Rangeland Ecology & Management 78 (2021) 5–14

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: www.elsevier.com/locate/rama

Comparative Pasture Management on Canadian Cattle Ranches With and Without Adaptive Multipaddock Grazing☆

Edward W. Bork[1,*], Timm F. Döbert[2], Jessica S.J. Grenke[3], Cameron N. Carlyle[1], James F. Cahill Jr.[3], Mark S. Boyce[2]

[1] Department of Agricultural, Food and Nutritional Science, Agriculture/Forestry Center, University of Alberta, Edmonton, Alberta, Canada, T6G 2P5
[2] Department of Biological Sciences, Centennial Centre for Interdisciplinary Science, University of Alberta, Edmonton, Alberta, Canada, T6G 2E9
[3] Department of Biological Sciences, Biological Sciences Building, University of Alberta, Edmonton, Alberta, Canada, T6G 2E9

ARTICLE INFO

Article history:
Received 27 October 2020
Revised 26 March 2021
Accepted 26 April 2021

Key Words:
Adaptive multipaddock grazing
Cultivation history
Grazing practices
Rest-to-grazing ratio
Seeded forages
Stock density

ABSTRACT

Significant interest exists in the potential for specialized grazing systems, including adaptive multipaddock (AMP) grazing, to enhance grassland health and function. However, specific pasture management practices associated with AMP grazing at the ranch level remain poorly understood in comparison with more regionally representative management systems. As part of a larger study examining grazing effects on soil carbon, greenhouse gases, and other ecosystem attributes, here we report on differences in disturbance history and grazing management practices on a sample of AMP operators and their neighboring (n-AMP) ranches at 32 paired sites across the prairie provinces of western Canada. Most ranches studied (77.5%) relied on pastures composed of introduced (seeded) forage. On average, the AMP ranches surveyed were larger in size, supported greater animal numbers, and were more likely to use seeded forages comprising diverse mixes. Relative to n-AMP ranches, AMP ranches used 18.6-fold higher average stock densities in smaller paddocks (22.3 vs. 120.7 ha) while grazing over a grazing season that was 76 d longer, although computed stocking rates remained similar ($P \geq 0.10$). AMP operators specifically used much shorter grazing periods (2.8 d) during the early growing season (i.e., before August 1) that were followed by a prolonged rest period (69 d) and could be used to compute a rest-to-grazing ratio for the first half of the grazing season for all ranches. This ratio, along with cattle stock density computed at the pasture scale, exhibited the greatest potential to differentiate the two groups of ranchers. Finally, both groups, and in particular ranchers within the AMP group, demonstrated high variability in management practices among individual operators, highlighting the importance of using specific management metrics rather than generalized descriptors of "grazing system type" to interpret their influence.

Introduction

Grasslands occur across nearly 40% of the Earth's terrestrial surface and are an important source of ecosystem goods and services (EG&S) including forage and livestock production, as well as soil carbon storage (Sanderson et al. 2020). Grasslands and their associated EG&S remain at risk of decline, including from conversion to agricultural crops and industrial uses (Allred et al. 2015). However, the effects of grazing on EG&S, including specialized grazing systems, remain less clear. Grazing systems involve complex disturbance regimes that simultaneously alter numerous management parameters, such as the timing of grazing initiation and cessation, livestock numbers and stock densities, as well as the frequency and duration of individual grazing periods (Hunt et al. 2014; Roche et al. 2017).

Given the inherent complexity of grazing strategies available, varying perspectives exist on whether, when, and how variation in grazing alters grassland function. For example, several studies conclude that the benefits of rotational grazing for maintaining grassland production and range condition may not be as large and consistent as previously thought, with the majority of studies reporting no difference between areas subject to rotational and continuous grazing (Holechek et al. 1999; Briske et al. 2008; Hawkins 2017). In contrast, McDonald et al. (2019) concluded that strategic rest appeared capable of enhancing ground cover and an-

☆ Funding for this project was provided by the Agricultural Greenhouse Gases Program of Agriculture and Agri-Food Canada, Project AGGP2-010.

* Correspondence: Edward Bork, Dept of Agricultural, Food and Nutritional Science, Agriculture/Forestry Ctr, University of Alberta, Edmonton, Alberta, Canada, T6G 2P5.

E-mail address: edward.bork@ualberta.ca (E.W. Bork).

https://doi.org/10.1016/j.rama.2021.04.010
1550-7424/

imal production per unit area relative to continuous grazing, with no changes to plant biomass, richness and diversity, or individual animal weight gain (McDonald et al. 2019). In their review of past studies examining rotational grazing, Teague et al. (2013) noted that past research had often failed to properly test rotational grazing due to the inability of controlled deductive studies to replicate the spatial scale, as well as the adaptive framework that involves flexible grazing over time, within which livestock production typically occurs. Moreover, studies evaluating grazing systems often confound stock density and stocking rate and employ limited sampling regimes in space and time at scales outside of those where grazing management decisions are made, further reducing their ability to evaluate the merits of alternative grazing practices (Teague et al. 2013). In general, while the unique knowledge and experience of ranchers is critical in shaping management behavior over time, individual rancher behavior, as manifest through management actions, has seldom been quantified or tested (Wilmer et al. 2018), although efforts are under way in this capacity as exemplified by a recent study implementing collaborative adaptive management directly involving ranchers (Derner et al. 2021).

Numerous studies have reported on the effects of grazing and/or defoliation on the provisioning of EG&S, including forage production (e.g., DeBruijn and Bork 2006) and soil conditions (e.g., Pyle et al. 2019), though most studies manipulate single variables such as the intensity, frequency, or timing of defoliation. At its core, select management actions, including stocking rates during the grazing season, are well known to influence grassland properties and ecosystem function (Holechek 1988). What is less understood under various rotational grazing systems is how variation in the timing of initial grazing, frequency of grazing and intermittent rest periods, and the relationship between alternating grazing and rest periods during the growing season varies among cattle producers, as well as how this might influence agroecological outcomes. Using a meta-analysis of global data, McDonald et al. (2019) reported that increases in the duration of rest period relative to grazing time led to measurable benefits on grasslands, including plant biomass, ground cover, and animal weight gain.

Many management-intensive grazing systems have their origins in rational grazing (Voisin 1961) and time-controlled (a.k.a. planned) grazing—an essential element of holistic management (Savory and Butterfield 1999). There are many related terms describing this concept, including *adaptive multipaddock* (AMP) grazing, a term described by Teague et al. (2011). AMP involves the use of rotational grazing patterns that are highly flexible in time and space to accommodate changing plant growth, foraging conditions, and animal needs. Operators place a relatively large number of animals at high stock density in a given pasture for short periods of time (Society for Range Management 1998) and usually at increased stocking rates (Teague et al. 2011). In theory, these systems balance the periodic removal of plant biomass with the need to facilitate prompt forage regrowth, thereby maintaining plant vigor and associated productivity. As a result, any assessment of these systems, including AMP grazing, is predicated on the notion that ranchers using AMP grazing can be differentiated from neighboring cattle ranches with respect to one or more of the aforementioned grazing management practices. For purposes of this study, AMP grazing is defined using the framework of Teague et al. (2011) to be grazing that "involved multiple paddocks per herd, high animal densities, very short periods of grazing, long recovery periods and higher stocking rates than were traditionally considered sustainable."

Similar to other regions of the world, native temperate grasslands in western Canada have markedly declined to less than a third of their original area (Gauthier and Wiken 2003), though the extent of loss varies from 57% in the Mixedgrass Prairie of Alberta (Adams et al. 2013) to > 85% in the highly fragmented Parkland (Kupsch et al. 2013). In the Parkland subregion, croplands together with planted pastures containing introduced forages now represent most of the agricultural land base, which together provide much of the feed stock for the Canadian beef industry (McCartney 1993). Given the significant footprint of cattle production in western Canada, particularly grazing-based operations (Alemu et al. 2015), a high level of interest exists in understanding how variation in ongoing land-use activities such as grazing alters grassland sustainability, including on lands never cultivated and those once seeded but now managed as permanent grassland. This knowledge gap extends to understanding whether and how specialized rotational systems, including AMP grazing, can alter key grassland functions such as ecosystem carbon storage and greenhouse gas fluxes.

