed potential management options, hypothesized potential outcomes, and ultimately made management decisions (Wilmer et al. 2018).

Study Site. Our study site is the 6 270-ha Central Plains Experimental Range (CPER), a USDA-Agricultural Research Service Long-Term Agroecosystem Research network site (https://ltar.ars.usda.gov/) in northeastern Colorado. This semiarid, shortgrass steppe ecosystem has a mean annual precipitation of 341 mm and a mean growing season (May–September) precipitation of 238 mm. Most of the study site is subdivided into 130-ha pastures that differ in terms of soil type, ecological sites, and dominant plant species (cool-season [C_3] vs. warm-season [C_4] grasses), thereby influencing vegetation structure and production.

Grazing Treatments. We implemented four grazing management treatments during the summers of 2016–2018. These treatments had the same stocking rate annually in a grazing season but varied in stocking densities from low to high and in adaptive or *nonadaptive* management (Table 1). We assessed the contribution of CAM to livestock weight gains by combining data from the CARM experiment (which compares TRM to CAM) with cattle performance data from two other prescriptive (i.e., *nonadaptive*) rotational grazing management strategies (external to the CARM experiment, but within the same study area). These two strategies represented stocking densities intermediate of the TRM and CAM treatments, but at the same stocking rate each year.

The lowest (23.4–28 steers 130 ha^{-1}) stocking density occurred under TRM (Bement 1969). TRM did not involve livestock rotation or any adaptive decision making (see Table 1). The highest stocking density (234–280 steers 130 ha^{-1}) occurred under CAM (Wilmer et al. 2018; Fernández-Giménez et al. 2019; Augustine et al. 2020). The overall stocking rate applied to the CAM and TRM pastures in any given year was decided by the Stakeholder Group, informed by monitoring data, seasonal climate forecasts, and an aim to increase total livestock production per unit land area while making progress toward other ecosystem objectives (see Table 1).

For TRM, a single herd of yearling steers grazed in each of ten 130-ha pastures for the entire grazing season (mid-May through October 1) with stocking densities 10% of those in the CAM treatment. In contrast, the CAM treatment consisted of 10 paired, 130-ha pastures managed adaptively by the Stakeholder Group (Wilmer et al. 2018). This group decided to manage steers in the CAM treatment as a single herd rotated among the 10 pastures, with 2 of these pastures selected each year for a planned season-long rest (Wilmer et al. 2018; Augustine et al. in review). This decision resulted in one to three pastures being rested in the CAM grazing treatment each year (Table 2), thereby increasing the “effective” stocking rate of this treatment at the 1-yr timescale. At the same time, the rested pastures were not available for other uses, and occasional season-long rest was considered part of the planned grazing treatment for each CAM pasture at the 10-yr timescale. Paired CAM and TRM pastures (i.e., blocks) had similar soils, ecological sites, plant communities, and topographic patterns as measured by a topographic wetness index (Beven and Kirkby 1979).

During the study period, the CAM decision process involved iterative objective setting, management actions, monitoring, evaluation, and adjustment of grazing management decisions (Wilmer et al. 2018; Fernández-Giménez et al. 2019). This process led to stakeholders learning iteratively to match grazing management decisions with heterogeneous plant species composition and dynamic plant phenology throughout pasture grazing sequences (see Table 2). As a result of this process and learning, the Stakeholder Group’s CAM herd movement decisions varied across years (Table 3).

The two prescriptive grazing management treatments (i.e., those external to the CARM experiment) began in 2016, when we established two new sets of pastures managed using rotational but *nonadaptive* grazing management at two stocking densities intermediate of those in the TRM and CAM treatments. The Prescriptive-Medium treatment had a stocking density of 88–106 steers 130 ha^{-1} across the 3 study yr. The Prescriptive-High treatment had a stocking density of 128–154 steers 130 ha^{-1}. Both prescriptive treatments had the same annual stocking rate and grazing season length as the TRM and CAM treatments (see Table 1). The pasture rotation sequences for grazing animals in the prescriptive treatments were selected randomly each year (Table 4).

For the Prescriptive-Medium treatment, limited availability of 130-ha pastures with soil and plant community heterogeneity like those used in the other treatments required that we instead used five 65-ha pastures for this treatment. Achieving experimental pasture sizes that are comparable with working ranches is a persistent and major logistical challenge. However, a pasture size of 65-ha

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Table 2
Grazing sequences for the single herd of yearling steers in the Collaborative Adaptive Rangeland Management (CARM) pastures as determined by the Stakeholder Group for 2016–2018. Cells with "R" indicate years in which a pasture was rested from grazing. The 10 paired traditional rangeland management (TRM) pastures were each grazed by yearling steers season-long, with the grazing season beginning approximately May 15 and ending approximately October 1 each yr.

Pasture	Ecological sites	2016		2017		2018	
		Order	Days grazed	Order	Days grazed	Order	Days grazed
26W	Loamy	5	25	6	21	5	13
10S	Loamy	R	0	3	21	6	16
21N	Loamy	R	0	4	7	R	0
25NW	Loamy, Sandy	4	18	5	19	4	21
31W	Loamy, Sandy	3	25	7	6	3	20
18S	Sandy	6	14	1	19	2	15
8E	Sandy, Loamy	1	25	9	10	7	14
20NW	Sandy, Saltflat	2	22	R	0	1	13
7SE	Loamy, Sandy, Saltflat	7	11	2	21	8	14
17S	Loamy, Sandy, Saltflat	R	0	8	15	9	14

Table 3
List of criteria approved by the Stakeholder Group each yr (2016–2018) that were used as triggers to guide the movement of cattle from one pasture to the next in the sequence in the Collaborative Adaptive Rangeland Management (CARM) treatment.

Criteria	2016	2017	2018
Minimum vegetation biomass (kg ha^{-1})			
Loamy pastures	400	400	400
Sandy pastures	490	490	490
Mixed pastures	445	445	445
Cattle behavior	"Pushing fences"	"Pushing fences"	"Pushing fences"
Maximum days in pasture	28	21	14 in early season, 21 mid and late season
Minimum days in last pasture in sequence	10	10	10

is still relatively large compared with most grazing experiments. Stocking rates (and hence also the stocking densities) in the two prescriptive *nonadaptive* grazing treatments were increased 5% in 2017 and an additional 15% in 2018 to match CAM and TRM increases (see Table 1).

Data Analysis

For all four grazing management treatments, we measured individual steer weights at the start and end of each grazing season. Seasonal gains (kg steer^{-1}) were divided by the number of days grazed to calculate average daily gains (ADG, kg steer^{-1} d^{-1}). We first determined the relationship between stocking density and ADG gain in each yr (2016–2018) using all individual ADG values from the three *nonadaptive* grazing management treatments: TRM, Prescriptive-Medium, and Prescriptive-High. We used linear regression (SigmaPlot, version 13.0) to assess these. The existence of only three stocking densities per year precluded curvilinear or more robust function relationships. Linear models of the annual relationships between ADG and stocking density with *nonadaptive* management were then extrapolated to the high stocking density (observed only under CAM) to generate an estimate of ADG at that stocking density level under *nonadaptive* management. We caution readers that the extension of these linear models beyond the stocking densities used to generate the relationships between ADG and stocking density may not be applicable in all contexts. However, prior studies have substantiated that livestock weight gains decrease with increasing stocking density in central North American rangelands (Bement 1969; McCollum et al. 1990; Olson et al. 2002; Harmoney and Jaeger 2011; Raynor et al. in press).

Next, we calculated absolute (kg steer^{-1} d^{-1}) and relative (%) contributions of CAM in each year, at the high stocking density, as the difference between the actual mean ADG value measured under CAM and the predicted ADG value from the extrapolated regression equation under *nonadaptive* management. Confidence intervals (95%) were calculated around ADG for each stocking density and for the linear regressions, which were extrapolated to the high stocking density. If the confidence intervals around the actual CAM ADG value and its corresponding extrapolated *nonadaptive* ADG value, then we interpreted this as a significant difference attributable to CAM.

Results

Stocking density affected ADG of yearling steers as anticipated; in all 3 yr, ADG values were significantly higher in the TRM treatment (lowest stocking density) than any of the other treatments, including the CAM treatment (see nonoverlapping 95% confidence

Table 4
Randomly determined grazing sequences for the two prescriptive *(nonadaptive)* rotational grazing management treatments at medium and high stocking density during 2016–2018. The grazing season began approximately May 15 and ended approximately October 1 each yr. Pasture 8NW was rested (denoted as "R") in 2016 as the water source failed that grazing season.