Rotational grazing has become more common in recent decades, and the majority of cattle producers (83%) in the prairie provinces of Canada now practice rotational rather than continuous grazing (Chorney and Josephson 2000; Pyle et al. 2018). What remains unclear is the extent to which variation in nuanced grazing practices among these cattle ranches regulates grassland responses, such as the length of grazing or subsequent rest periods (Heitschmidt and Taylor 1991). Advocates of AMP (and holistic) grazing highlight the need for high stock densities (i.e., animals per unit land area) for short periods at the optimal time during the growing season to maximize benefits (Savory and Butterfield 1999; Teague et al. 2011, 2013), a response that can vary with environmental conditions (Hawkins 2017).

In 2016 we initiated a comprehensive study to compare agronomic and environmental outcomes on a set of ranches situated across the prairie provinces of western Canada with the support of the Agricultural Greenhouse Gases Program of Agriculture and Agri-Food Canada. One aspect of this work compared metrics of grazing practices between beef cattle ranches employing AMP grazing with neighboring ranches, where the latter can be regarded as regionally representative management for the cattle industry. Here, we report on the specific differences in grazing practices and historical disturbance regimes taking place between and within these two groups of beef producers. Specific objectives were to 1) quantify differences in management practices between self-identified AMP ranchers and their neighboring (n-AMP) ranches and 2) identify management metrics that might show differences in agroecological attributes among these cattle ranches in western Canada.

Methods

Study area and selection of participants

We identified and surveyed 64 beef cattle producers, as 32 neighboring pairs of ranches, located across Alberta, Saskatchewan, and Manitoba in the prairie region of western Canada (Fig. 1). Each pair included an AMP grazer initially identified through a self-selection process in which participants were solicited through a brief online questionnaire that was advertised at grazing workshops and conferences. Survey questions were designed to identify producers who used highly flexible, multipaddock grazing to facilitate short grazing periods and long recovery spells during the growing season, as described by Teague et al. (2013). A total of 93 ranchers initially responded to the screening survey. Follow-up phone calls were used to clarify the ongoing grazing practices on these operations, after which the number of eligible AMP grazers was reduced to 60 for a number of reasons, including that participants were restricted to those grazing beef cattle rather than other livestock, and that all operations had to have an area > 10 ha under AMP grazing that was not subject to supplementary bale feeding on pasture, because bale feeding would have

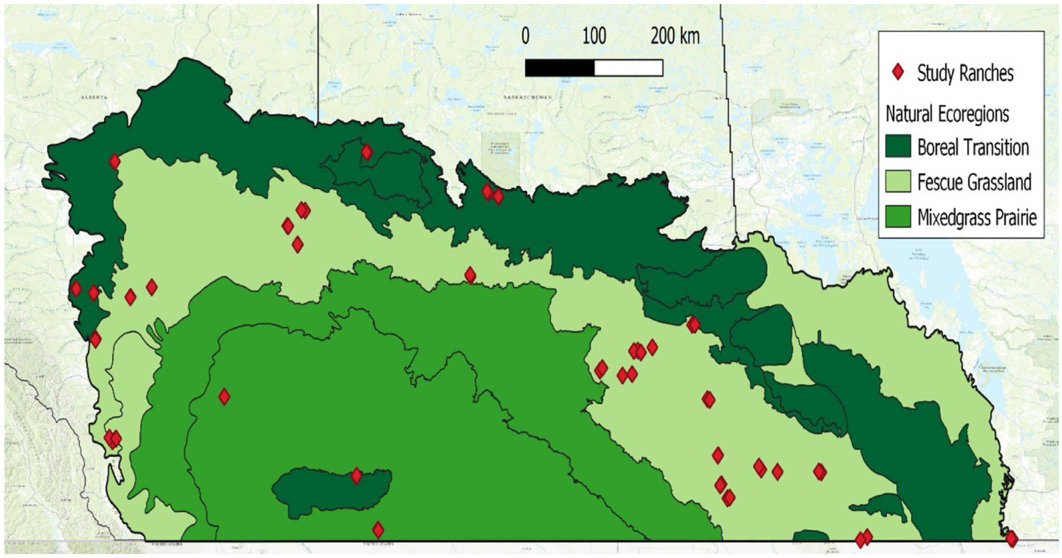

Figure 1. Distribution of the 32 paired ranches across the Canadian prairie provinces whose operators were surveyed to obtain information on land management, cattle herd metrics, and routine grazing practices for the study pastures.

confounded our assessment of ecosystem responses (e.g., carbon stocks) relative to grazing system. No attempt was made to exclude neighboring ranches based on their grazing system, though several AMP ranches were eliminated due to the lack of a suitable (n-AMP) comparison ranch, either due to the altogether absence of a neighboring cattle operator in close proximity (i.e., if all surrounding land was in crop production), incompatibility among livestock types (i.e., grazing occurred only with horses), or marked differences in land-use history (e.g., where one of the two ranches had been cultivated more recently). Similarly, all n-AMP needed to meet the criteria of having a representative area free of bale feeding on pasture. Pairs of ranches had to have a similar cultivation history (either both noncultivated or seeded before 1997, or seeded after 1997) to avoid confounding effects of this disturbance on soil and vegetation. Next, all ranches were further screened in field reconnaissance surveys to determine whether the AMP candidate ranches met our criteria for AMP grazing (established using many paddocks per herd during rotational grazing, and flexible grazing patterns in space and time, and in operation for at least 10 yr) and had neighboring ranches for comparison (within 5 km typically) on similar ecosites (e.g., landform, slope, soil texture, and series type). Soil information was obtained from the Soil Landscapes of Canada website version 2.2 (https://open.canada.ca/data/en/dataset/4b0ae142-9ff0-4d8f-abf5-36b2b4edd52d).

A final subset of 40 AMP ranches met these criteria, of which 32 were randomly selected for more in-depth evaluation via both management surveys and pasture vegetation and soil attributes; only the management survey results are presented here. These operations were located in the Boreal ($n = 7$ pairs), Fescue Grassland/Parkland ($n = 23$), and Mixedgrass ($n = 2$) ecoregions (see Fig. 1). The largest number of ranch pairs were in the province of Saskatchewan ($n = 15$), followed by Alberta ($n = 12$) and Manitoba ($n = 5$). Typical environmental conditions for the different regions are provided in Table 1, with mean annual precipitation (MAP) increasing from the Mixedgrass, through the Fescue, and peaking in the Boreal. Mean annual temperatures (MAT) followed the opposite pattern, as did measures of aridity (represented by the annual heat-to-moisture index; Mbogga et al. 2010). Weather data were extracted from the ClimateNA_MAP website, an interactive platform for visualization and data access (http://www.climatewna.com/) using 30-yr data from 1989 to 2018. Generalized soil types ranged from Brown to Dark Brown Chernozems in the Mixedgrass, to primarily Black Chernozems in the Fescue, to Dark Grey Chernozems and Gray Luvisols in the Boreal (see Table 1).

Ranch management surveys

Management surveys were designed to collect comprehensive information on the recent disturbance history of the grazing lands in question, including whether they were previously cultivated, seeded, and their grazing management practices, with all procedures approved by the University of Alberta Research Ethics Office for work on human subjects (Application RES0032548). Information on the land base included the total area grazed, the number and average size of paddocks, start and end of each grazing season, as well as the length and duration of typical grazing periods during the growing season. Data on the number of cattle, class of stock (mature cows/bulls vs. yearlings), and entry and exit dates were used to compute stocking rates (animal unit mo [AUM] ha^{-1}) for each ranch, with paddock sizes used to calculate mean instantaneous stock densities while grazing (animal units [AU] ha^{-1}). AU equivalencies for mature cows, yearlings, and bulls were set at 1.25, 0.8, and 1.5, respectively, based on recently obtained regional information on animal weights for each class of stock (Bao et al. 2019). Supplemental questions addressed management practices undertaken to increase productivity, such as fertilization, weed control, or other inputs. A list of questions addressed in the survey is provided in Table S1, available online at ….

Data analysis

Data were collected to address two questions: 1) Do management practices differ between operations considered to practice AMP grazing and those on neighboring properties? and 2) Can specific management metrics be used as indicators of AMP and n-AMP grazing system operators across these beef cattle ranches? To address the first question, mean metrics of individual grazing management practices in relation to AMP and n-AMP ranches were compared using a mixed model analysis of variance, assessed with Statistical Analysis Software v9.4 (SAS Institute Inc., Cary, NC), with significance set at $P < 0.05$. Pairs of ranches (as blocks) were included as a random factor in the model. Metrics such as stocking rate, the date of initial grazing (Julian days), length of the grazing period during the early growing season (before August 1), and

Table 1
Summary attributes of the 32 paired ranches from which detailed land, cattle herd, and grazing management data were collected from 2018 through 2019. Values are means (± 1 standard of error in parentheses).