Stocking density	Pasture	Ecological sites	2016		2017		2018	
			Order	Days grazed	Order	Days grazed	Order	Days grazed
Medium	6E	Sandy	4	39	5	32	1	27
Medium	8NW	Loamy, Sandy	R	0	4	25	2	28
Medium	15SW	Loamy	3	41	1	27	3	28
Medium	21S	Loamy, Saltflat	2	32	2	28	4	29
Medium	30NW	Loamy, Sandy	1	28	3	27	5	28
High	1E	Loamy, Saltflat	4	42	2	28	2	28
High	1W	Loamy	5	24	3	27	1	27
High	6W	Sandy	3	19	1	27	5	28
High	24E	Loamy, Sandy	1	27	5	32	4	29
High	32W	Loamy, Sandy	2	28	4	25	3	28

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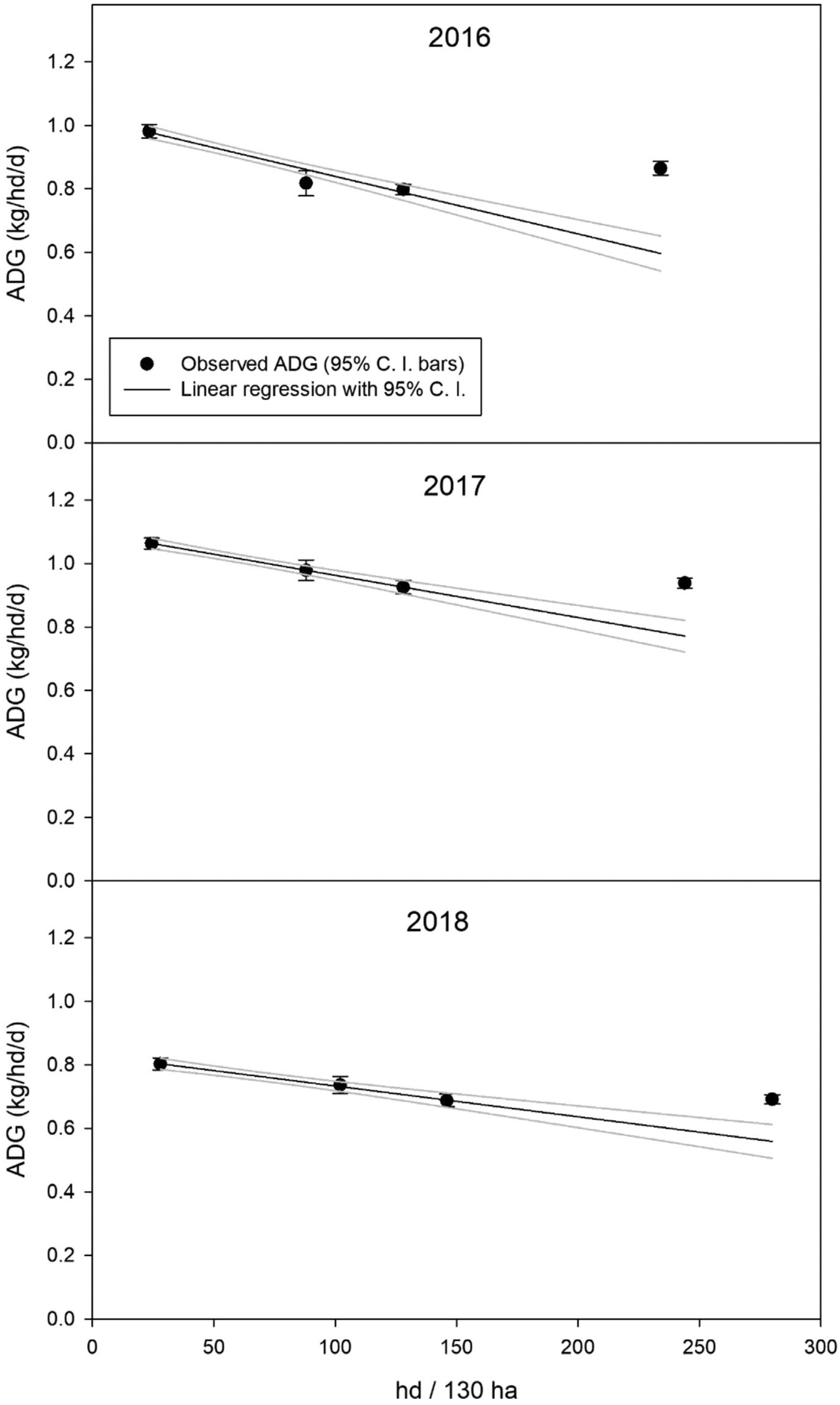

Figure 1. Responses of livestock weight gains (average daily gain, kg steer^{-1} d^{-1}) to four stocking densities (number of steers 130-ha pasture^{-1}) in 2016 (top panel), 2017 (middle panel), and 2018 (bottom panel) with the three lowest stocking densities ***not having*** collaborative adaptive management (CAM) involved in decision making. Linear relationships were fit to these three stocking densities in each yr (2016: $P = 0.181$, $r^2 = 0.96$; 2017: $P = 0.061$, $r^2 = 0.99$; 2018: $P = 0.038$, $r^2 = 0.99$). They were then extended with 95% confidence intervals (gray lines) to the highest stocking density level (observed only under CAM) to predict average daily gains at that stocking density level ***without*** CAM.

intervals in Fig. 1). However, the significance of the modeled linear relationship between stocking density and ADG varied across years, potentially due to differences in growing-season precipitation. Drought conditions occurred in the 2016 growing season (May—September, 38% below the long-term 78-yr mean, 147 mm vs. 238 mm). Precipitation was near normal for the 2017 growing season (250 mm vs. 238 mm) and 25% below the long-term mean for the 2018 growing season (179 mm vs. 238 mm).

Under the drought conditions of 2016, the linear relationship between stocking density and ADG in *nonadaptively* managed systems had a slope that was not significantly different from zero ($P = 0.181$). Though the slope was nonsignificant, we extended the

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Table 5
Absolute (kg steer^{-1} d^{-1}), relative (%), and grazing season (kg steer^{-1}) livestock gains associated with collaborative adaptive management (CAM) by the 11-member Stakeholder Group compared with the values predicted from extending the linear relationship determined from the three stocking density levels **without** adaptive management (see Fig. 1). Value of gain ($ kg^{-1}) each yr was multiplied by the grazing season livestock gains attributable to CAM to estimate additional gross revenue returns per steer. Values for 2016 are not provided as the linear relationship between average daily gain and stocking density was nonsignificant.

Yr	Livestock gain enhancement attributable to CAM			Value of gain ($ kg^{-1})	Gross revenue returns ($ steer^{-1})
	Absolute (kg steer^{-1} d^{-1})	Relative (%)	Grazing season (kg steer^{-1})		
2016	.	.	.	.	.
2017	0.191	25.41	26.70	2.08	55.54
2018	0.131	23.43	18.38	2.62	48.16

linear regression to the high stocking density, resulting in a predicted ADG of 0.58 kg steer^{-1} d^{-1} *without* CAM, compared with the observed ADG with CAM of 0.87 kg steer^{-1} d^{-1} (see Fig. 1).

In the near-normal precipitation yr of 2017, the linear relationship between ADG and stocking density values across the three treatments *nonadaptively* managed was significantly negative ($P = 0.036$) and the R^2 value exceeded 0.99. At the highest stocking density, predicted ADG ***without*** CAM was 0.75 kg steer^{-1} d^{-1}, while actual ADG with CAM was 0.94 kg steer^{-1} d^{-1} (see Fig. 1). Thus, the estimated contribution of CAM to livestock production was 0.19 kg steer^{-1} d^{-1}, corresponding to a relative increase of 25.4% (Table 5).

In the dry growing season of 2018, the linear relationship between ADG and stocking density values *nonadaptively* managed was significantly negative ($P = 0.063$) and the R^2 value exceeded 0.99. At the highest stocking density, predicted ADG was 0.56 kg steer^{-1} d^{-1} *without* CAM (see Fig. 1), while actual ADG with CAM was 0.69 kg steer^{-1} d^{-1}. Thus, the estimated contribution of CAM to livestock production was 0.13 kg steer^{-1} d^{-1}, a relative increase of 23.4% (see Table 5).

Applying the above-calculated absolute increases in ADG with CAM to the entire grazing season (140 d), we calculated the amount of grazing season gain (kg) per steer attributable to this management strategy. Across the 2 yr in which the linear regression was significant (2017 and 2018, but not in the drought yr 2016), we estimated that CAM resulted in an additional weight gain of 18.4 to 26.7 kg steer^{-1} over the grazing season (see Table 5). These additional weight gains were then converted to monetary values on a per-animal basis ($ kg^{-1}, see Windh et al. 2019), accounting for the price slide (i.e., that $ kg^{-1} tends to decrease as animals add weight). CAM increased gross revenue returns, on average, by $48.16 steer^{-1} (in 2018) to $55.54 (in 2017) steer^{-1} (see Table 5).