Region	Number of ranch pairs	Mean annual precipitation (mm)	Mean annual temperature (°C)	Annual heat moisture index[1]	Predominant soil type
Mixedgrass Prairie	2	355.1 (39.0)	4.49 (0.57)	43.0 (2.2)	Brown to dark brown chernozems
Parkland & Fescue Grassland	23	474.2 (11.5)	2.70 (0.17)	28.1 (0.6)	Black to eluviated black chernozems
Boreal Transition	7	494.7 (20.8)	2.39 (0.31)	26.1 (1.2)	Dark gray chernozems to gray luvisols

[1] Measure of increasing moisture deficit, or aridity.

the minimum days of rest following early-season grazing were assessed as continuous variables. In addition, the number of days of rest per day of early season grazing (hereafter known as the *rest-to-grazing ratio*), similar to that reported by McDonald et al. (2019), was quantified. When assessing dates of grazing, we established the earliest date of spring grazing as March 15, which coincided with up to 1 mo of dormant season grazing before spring green-up, which typically ranges from April 15 to May 15 across the study region. Few ranches reported grazing before April 15. Similarly, we used a cutoff date of August 1 for separating the date of early-season grazing from late-season grazing, as most plant communities reach peak forage growth by late July across the study region, after which plant growth slows markedly in the lead-up to the first killing frost, normally in early September. Frequency data are reported for categorical management actions such as cultivation history and fertilization. In addition, stocking rates were regressed against rest-to-grazing ratios, separately by grazing treatment, to test whether specialized intensive grazing systems altered overall levels of cattle use.

To evaluate the consistency in management actions across all 64 ranches [second question], including within treatment groupings, a subset of management practices hypothesized to influence pasture productivity and condition (initial start date of grazing: "range readiness," stocking rate: "forage use intensity," cattle stock density: "herd effect," and rest-to-grazing ratio: "intensity of rotational grazing") were used to perform a nonmetric multidimensional scaling (NMDS) ordination of all 64 ranches, using PC Ord v.7.03 (MjM Software, Gleneden Beach, OR). The resulting ordination was used to examine the extent to which differences in management metrics effectively separated the a priori treatment groupings, with additional overlays of vectors for climate (MAP and AHM); land-use (cultivation) history; ranch attributes (mean herd size, pasture size, number of paddocks, and history of fertilization); and grazing metrics (total length of the grazing season, early season grazing period, and minimum rest period after early grazing). A blocked multiresponse permutation procedure (MRPP) was used to test for overall differences between treatments, and a test of homogeneity in variance was used to evaluate differences in management variability between AMP and n-AMP ranches.

Results

All 64 cattle ranches, including both AMP and n-AMP, participated in the detailed survey to gather information on land-use history and management practices. A similar proportion of ranches reported a history of cultivation (74% and 81%) regardless of the management group (see Table 1). Where lands were cultivated, the mean reported time elapsed since cultivation was similar between AMP and n-AMP ranches (~19 yr), reinforcing the effectiveness of the screening method established during site selection, which sought to have similar long-term disturbance histories before the onset of grazing.

Of those grazing lands that had a known cultivation history where producers reported the identity of seeded forages (40 of 44 producers), legumes were included in more than 90% of seeded pastures (Fig. 2). Alfalfa was the primary legume seeded, followed by clovers (either white *[Trifolium repens]*, alsike *[Trifolium hybridum]*, red *[Trifolium pratense]* or sweet clover (*Melilotus* spp.), or mixtures thereof), with occasional use of cicer milkvetch *(Astragalus cicer)* and birdsfoot trefoil *(Lotus corniculatus)*. Among grasses, introduced bromegrasses (meadow *[Bromus biebersteinii]*, smooth *[Bromus inermis]*, or hybrid brome *[B. beibersteinii* × *B. inermis]*) were included in > 70% of seeded pastures, followed by timothy *(Phleum pratense)*, with a minor inclusion of arid-adapted agronomic grasses (crested wheatgrass *[Agropyron cristatum]* or Russian wildrye *[Psathyrostachys junceus]*), as well as cool-season rhizomatous grasses (either Kentucky bluegrass *[Poa pratensis]* or creeping red fescue *[Festuca rubra]*). Few differences were evident in the composition of seeded legumes and grasses between cattle producers adhering to AMP management and their neighboring operations (see Fig. 2), though native plant species were included in nearly 20% of planted pastures, but then only on ranches using AMP management (4 of 23; see Fig. 2). Similarly, pastures seeded within AMP grazing lands were more likely to have been seeded to mixtures of greater complexity (i.e., at least 3 or 5 forage species together) compared with adjacent lands (see Fig. 2). Finally, when asked whether they had fertilized their pastures in the previous 3 yr, a greater number of n-AMP operators indicated they had fertilized (25%) relative to AMP operators (9%), with the overall average at 17%.

Producers using AMP management grazed an area nearly five-fold larger than their n-AMP counterparts (Table 2). In addition, marked differences were evident in how pastures were configured spatially. On average, AMP operations had > 10 × as many individual pastures as n-AMP producers, which, in turn, led to individual pastures that were about one-fifth the size of that found in n-AMP operations (see Table 2).

Similar to the pattern for land area, our survey showed that AMP operations supported, on average, more than 3.5-fold more animal units (AU) in total than neighboring properties (see Table 2). Our comparison of cattle stocking rates, computed directly from the survey data, revealed no significant difference between AMP and n-AMP producers ($P = 0.11$; see Table 2). In contrast, AMP producers maintained a mean stock density (AU ha^{-1}) roughly 23-fold greater than n-AMP producers (see Table 2), which, in turn, could be attributed to much smaller pasture sizes.

Ranches using AMP management began grazing earlier in the year, with a mean initiation date of grazing of April 25, as compared with May 17 for n-AMP operations (see Table 2). Notably, four AMP operations reported "year-round" grazing, which for the purpose of the previous calculation, was limited to a March 15 start because any grazing before then would have coincided with the winter dormant season and represented extended grazing in the absence of forage growth in these northern grasslands. Not surprisingly, the total length of grazing was 54% longer (at nearly 7 mo) on ranches using AMP grazing (see Table 2), even after the adjustment for dormant season grazing.

Ranchers using AMP management consistently reported short grazing periods (e.g., < 7 d; Fig. 3A) while grazing on actively

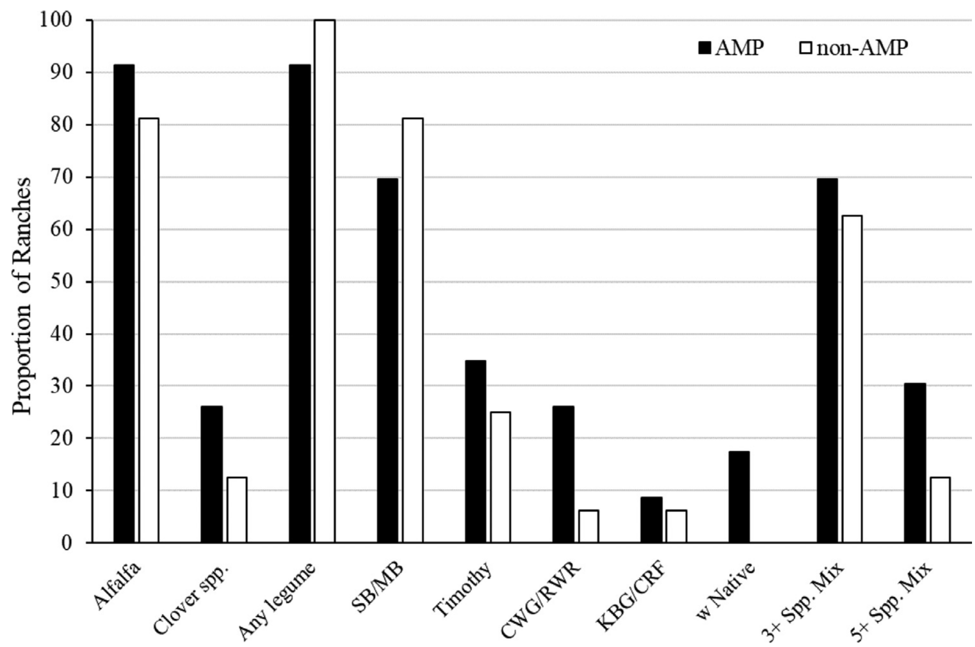

Figure 2. Comparative frequency of occurrence for forages associated with pastures that were reported as seeded on either adaptive multipaddock (AMP) or neighboring AMP ranches. Categories include legumes, dominant grasses such as smooth or meadow brome (SB/MB), the arid-adapted grasses crested wheatgrass or Russian wild rye (CWG/RWR), the sod grasses Kentucky bluegrass or creeping red fescue (KBG/CRF), the inclusion of native forage species, as well as mixes involving a minimum of either three or five forage species.