Discussion

The Stakeholder Group implemented collaborative adaptive management (CAM) using local, experiential, and professional knowledge of ecological sites, plant community composition, diet quality, and monitoring data to make annual pasture sequence and adaptive livestock rotation decisions. CAM enabled the Stakeholder Group to graze “the right pastures at the right time”—flexibly matching animal forage demand with the spatial and temporal heterogeneity of precipitation (Augustine 2010), forage quantity, and forage quality among ecological sites and plant communities.

This application of CAM resulted in absolute production increases of 0.13 to 0.19 kg steer^{-1} d^{-1} or 23–25% relative to the predicted ADG under *nonadaptive* grazing at the highest stocking density in nondrought years. Our results also document that livestock weight gains decreased with increasing stock density in nondrought growing seasons, consistent with multiple previous investigations in central North American rangelands (McCollum et al. 1990; Olson et al. 2002; Harmoney and Jaeger 2011; Raynor et al. in press), grasslands with Mediterranean climates (Gutman et al. 1990), and forage monocultures (Mezzadra et al. 1992; Kaitibie et al. 2003).

Even in the driest study yr of 2016, however, the weight gain achieved with CAM at a high stocking density (234 steers 130 ha^{-1}) was greater than that achieved with *nonadaptive* management at stocking densities of 88–128 steers 130 ha^{-1} (see Fig. 1). This indicates that CAM can partially offset declines in ADG associated with higher stocking densities via adaptive decision making supported with monitoring data. However, CAM did not achieve equivalent weight gains to cattle managed under the traditional, season-long grazing treatment with a low stocking density of 20–25 head 130 ha^{-1}. Thus, while CAM generated significant benefits for livestock production, it could not fully overcome the negative effects of high stocking density on individual livestock weight gains. In addition, the use of CAM did not enhance vegetation responses in terms of the density, abundance, and productivity of perennial C_3 graminoids and did not enhance total aboveground forage production (Augustine et al. 2020). CAM did benefit some grassland birds of conservation concern by creating taller-structure vegetation (Davis et al. 2020).

The Stakeholder Group developed both strategic and tactical management decisions—via interpretation of regular, intensive monitoring data and local knowledge—which resulted in substantial increases in both absolute (0.13 to 0.19 kg steer^{-1} d^{-1}) and relative (23-35%) ADG compared with an extrapolated *nonadaptive* strategy at the same high stocking density. Three related reasons suggest that values observed are likely conservative and could potentially be increased further with greater emphasis on livestock production, although this emphasis would also likely be associated with a loss of progress toward other management objectives. First, the CAM process in this study emphasized the provision of multiple ecosystem services, including grassland bird conservation (Wilmer et al. 2018; Davis et al. 2020), rather than solely livestock production. Second, decisions determined by consensus or a supermajority ($>$ 75%) of the 11-member Stakeholder Group involved compromises associated with the diverse interests and priorities of the group members, including ranchers, nongovernmental conservation group representatives, and state/federal land managers (Wilmer et al. 2018). Third, decision making by individual ranchers with high levels of experiential knowledge about specific rangeland locations (Wilmer et al. 2019) could result in enhanced outcomes, specifically for livestock production (Teague et al. 2013).

Our experimental approach enabled us to partially disentangle the benefits of CAM from the design and implementation of a specific grazing system (i.e., a stocking density, stocking rate, and season-long vs. rotational grazing strategy). However, this

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experimental approach likely minimized some of the stakeholder and logistical complexity characteristic of other, real-world applications of CAM to natural resources management (Allen and Gunderson 2011). Although the Stakeholder Group represented diverse backgrounds and natural resource objectives, its members did not face an intense controversy and had not experienced negative direct interactions before this investigation. Furthermore, the research team worked in parallel with the Stakeholder Group by regularly providing, analyzing, and interpreting biophysical and ecological monitoring data describing the outcomes of specific management decisions (Fernández-Giménez et al. 2019). The resources and expertise needed to create this data-management feedback loop are unlikely to be available in other applications of CAM. The challenge is to find ways to mimic this approach by using the lessons learned here to identify critical decision points and develop simple heuristics to evaluate and implement them.

Our results suggest that the benefits of CAM as applied to multipaddock rotational grazing arose from the Stakeholder Group's ability to incorporate adaptive movements of livestock across a spatially and temporally variable landscape, rather than the simple alternation of grazing and rest (Briske et al. 2008; Hawkins 2017). Relative to a *nonadaptive* approach, and excluding drought conditions, CAM's increased livestock production at the high stocking density was a direct outcome of its unique decision process bolstered by knowledge of varying soil types, ecological sites (Reynolds et al. 2019), and plant communities in this landscape. This knowledge was also combined with regular monitoring, data analysis, and discussion of outcomes relative to management objectives by the Stakeholder Group and research team (Wilmer et al. 2018; Fernández-Giménez et al. 2019). Benefits of CAM were evident in the ability of the Stakeholder Group to identify multiple management objectives and effectively navigate tradeoffs among them while simultaneously increasing livestock production above values frequently associated with these high stocking densities used. This represents an example of how science-management partnerships can achieve both production and conservation objectives (Fernández-Giménez et al. 2019).

The application of CAM in environments with scarce and variable resources provides an opportunity to 1) employ monitoring data to establish feedback loops between decision making and desired outcomes (Fernández-Giménez et al. 2019), 2) integrate spatial and temporal resource variability into management planning and strategies (Derner and Augustine 2016), and 3) incorporate seasonal temperature, precipitation, and forage outlooks into management decisions (Peck et al. 2019). CAM can contribute to the attainment of multiple and potentially conflicting natural resource objectives by creating opportunities for intentional resting of pastures (i.e., grass banking or forage reserves) within a multipaddock rotational system as the location of the pastures can be alternated across years. This enhances resilience and reduces risk by providing built-in "insurance" that can be used, if necessary, during drought years. This approach, within the CARM experiment, has also created taller-structure vegetation for grassland birds of conservation concern (Davis et al. 2020). Additionally, it has facilitated prescribed patch-burn grazing, which reduced densities of unpalatable plants (e.g., *Opuntia polyacantha,* prickly pear cactus), created breeding habitat for grassland birds of conservation concern needing short vegetation structure, and enhanced forage quality accessible to livestock (Augustine and Derner 2012).

These results indicate that CAM, supported with substantial and timely monitoring data, can minimize the reductions in animal production and profitability associated with high stocking densities used in multipaddock rotation systems. However, in this experimental context, the economic benefits of increased cattle production associated with CAM were likely insufficient to offset the substantial cost of this approach. These costs are associated with extensive monitoring of vegetation, grassland bird habitat, and livestock weight gains, analysis and summarization of these monitoring data, and the CAM decision making processes including quarterly meetings (Wilmer et al. 2018; Fernández-Giménez et al. 2019).

Adaptive, multipaddock rotational systems become more difficult to justify when the inherent cost of these systems is added to the cost of CAM. Additional infrastructure (e.g., water and fencing) is often required (Windh et al. 2019), livestock weight gains are reduced compared with traditional grazing systems (Augustine et al. 2020), and time and resources required for animal movement between pastures can increase. Reductions in individual animal weight gains can be partially compensated for by higher prices for lighter weight animals (i.e., the price slide, Windh et al. in press). At the same time, labor costs may be reduced when cattle are in fewer herds and can be checked and located more readily. The critical question regarding the benefits of CAM in multipaddock grazing hinges on whether it can enhance attainment of multiple management objectives in a way that offsets additional implementation costs. Experimental evidence to date has shown only benefits for enhanced grassland bird habitat in multipaddock rotation systems supported with CAM (Augustine et al. 2020; Davis et al. 2020), and it is unclear whether these benefits are enough to offset added costs. Comparable or greater benefits to grassland bird habitat may be created with the application of CAM to landscapes managed with traditional grazing systems via strategic seasonal or annual pasture deferment or via periodic prescribed burning (Augustine and Derner 2015).

Implications

Cattle weight gains were increased with CAM above those expected with *nonadaptive* grazing management at a comparably high stocking density. This resulted from the flexible matching of animal forage demand to forage quantity and quality, which capitalized on inherent spatiotemporal variation in plant communities, phenology, precipitation, and forage production among ecological sites. However, CAM was unable to completely overcome the negative effects of high stocking density on livestock production. When multiple systems were compared using similar stocking rates, individual livestock weight gains were consistently highest in the traditional, season-long grazing treatment associated with low stock densities.