Table 2
Comparison of attributes between adaptive multipaddock (AMP) and neighboring (classified as "n-AMP") beef cattle operations assessed across 32 paired study locations during 2018 and 2019 across the prairie provinces of western Canada. Values are means (± 1 standard error of the mean in parentheses). Also shown are the F-statistics and associated *P* values comparing attribute means between AMP and n-AMP ranches.

Ranch attribute	AMP ranch	Neighboring ranch	F-Stat	*P* value
Land properties				
Cultivation history (% of ranches)	81.3%	68.8%[1]	–	–
Time since cultivation (yr)	19.5 (1.4)	19.7 (1.5)	0.00	0.98
Total area grazed (ha)	1374 (270)	303 (264)	12.0	< **0.01**
Number of pastures[2]	61.0 (5.1)	5.2 (5.1)	62.2	< **0.0001**
Mean pasture size (ha)—computed	22.3 (36.0)	120.7 (36.0)	4.40	**0.044**
Typical pasture size (ha)—reported	20.1 (36.2)	121.6 (36.8)	4.73	**0.038**
Cattle herd attributes				
Total animal units[3] (AUs)	405.1 (47.3)	117.5 (47.3)	21.9	< **0.0001**
Stocking rate (AU mo ha^{-1})	3.63 (0.39)	2.85 (0.39)	2.87	0.10
Computed mean stock density per pasture (AU ha^{-1})	42.7 (8.6)	2.3 (8.6)	11.1	< **0.01**
Grazing management				
Initial grazing date (Julian day)	117 (4.5) (April 25)	138 (4.6) (May 17)	14.9	< **0.0001**
Total grazing season length (d)	217.3 (11.5)	141.0 (11.5)	21.9	< **0.0001**
Early-season (July 31 or sooner) grazing period (d)	2.8 (8.1)	77.5 (8.1)	42.5	< **0.0001**
Minimum rest after early-season grazing (d)	68.9 (5.6)	26.5 (5.6)	52.5	< **0.0001**
Rest-to-grazing ratio[4] (RGR)	50.7 (8.2)	1.7 (8.2)	17.9	< **0.0001**

[1] An additional two n-AMP pastures were described as being mechanically cleared of forest, but no further details were available on cultivation history and were therefore assumed to be noncultivated.
[2] The number of pastures associated with one AMP ranch was capped at 150 for this calculation despite reporting the use of > 1 000 paddocks.
[3] Animal units were computed using established equivalencies for cattle in the region from Bao et al. (2019) of 1.25 for each mature cow (with or without a calf), 0.8 for yearlings, and 1.5 for bulls.
[4] Defined as the minimum number of days of rest per day of early-season grazing, where the latter was considered grazing before August 1.

growing forage (before August 1). This in turn, was followed by a much longer rest period that often extended beyond 2 mo in duration (see Table 2; Fig. 3B). In contrast, n-AMP ranches reported the use of longer individual grazing periods and shorter subsequent rest intervals (see Table 2). However, n-AMP ranchers also were less consistent and more variable in their temporal pattern of grazing activities (see Fig. 3A and 3B). Many n-AMP operators used little to no rest in their rotation, while a small number (4 of 32) had grazing practices that more closely approximated AMP operators than season-long grazers, with relatively short grazing periods (≤ 15 d) and long recovery intervals.

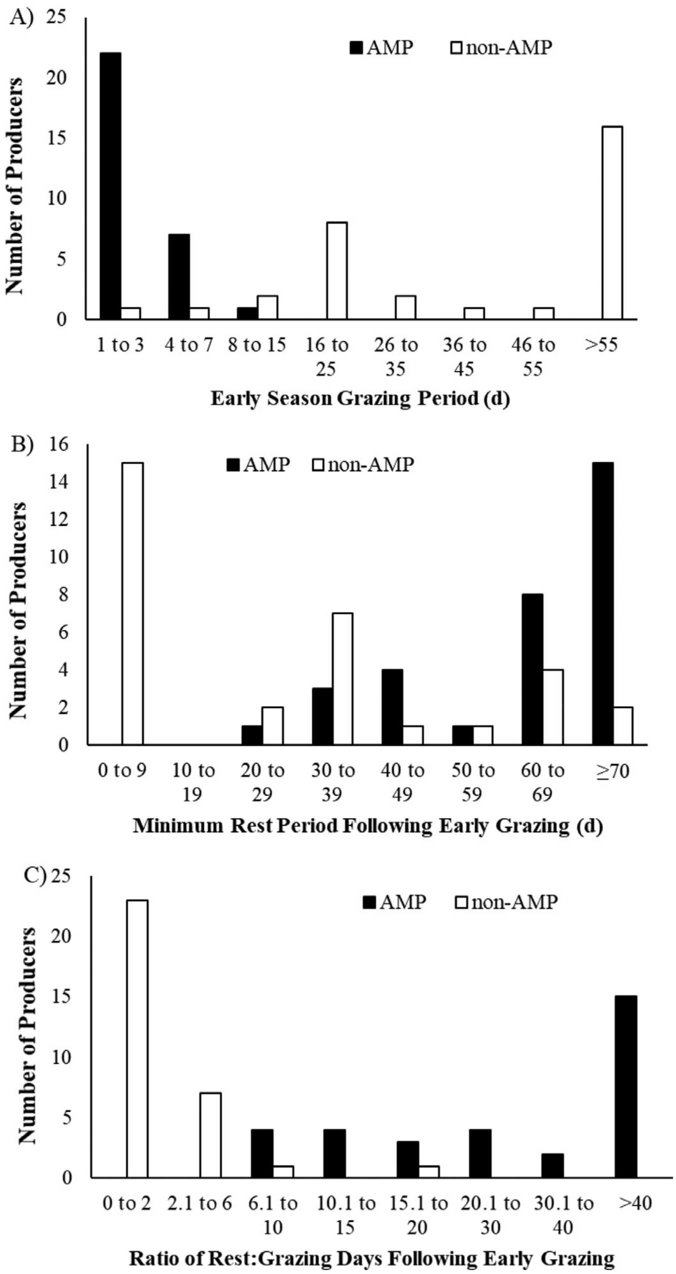

Figure 3. Comparative frequency distribution of A, the length of the early season grazing period before July 31 (days), B, the minimum rest period following early season grazing (days), and C, the computed ratio of rest days for each day of grazing during the early season (grazing before July 31), as reported either by cattle ranches using adaptive multipaddock (AMP) grazing or from their neighboring AMP operations.

We examined the ratio of rest-to-grazing days following early-season grazing during the growing season (before August 1) to better assess variation in temporal use patterns of pastures among all ranch operators and therefore the potential to increase vegetation regrowth after defoliation. AMP operators consistently provided a longer recovery time after grazing events relative to n-AMP operators (see Table 2), with the former providing at least 6 d of rest for each day of early-season grazing (see Fig. 3C). In contrast, n-AMP ranches rarely exceeded this value and more commonly had a rest-to-grazing ratio $<$ 2.

Our survey data revealed a positive relationship between stocking rate and rest-to-grazing ratio when examined across all ranches (SR = 2.581 + 0.0324RGR; Adj. $R^2 = 0.165$; $P = 0.01$). Separate inspection of this relationship for the AMP and n-AMP

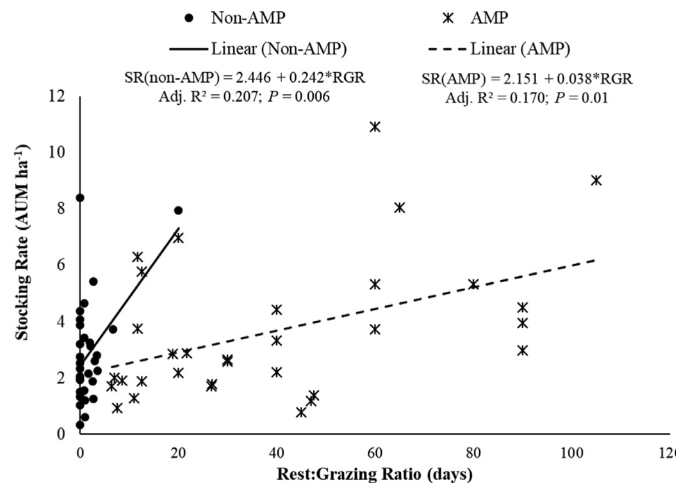

Figure 4. Relationship between stocking rates and the rest-to-grazing ratio, further stratified by adaptive multipaddock (AMP) and neighboring AMP ranches, as computed from survey information reported by ranchers across the study area.

ranches indicated a positive relationship existed between stocking and lengthening pasture rest for both grazing treatments (Fig. 4), though the pattern differed sharply between the two. Within n-AMP operations even small increases in rest above continuous grazing (i.e., RGR $>$ 0) coincided with increases in stocking, particularly in comparison with the AMP operations (see Fig. 4). In contrast, stocking rates on AMP ranches increased more gradually with longer RGRs.

Finally, our assessment of variation in grazing management practices across all ranches indicated the two rancher treatment groups were distinct from one another (blocked MRPP: T = −13.93, A = 0.166, $P < 0.0001$), with AMP ranches more heavily influenced by stock density and RGR, than stocking rate or the initiation date of grazing in spring. A test of homogeneity of variance between groupings showed AMP ranchers were more variable in their grazing practices (F = 15.8, $P = 0.0002$) than n-AMP ranchers (average distance to median: AMP = 0.207 vs. non-AMP = 0.113). Perhaps most notable is that all study ranches, including AMP and n-AMP, formed a continuous gradient of increasing pasture management activity in relation to NMDS Axis 1, with no clear separation between treatment groups in ordination space (Fig. 5).

Discussion

Land-use history and ranch properties

A similar proportion of ranches surveyed had a history of cultivation, which is not surprising given that we sought to compare grazing treatments on areas with a similar long-term disturbance history aside from grazing. Given the overriding effect of land-use conversion on grassland composition elsewhere in the study region (Pyle et al. 2018), this finding supports the notion that the majority of grazing lands studied here, as recruited from AMP operators, are unlikely to have native vegetation, with a much greater dependency on introduced forage species instead (McCartney 1993). This also reinforced the greater likelihood that AMP operations and, therefore our study sites in general, tend to be found in regions where native grassland is less common and introduced (seeded) forage is more prevalent as grazing land (Bao et al. 2018).

Legumes were a consistent component of pastures subject to prior seeding, consistent with a general understanding that plant productivity is nitrogen limited in subhumid grasslands (Burke et al. 1998) and that legumes can alleviate this deficiency, thereby boosting forage production (Popp et al. 2000). While the

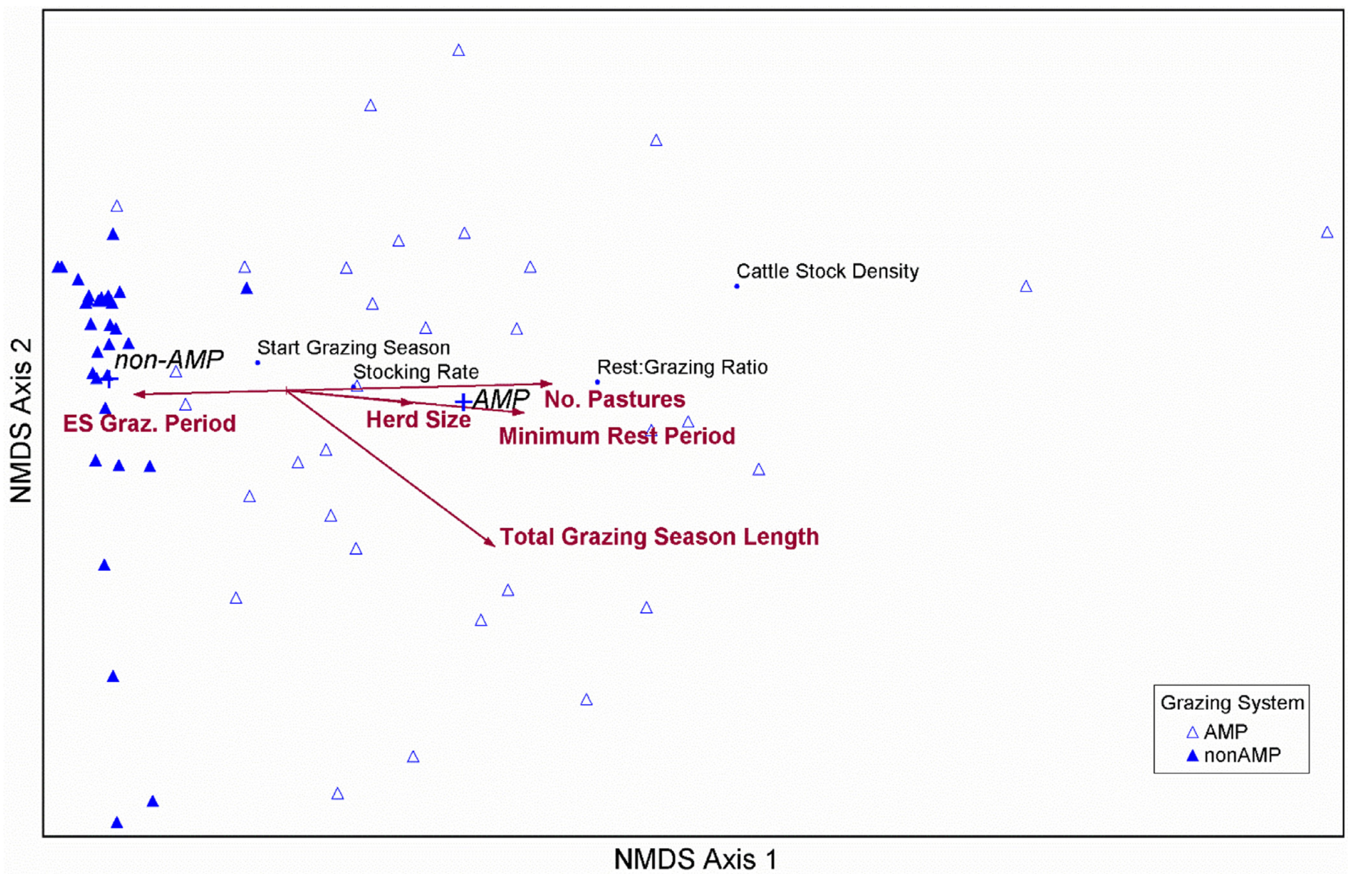

Figure 5. Resulting nonmetric multidimensional scaling ordination of 64 ranches based on variation in grazing practices, specifically stocking rate, cattle stock density, initiation date of grazing in spring, and the rest-to-grazing ratio during the early grazing season (before August 1). Final ordination had a stress of 6.884, I = 0.835, and A = 0.466 for a two-dimensional solution. Also shown are vectors for supplementary environmental metrics correlated at $r^2 \geq 0.10$ with the axes, including herd size and the mean number of pastures, and other grazing parameters (total grazing season length, early-season grazing period, and minimum rest period). Paddock size, together with fertilization and cultivation history, and climatic metrics were not associated with the resulting axes ($r^2 < 0.10$).

overall proportion of ranches reporting fertilizer use in the past 3 yr remained similar (19%) to that reported in a broader survey of the Canadian cattle industry (Sheppard et al. 2016), our results indicated that n-AMP producers were more likely to use fertilizer. This pattern is notable and may reflect several factors, including philosophical differences toward fertilization, or discrepancies in the fundamental need of producers within each group to enhance forage availability and/or quality via nutrient amendment. For example, rotational grazing has been touted as a means to increase the spatial uniformity of animal use (Probo et al. 2014), including among forage plants (Anderson 1988), and in the process could provide for more uniform nutrient removal and return to the soil, thereby reducing nutrient imbalances across pastures and the need for fertilization. Conversely, if n-AMP pastures were in poorer condition due to less uniform use, this could have increased the necessity for pasture renovation with periodic fertilizer within this treatment group, a practice that remains common in the region (Lardner et al. 2000).