Weight gains attributed to CAM were supported by regular, intensive monitoring by the research team of ecological and economic objectives and outcomes of previous management decisions, which created effective information feedback loops (Fernández-Giménez et al. 2019). If producers employ a multipaddock rotational grazing system, the key advantage is the capacity to incorporate adaptive management, which provides greater livestock and ecological benefits than the potential ecological benefits derived from successive graze–rest periods alone (Briske et al. 2011; Derner and Augustine 2016). Our results imply that the development of a multipaddock rotational grazing strategy should emphasize adaptive management supported by monitoring data, rather than just technical design details such as the order and duration of pasture rotations. Science-management partnerships organized around the CAM process may provide an effective framework for sustainably managing semiarid rangelands for multiple ecosystem services (Wilmer et al. 2018).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Allen, D.R., Gunderson, L.H., 2011. Pathology and failure in the design and implementation of adaptive management. Journal of Environmental Management 92, 1379–1384. doi:10.1016/j.jenvman.2010.10.063.

Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.L., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N.C., Johnson, D.S., Marschke, M., McConney, P., Pinkerton, E.W., Wollenberg, E.K., 2009. Adaptive co-management for socio-ecological complexity. Frontiers in Ecology and the Environment 7, 95–102. http://www.jstor.org/stable/25595062.

Augustine, D.J., 2010. Spatial versus temporal variation in precipitation in a semiarid ecosystem. Landscape Ecology 25, 913–925. doi:10.1007/s10980-010-9469-y.

Augustine, D.J., Derner, J.D., 2012. Disturbance regimes and mountain plover habitat in shortgrass steppe: large herbivore grazing does not substitute for prairie dog grazing or fire. Journal of Wildlife Management 76, 721–728.

Augustine, D.J., Derner, J.D., Fernández-Giménez, M.E., Porensky, L.M., Wilmer, H., Briske, D.D., Stakeholder Group, CARM, 2020. Adaptive, multi-paddock rotational grazing management: a ranch-scale assessment of effects on vegetation and livestock performance in semi-arid rangeland. Rangeland Ecology & Management doi:10.1016/j.rama.2020.07.005, (inpress).

Bement, R.E., 1969. A stocking-rate guide for beef production on blue-grama range. Journal of Range Management 22, 83–86. doi:10.2307/3896186.

Beven, K., Kirkby, M., 1979. A physically based, variable contributing area model of basin hydrology. Hydrological Sciences Bulletin 24, 43–68.

Briske, D.D., Derner, J.D., Brown, J.R., Fuhlendorf, S.D., Teague, W.R., Havstad, K.M., Gillen, R.L., Ash, A.J., Willms, W.D., 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangeland Ecology & Management 61, 3–17. doi:10.2111/06-159R.1.

Briske, D.D., Sayre, N.F., Huntsinger, L., Fernández-Giménez, M., Budd, B., Derner, J.D., 2011. Origin, persistence, and resolution of the rotational gazing debate: integrating human dimensions into rangeland research. Rangeland Ecology & Management 64, 325–334. https://doi.org/10.2111/REM-D-10-00084.1.

Burboa-Cabrera, F.R., Schacht, W.H., Anderson, B.E., 2013. Utilization and grazing distribution of cattle at 4 stocking densities. Journal of Range Management 328–333. doi:10.2307/4004035.

Davis, K.P., Augustine, D.J., Monroe, A.P., Derner, J.D., Aldridge, C.L., 2020. Adaptive rangeland management benefits grassland birds utilizing opposing vegetation structure in the shortgrass steppe. Ecological Applications 30 (1), e02020. doi:10.1002/eap.2020.

Derner, J.D., Augustine, D.J., 2016. Adaptive management for drought on rangelands. Rangelands 38, 211–215. doi:10.1016/j.rala.2016.05.002.

Fernández-Giménez, M.E., Augustine, D.J., Porensky, L.M., Wilmer, H., Derner, J.D., Briske, D.D., Stewart, M.O., 2019. Complexity fosters learning in collaborative adaptive management. Ecology and Society 24, 29. doi:10.5751/ES-10963-240229.

Gutman, M., Holzer, Z., Seligman, N.G., Noy-Meir, I., 1990. Stocking density and production of a supplemented beef herd grazing yearlong on Mediterranean grassland. Journal of Range Management 43, 535–539. doi:10.2307/4002359.

Harmoney, K.R., Jaeger, J.R., 2011. Animal and vegetation response to modified intensive-early stocking on shortgrass rangeland. Rangeland Ecology & Management 64, 619–624. https://doi.org/10.2111/REM-D-10-00149.1.

Hawkins, H., 2017. A global assessment of Holistic Planned Grazing compared with season-long, continuous grazing: meta-analysis findings. African Journal of Range & Forage Science 34, 65–75. doi:10.2989/10220119.2017.1358213.