The larger average size of AMP operations suggests that ranches employing this strategy relied on a larger land base or that AMP ranches were more likely to use intensive management strategies once the area of land used for grazing was above a minimum threshold area. Alternatively, n-AMP ranches could have relied on a greater proportion of cultivated land in their entire operation (particularly if "mixed" farms), although our survey was not designed to address this possibility as we did not ask questions involving the whole business enterprise. A recent survey of pasture managers in a periurban area in central Alberta (comprising a smaller portion of the area studied here) showed that many landowners were hobby farmers with relatively small grazing areas (Pyle et al. 2018). This form of land tenure was less likely to be associated with rotational grazing in general (and therefore AMP management), possibly due to the greater infrastructure and time commitment required to facilitate intensive rotational grazing. In hindsight, the collection of data on the motivating factors regulating individual grazing practices among producers would have been helpful (Dahl. 2019) and should be included in future studies. As the current study was more regional in distribution, it might have better captured the range in size of beef cattle operations among Canadian producers. Bao et al. (2018) reported on a sample of pastures grazed by beef producers in Alberta and found much larger pastures in the more arid grassland region (1 375 ha) than the parkland (136 ha) or boreal (89 ha). Given that the average size of n-AMP ranches in this study (303 ha) was closer to the latter, it appears the AMP ranches examined here are indeed larger than the norm, a pattern that warrants further evaluation, particularly if larger land areas are an important socioeconomic catalyst for the use of AMP grazing.

Not surprisingly, cattle herd sizes mirrored the pattern of grazing land available, being greater for AMP ranches. We are unable to discount the possibility that our initial recruitment of AMP ranchers for inclusion in this study self-selected for cattle producers with larger land bases and greater accompanying herd sizes, as well as producers who were more likely to attend the technology transfer events from where we recruited study participants. However, this remains speculative and warrants further testing by surveying a larger number of cattle producers, including more ranchers using AMP grazing, and also across a more geographically diverse set of conditions, both environmental (natural regions) and socioeconomic (i.e., business and production models).

Cattle management

The mean cattle stocking rates applied between AMP and n-AMP ranches was surprisingly similar, even though there was a tendency for AMP producers to manage their grazing lands at 27% greater stocking rates compared with n-AMP neighbors. The statistical similarity in stocking arose due to the highly variable and unpredictable nature of stocking among ranches, including between AMP and n-AMP ranches within individual pairs. For example, stocking rates on AMP ranches ranged from 0.78 to 10.91 AUM ha^{-1} (1 stdev = 3.48 AUM ha^{-1}), while n-AMP ranches ranged from 0.33 to 8.39 AUM ha^{-1} (1 stdev = 1.84 AUM ha^{-1}). The adoption of AMP grazing or similar intensive grazing methods is often championed as capable of supporting greater stocking rates due to more favorable regrowth of vegetation (Savory and Butterfield 1999). Despite this, few studies have reported increased stocking rates under rotational grazing, with instead AMP grazing leading to similar effects to low-intensity continuous grazing rather than high-intensity continuous grazing (e.g., Hillenbrand et al. 2019). In addition, several of the AMP grazers here reported the use of bale-grazing during winter on at least a portion (though not all) of their pastures. As the frequency and amount of bale grazing was not accounted for in our study, this could distort actual stocking levels impacting the pasture resource. We agree with Teague et al. (2013) for the need to robustly distinguish between the impacts of grazing system per se (i.e., the pattern and timing of grazing) from stocking rate itself and further note the importance of clarifying the role of any feed inputs in this process, whether it be during the summer growing season or during the overwinter feeding period.

Studies in western Canada specifically examining the impact of specialized grazing systems (such as short-duration grazing) are limited. Dormaar et al. (1988) evaluated foothills fescue grassland responses to short-duration (SD) grazing, concluding that the latter led to reduced grassland health and losses in hydrologic function. However, that study, like many others (see Teague et al. 2013), confounded a twofold to threefold increase in stocking rate with changes in the timing and frequency of grazing (i.e., grazing system). Therefore, the increase in stocking rate rather than the use of a specialized grazing system might have been responsible for the poor performance of SD grazing. While Briske et al. (2008) concluded that the effects of rotational grazing are independent of stocking, other studies indicate that when rotational and continuously grazed areas are compared at similar (i.e., standardized) stocking rates, rotational grazing may better maintain community composition and productivity (e.g., within moist grasslands of Argentina, Jacobo et al. 2006). Notably, a comparison of rotational and continuous grazing by Walton et al. (1981) in the Aspen Parkland of central Alberta encompassing the current study area reported greater individual cattle weight gains under rotational grazing despite the use of higher stocking rates, which they attributed to the improved ability of rotational grazing to maintain high-quality desirable forage species such as alfalfa (*Medicago sativa* L.). Ultimately, it remains unclear how subtle variation in defoliation regimes, including those specific to the northern temperate grasslands of western Canada documented here, translate into changes in EG&S, including agronomic and environmental outcomes. This is particularly important within AMP ranching operations where adaptive practices (i.e., flexible in time and space) are key ingredients for success at the whole ranch level (Teague et al. 2013).

Another factor considered important in the use of AMP grazing systems is the use of a high stock density. Savory and Butterfield (1999) emphasized the importance of high animal densities to generate "herd effect" to facilitate nutrient cycling of decadent plant material and enhance other ecosystem processes (e.g., water infiltration). In our comparison of ranches known to be using AMP grazing with neighboring cattle ranches, the former used much higher stock densities that were made possible by markedly reduced pasture sizes. This pattern highlights the unique spatiotemporal nature in which AMP ranches applied grazing to their land base relative to regionally representative ranches. Perhaps equally important, as this finding coincided with little to no change in overall stocking rate, the difference in stock density might not translate into pronounced differences in forage removal (e.g., if AMP systems were to lead to greater [spatial] efficiency of forage use across the landscape, Barnes et al., 2008; Norton et al. 2013) rather than differences in actual grazing pressure (Smart et al. 2010). However, this conclusion is not supported by studies evaluating AMP grazing on introduced forages in the eastern United States (Tracy and Bauer 2019) or in rotational systems of arid environments in the southwestern United States (Bailey and Brown 2011), both of which revealed no benefit of intensive rotational grazing. Moreover, previous studies have suggested that trampling associated with intensive grazing increases soil compaction and negatively impacts grassland soils (Warren et al. 1986). Further testing is warranted to better understand the influence of specialized grazing systems, including nuanced grazing practices therein, under a wider range of operational production environments.

While we made screening a priority to ensure that AMP producers had at least a portion of their grazing lands without in-situ bale grazing to facilitate testing of environmental (vegetation and soil, including carbon stock) responses in the absence of large additions of organic matter, we nevertheless had a number of producers comment on the use of bale grazing on at least a portion of their land base. This is consistent with other studies in Canada indicating that up to 18% of beef cattle producers fed perennial forage (hay or silage) on pasture in summer, which has been reported to increase to 35% in winter (Sheppard et al. 2016).

Grazing management practices

Given the similarity in overall stocking rates between AMP and n-AMP ranches, our results indicate that the primary difference between these groups was in how grazing was conducted, both spatially and temporally. Grazing of AMP lands began earlier in the year, occurred over a longer grazing season, and specifically manifested as brief early-season grazing periods within each paddock, which was then followed by an extended rest period before regrazing. Also notable was that our results provided an indication of the frequency at which AMP grazing occurred within our random sample of neighboring cattle producers (~13%), which reinforces the importance of understanding how this increasingly common grazing system impacts grasslands of the region.

The overall frequency of use of rotational grazing of any type (essentially excluding season-long use) among n-AMP operators in the current study was 56.2%, which is similar to the 57% reported by Pyle et al. (2018) for north central Alberta. However, this frequency is below the 80% reported by Chorney and Josephson (2000) in western Canada and below that from a more recent Canadian-wide study of beef production practices (Sheppard et al. 2016) wherein beef producers practiced rotational grazing on 65% and 75% of native and tame (seeded) pastures, respectively. Another study indicated that more complex rotational systems relying on a greater number of pastures were more likely to occur on tame pastures, while grazing on native pasture used fewer paddocks (Sheppard et al. 2015). Coincidentally, rest was twice as likely to occur on native than tame pastures (Sheppard et al. 2015). As our sample size of beef producers surveyed was limited, we were unable to analyze patterns for native and tame pastures separately, and these results should not be taken as a rigorous overview of commercial beef industry practices but rather serve as a baseline to which AMP responses can be compared. While we did not exclude ranches in the Mixedgrass Prairie from the study, few operators practicing AMP grazing offered to participate and our study design was not intended to identify and evaluate interactions of environmental constraints (e.g., agroclimatic regime) with grazing system on management practices, as this would have required larger sample sizes from arid regions where native grasslands are more common. As a result, our results may underrepresent the grazing management taking place on native grasslands that are more common in drier regions such as the Mixedgrass Prairie, with the current results instead more applicable to seeded pastures of the Parkland, Foothill, and Boreal regions. It is unclear whether the low sample size of AMP ranchers in the Mixedgrass Prairie was due to a generalized reduction in the use of this grazing strategy within this region (i.e., compared with mesic grasslands) or whether these operators were simply less likely to become aware of (or participate in) our study.

The marked differentiation in temporal patterns of grazing and rest between AMP and n-AMP ranchers perhaps best exemplifies the different management strategies employed as ranchers seek to balance forage removal by livestock with subsequent vegetation recovery and arguably lends support to the findings of McDonald et al. (2019) that the specific rest and grazing intervals are of key biological and agronomic importance on grazed lands. Given this separation, we expected that a longer rest-to-grazing ratio may facilitate greater stocking rates over time, particularly if this metric led to greater plant productivity (McDonald et al. 2019), a hypothesis that was only partially supported here. Despite the similarity in stocking between treatment groups, our survey data revealed a positive relationship between stocking and rest-to-grazing ratio, a pattern that increased more dramatically for n-AMP ranches as compared with AMP grazed lands. This finding suggests there may be less incremental benefit (based on producer behavior) to using extended rest periods among AMP grazers with heightened stocking and instead could reflect the lengthy rest-to-grazing ratios (RGR $\geq$ 6) already in use among cattle producers belonging to this cohort. If true, this would minimize the expression of differences among AMP operations, particularly if prolonged rest-to-grazing ratios led to minimal incremental benefits in either forage growth or utilization. In contrast, increases in stocking within n-AMP ranches were more closely tied to the use of small increases in rest following early-season grazing, even though they represented rest levels far below those associated with AMP operations (see Fig. 4).

In general, all of the study ranches examined followed a more continuous distribution of nuanced producer "management behavior" rather than separating clearly into distinct treatment groupings of AMP and n-AMP. Given this result, it would appear that the use of individual grazing metrics may be a superior means to characterize the real-world variance in management practices used by cattle ranches, particularly in comparison with the nominal classes of "AMP" or "n-AMP." This finding, coupled with high environmental variability, might explain the difficulty of generalized "systems type" research in detecting significant effects in field studies (Hawkins et al. 2017).

Implications

Information provided by beef cattle producers in our study highlights key physical and managerial differences between AMP operators and their neighboring ranches. More specifically, AMP ranches were composed of a larger land base supporting more cattle, with extensive subdivision of the land base used to increase cattle densities but not necessarily stocking rates. In addition, AMP operations were typified by brief grazing periods during the early growing season (before August 1), which were then followed by extended rest periods before regrazing, particularly in comparison with neighboring beef cattle operations. Perhaps most notable is that both AMP and neighboring ranchers were characterized by widespread variation in management practices within each grazing system cohort, with this continuous variation better representing the full diversity in management taking place, including of their grazing systems (Hawkins et al. 2017).

Despite the limited sample sizes of producers surveyed here, our evaluation is a significant step forward from previous investigations that are known to be highly restrictive in their evaluation of the adaptive process that cattle producers employ when developing their grazing systems (Provenza et al. 2013; Teague et al. 2013) and, critically, also account for the human element in ongoing resource stewardship and management (Gosnell et al. 2020). We recommend that more in-depth studies be undertaken to better understand the relationship between detailed cattle grazing practices, including grazing and rest periods within grasslands, and their effects on animal behavior, forage growth and productivity, as well as associated pasture and environmental conditions. Moreover, this should be tested under varying agroclimatic regions and include the diversity and flexibility exhibited by ranchers arising due to socioeconomic drivers (Wilmer et al. 2018; Gosnell et al. 2020). Future papers in this investigation will report on the vegetation (biomass, diversity, and composition) and soil (water infiltration, carbon storage, and greenhouse gas fluxes) responses across our study ranches and link these to grazing practices within these northern temperate grasslands, thereby increasing our understanding of how AMP grazing and different complexities of rotational grazing in general alter grassland ecosystem function.

Declaration of Competing Interest

The authors declare they have no conflicts of interest.

Acknowledgments

Special thanks are extended to Sue DeBruijn for assistance in collecting much of the survey data from cattle producers and Allison Dunlop for administrative support. Thanks to Richard Teague, Steve Apfelbaum, and his AES team for assisting with ranch screening and selection. In particular, we thank the numerous beef producers who volunteered their time, expertise, and property for this study and who laid the foundation for a greater understanding of how cattle grazing and pasture management practices influence grassland attributes and ecosystem function.

Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rama.2021.04.010.

Literature Cited

Adams, B. W., Richman, J., Poulin-Klein, L., France, K., Moisey, D., and McNeil, R. L. 2013. Rangeland plant communities for the Dry Mixedgrass Natural Subregion of Alberta. Second Approximation. Lethbridge, AB, Canada: Rangeland Management Branch, Policy Division, Alberta Environment and Sustainable Resource Development. Pub. T/040. 135 p.

Alemu, A.W., Amiro, B.D., Bittman, S.D., MacDonald, D., Ominski, K.M., 2015. A typological characterization of Canadian beef cattle farms based on a producer survey. Canadian Journal of Animal Science 96, 187–202.

Allred, B.W., Smith, W.K., Twidwell, D., Haggerty, J.H., Running, S.W., Naugle, D.E., Fuhlendorf, S.D., 2015. Ecosystem services lost to oil and gas in North America: net primary production reduced in crop and rangeland. Science 348, 401–402.