Kaitibie, S., Epplin, F.M., Brorsen, B.W., Horn, G.W., Krenzer, E.G., Paisley, S.I., 2003. Optimal stocking density for dual-purpose winter wheat production. Journal of Agricultural and Applied Economics 35, 29–38. doi:10.1017/S1074070800005915.

Kachergis, E., Derner, J.D., Cutts, B.B., Roche, L.M., Eviner, V.T., Lubell, M.N., Tate, K.W., 2014. Increasing flexibility in rangeland management during drought. Ecosphere 5, 1–14. http://dx.doi.org/10.1890/ES13-00402.1.

McCollum, F.T., Gillen, R.L., Engle, D.M., Horn, G.W., 1990. Stocker cattle performance and vegetation response to intensive early-stocking of Cross Timbers rangeland. Journal of Range Management 43, 99–103.

Mezzadra, C., Escuder, J., Miquel, M.C., 1992. Effects of genotype and stocking density on post-weaning daily gain and meat production per hectare in cattle. Animal Science 55, 65–72. doi:10.1017/S0003356100037284.

Olson, K.C., Jaeger, J.R., Brethour, J.R., Avery, T.B., 2002. Steer nutritional response to intensive-early stocking on shortgrass rangeland. Journal of Range Management 55, 222–228. 10.2458/azu_jrm_v55i3_olson.

Peck, D., Derner, J.D., Parton, W., Hartman, M., Fuchs, B., 2019. Flexible stocking with Grass-Cast: a new grassland productivity forecast to translate climate outlooks for ranchers. Western Economics Forum 17 (1), 24–29.

Raynor, E. J., Derner, J. D., Baldwin, T., Ritten, J. P., and Augustine, D. J. Multi-decadal shift in shortgrass stocking rates. Rangeland Ecology & Management, in press.

Reynolds, A.Q., Derner, J.D., Augustine, D.J., Porensky, L.M., Wilmer, H., Jorns, T., Briske, D.D., Scasta, J.D., Fernández-Giménez, M.E.CARM Stakeholder Group, 2019. Ecological sites: can they be managed to promote livestock production. Rangelands 41, 239–243. doi:10.1016/j.rala.2019/07.003.

Roche, L.M., Cutts, B.B., Derner, J.D., Lubell, M.N., Tate, K.W., 2015. On-ranch grazing strategies: context for the rotational grazing debate. Rangeland Ecology & Management 68, 248–256. http://dx.doi.org/10.1016/j.rama.2015.03.011.

Teague, R., Provenza, F., Kreuter, U., Steffens, T., Barnes, M., 2013. Multi-paddock grazing on rangelands: Why the perpetual dichotomy between research results and rancher experience. Journal of Environmental Management 128, 699–717. doi:10.10126/j.jenvman.2013.05.064.

Teague, R., Barnes, M., 2017. Grazing management that regenerates ecosystem function and grazingland livelihoods. African Journal of Range & Forage Science 24, 77–86. doi:10.2989/10220119.2017.1334706.

Westgate, M.J., Likens, G.E., Lindenmayer, D.B., 2013. Adaptive management of biological systems: a review. Biological Conservation 158, 128–139. doi:10.1016/j.biocom.2012.08.016.

Wilmer, H., Derner, J.D., Fernandez-Gimenez, M.E., Briske, D.D., Augustine, D.J., Porensky, L.M.CARM Stakeholder Group, 2018. Collaborative adaptive rangeland management fosters management-science partnerships. Rangeland Ecology & Management 71, 646–657. doi:10.1016/j.rama.2017.07.008.

Wilmer, H., Porensky, L.M., Fernandez-Gimenez, M.E., Derner, J.D., Augustine, D.J., Ritten, J.P., Peck, D.P., 2019. Community-engaged research builds a nature-culture of hope on North American Great Plains Rangelands. Social Sciences 8, 22. doi:10.3390/socsci8010022.

Windh, J.L., Ritten, J.P., Derner, J.D., Paisley, S.I., Lee, B.P., 2019. Economic cost analyses of continuous-season-long versus rotational grazing systems. Western Economics Forum 17, 62–72.

Windh, J. L., Ritten, J. P., Derner, J. D., Paisley, S., and Lee, B. Effects of long-term cattle market conditions on continuous season-long and rotational grazing system revenues. The Rangeland Journal (in press)

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