Anderson, D.M., 1988. Seasonal stocking of tobosa managed under continuous and rotational grazing. Journal of Range Management 41, 78–83.
Bailey, D.W., Brown, J.R., 2011. Rotational grazing systems and livestock grazing behavior in shrub-dominated semi-arid and arid rangelands. Rangeland Ecology & Management 64, 1–9.
Bao, T., Carlyle, C.N., Bork, E.W., Becker, M., Alexander, M.J., DeMaere, C., Maia de Souza, D., Farr, D., McAllister, T.A., Selin, C., Weber, M., Cahill Jr., J.F., 2019. Survey of cattle and pasture management practices on focal pastures in Alberta. Canadian Journal of Animal Science 99, 955–961.
Barnes, M.K., Norton, B.E., Maeno, M., Malechek, J.C., 2008. Paddock size and stocking density affect spatial heterogeneity of grazing. Rangeland Ecology & Management 61, 380–388.
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.
Burke, I.C., Laurenroth, W.K., Vinton, M.A., Hook, P.B., Kelly, R.H., Epstein, H.E., Aguiar, M.R., Robles, M.D., Aguilera, M.O., Murphy, K.L., Gill, R.A., 1998. Plant–soil interactions in temperate grasslands. Biogeochemistry 42, 121–143.
Chorney, B., Josephson, R, 2000. A survey of pasture management on the Canadian prairies with emphasis on rotational grazing and managed riparian areas [thesis]. Department of Agricultural Economics and Farm Management, University of Manitoba, Winnipeg, Manitoba, Canada.
Dahl, K.M., 2019. Relationships of range health scores with grazing management practices and producer perspectives in Alberta. University of Alberta, Edmonton, Alberta, Canada, p. 113 Canada [thesis]p.
DeBruijn, S.L., Bork, E.W., 2006. Biological control of Canada thistle in temperate pasture using high density rotational cattle grazing. Biological Control 36, 305–315.
Derner, J.D., Augustine, D.J., Briske, D.D., Wilmer, H., Porensky, L.M., Fernández-Giménez, M.E., Peck, D.E., Ritten, J.P., Stakeholder Group, CARM, 2021. Can collaborative adaptive management improve cattle production in multi-paddock grazing systems? Rangeland Ecology & Management 75, 1–8.
Dormaar, J.F., Smoliak, S., Willms, W.D., 1988. Vegetation and soil responses to short-duration grazing on fescue grasslands. Journal of Range Management 42, 252–256.
Gauthier, C.W., Wiken, E.B., 2003. Monitoring the conservation of grassland habitats, Prairie Ecozone, Canada. Environmental Monitoring & Assessment 88, 343–364.
Gosnell, H., Grimm, K., Goldstein, B.E., 2020. A half century of holistic management: what does the evidence reveal? Agriculture and Human Values 37, 849–867.
Hawkins, H.J., 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.
Heitschmidt, R.K., Taylor Jr., C.A., 1991. Livestock production. In: Heitschmidt, R.K., Stuth, J.W. (Eds.), Grazing management: an ecological perspective. Timber Press, Portland, OR, USA, pp. 161–177.
Hillenbrand, M., Thompson, R., Wang, F., Apfelbaum, S., Teague, R., 2019. Impacts of holistic planned grazing with bison compared to continuous grazing with cattle in South Dakota shortgrass prairie. Agriculture Ecosystems & Environment 279, 156–168.
Holechek, J.L., 1988. An approach for setting the stocking rate. Rangelands 10, 10–14.
Holechek, J.L., Gomes, H., Molinar, F., Galt, D., 1999. Grazing studies: what we've learned. Rangelands 21, 12–16.
Hunt, L.P., McIvor, J.G., Grice, A.C., Bray, S.G., 2014. Principles and guidelines for managing cattle grazing in the grazing lands of northern Australia: stocking rates, pasture resting, prescribed fire, paddock size and water points—a review. Rangeland Journal 36, 105–119.
Jacobo, E.J., Rodrigues, A.M., Bartoloni, N., Deregibus, V.A., 2006. Rotational grazing effects on rangeland vegetation a farm scale. Rangeland Ecology & Management 59, 249–257.
Kupsch, T., France, K., Loonen, H., Burkinshaw, A., Willoughby, M. G., and McNeil, R. L. 2013. Rangeland plant communities and range health assessment guidelines for the Central Parkland Subregion of Alberta. Second Approximation. Lethbridge, AB, Canada: Rangeland Management Branch, Policy Division, Alberta Environment and Sustainable Resource Development. Pub. T/265. 213 p.
Lardner, H.A., Wright, S.B., Cohen, R.D.H., Curry, P., MacFarlane, L, 2000. The effect of rejuvenation of Aspen Parkland ecoregion grass-legume pastures on dry matter yield and quality. Canadian Journal of Plant Science 80, 781–791.
Mbogga, M.S., Hansen, C., Wang, W., Hamann, A., 2010. A comprehensive set of interpolated climatic data for Alberta. Government of Alberta, Edmonton, Alberta, Canada, p. 7 Pub. No. T/235.
McCartney, D.H., 1993. History of grazing research in the Aspen Parkland. Canadian Journal of Animal Science 73, 749–763.
McDonald, S.E., Lawrence, R., Kendall, L., Rader, R., 2019. Ecology, biophysical and production effects of incorporating rest into grazing regimes: a global meta-analysis. Journal of Applied Ecology 56, 2723–2731.
Norton, B.E., Barnes, M., Teague, R., 2013. Grazing management can improve livestock distribution increasing accessible forage and effective grazing capacity. Rangelands 35, 45–51.
Popp, J.D., McCaughey, W.P., Cohen, R.D.H., McAllister, T.A., Majak, W, 2000. Enhancing pasture productivity with alfalfa: a review. Canadian Journal of Plant Science 80, 513–519.
Probo, M., Lonati, M., Pittarello, M., Bailey, D.W., Garbarino, M., Gorlier, A., Lombardi, G., 2014. Implementation of a rotational grazing system with large paddocks changes the distribution of grazing cattle in the south-western Italian Alps. Rangeland Journal 36, 445–458.
Provenza, F., Pringle, H., Revell, D., Bray, N., Hines, C., Teague, R., Steffens, T., Barnes, M., 2013. Complex creative systems: principles, processes, and practices of transformation. Rangelands 35, 6–13.
Pyle, L.A., Hall, L.M., Bork, E.W., 2018. Linking management practices with range health in northern temperate pastures. Canadian Journal of Plant Science 98, 657–671.
Pyle, L.A., Hall, L.M., Bork, E.W., 2019. Soil properties in northern temperate pastures do not vary with management practices and are independent of rangeland health. Canadian Journal of Soil Science 99, 495–507.
Roche, J.R., Berry, D.P., Bryant, A.M., Burke, C.R., Butler, S.T., Dillon, P.G., Donaghy, D.J., Horan, B., Macdonald, K.A., Macmillan, K.M., 2017. A 100-year review: a century of change in temperate grazing dairy systems. Journal of Dairy Science 100 0189−10233.
Sanderson, J.S., Beutler, C., Brown, J.R., Burke, I., Chapman, T., Conant, R.T., Derner, J.D., Easter, M., Fuhlendorf, S.D., Grissom, G., Herrick, J.E., Liptzin, D., Morgan, J.A., Murph, R., Pague, C., Rangwala, I., Ray, D., Rondeau, R., Schuz, T., Sullivan, T., 2020. Cattle, conservation, and carbon in the western Great Plains. Journal of Soil & Water Conservation 75, 5A–12A.
Savory, A., Butterfield, J., 1999. Holistic management: a new framework for decision making, 2nd ed.. Island Press, Washington, DC, USA, p. 616.
Sheppard, S.C., Bittman, S., Donohoe, G., Flatten, D., Wittenberg, K.M., Small, J.A., Berthiaume, R., McAllister, T.A., Beauchemin, K.A., McKinnon, J., Amiro, B.D., MacDonald, D., Mattos, F., Ominski, K.H., 2015. Beef husbandry practices across ecoregions of Canada in 2011. Canadian Journal of Animal Science 95, 305–321.
Sheppard, S.C., Bittman, S., MacDonald, D., Amiro, B.D., Ominski, K.H., 2016. Changes in land, feed, and manure management practices on beef operations in Canada between 2005 and 2011. Canadian Journal of Animal Science 96, 252–265.
Smart, A.J., Derner, J.D., Hendrickson, J.R., Gillen, R.L., Dunn, B.H., Mousel, E.M., Johnson, P.S., Gates, R.N., Sedivec, K.K., Harmoney, K.R., Volskey, J.D., Olson, K.C., 2010. Effects of grazing pressure on efficiency of grazing on North American Great Plains grasslands. Rangeland Ecology & Management 63, 397–406.
Society for Range Management, 1998. Glossary of terms used in range management. In: Bedell, T.E. (Ed.), Glossary Update Task Group, 4th ed.. Society for Range Management, Wichita, KS, USA chairman.
Teague, W.R., Dowhower, S.L., Baker, S.A., Haile, N., DeLaune, P.B., Conover, D.M., 2011. Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. Agriculture, Ecosystems & Environment 141, 310–322.
Teague, R., Provenza, F., Kreuter, U., Steffens, T., Barnes, M., 2013. Multi-paddock grazing on rangelands: why the perceptual dichotomy between research results and rancher experience? Journal of Environmental Management 128, 699–717.
Tracy, B.F., Bauer, R.B., 2019. Evaluating mob stocking for beef cattle in a temperate grassland. PLoS ONE E14, e0226360.
Voisin, A., 1961. Grass productivity. Crosby Lockwood & Sons. 311 p, London, UK.
Walton, P.D., Martinez, R., Bailey, A.W., 1981. A comparison of continuous and rotational grazing. Journal of Range Management 34, 19–21.
Warren, S.D., Blackburn, W.H., Taylor Jr., C.A., 1986. Soil hydrologic response to number of pastures and stocking density under intensive rotation grazing. Journal of Range Management 39, 500–504.
Wilmer, H., Derner, J.D., Fernández-Giménez, M.E., Briske, D.D., Augustine, D.J., Porensky, L.M, 2018. Collaborative adaptive rangeland management fosters management-science partnerships. Rangeland Ecology & Management 71, 646–657.