A GPS-Based Evaluation of Factors Commonly Used to Adjust Cattle Stocking Rates on Both Extensive and Mountainous Rangelands

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A GPS-based Evaluation of Factors Commonly Used to Adjust Cattle Stocking Rates on Both Extensive and Mountainous Rangelands

By Michael F. Millward, Derek W. Bailey, Andres F. Cibils, and Jerry L. Holechek

On the Ground

- Published research provides guidelines to reduce stocking rates on areas >10% slope and >1.6 km from water because these areas may be considered ungrazeable.
- Data from 180 cattle tracked by GPS collars for 1 to 4 months at seven ranches in New Mexico, Arizona, and Montana on average resulted in grazeable area calculations that were approximately 10% higher than those derived from published guidelines.
- In several cases, published guidelines yielded more conservative stocking rate estimates compared with our GPS-based calculations. However, our data should be interpreted with caution because most data were collected over a single season or year.
- Our results support recommending local experience and information be used in applying published guidelines to adjust stocking rates. These guidelines may not reflect site-specific management and the adaptability of cattle to local conditions.
- Animal GPS tracking is a sound tool to monitor spatial impact of grazing on rangelands and could be used to enhance commonly used stocking rate adjustment tools, such as annual monitoring of precipitation, forage production, and grazing intensity on key areas.

Keywords: Cattle, Grazing Distribution, Stocking Rates, GPS Tracking, Grazeable Areas

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Introduction

Proper livestock distribution is one of the four principles of grazing management, which also includes stocking rate, season of use, and kind and class of animals.[1] Distribution is an important factor because cattle typically spend less time at areas far from water and avoid steep slopes.[2,3] Holechek[4] summarized these and other studies and proposed two adjustments in stocking rates to account for typical responses of cattle to horizontal distance from water and slope. These adjustments have been incorporated into many grazing plans by both private and public land managers.[5] Although grazing distribution patterns vary with stocking rate, we know that even at conservative stocking rates cattle tend to avoid areas far from water or with steep slopes,[2,3] but the degree to which they do this has not been easily measured until recently. Holechek[4] intended the adjustments for distance to water and slope to be guidelines for setting initial stocking rates that could be later modified with experience. With the advent and affordability of GPS tracking collars, the actual distribution of livestock on the landscape can be measured accurately and consistently,[6] which can help managers improve their estimate of grazeable pasture area to determine annual stocking rate adjustments and evaluate other aspects of grazing management. Current affordability of livestock GPS trackers allows managers to monitor many animals over several years and thus account for variation in distribution patterns that occur as a result of weather, season, phenology, and production of forage plants, as well as animal experience and genetics.

As part of a previous study,[7] we tracked cattle from seven different ranches in New Mexico, Arizona, and Montana. These ranches have extensive pastures of differing size with varying slopes, vertical relief (elevation) and distances to water. The objectives of our current case study were to determine if cattle distribute themselves over the landscape as described by Holechek[4] and to describe GPS tracking-based, site-specific stocking rate adjustments for livestock distribution that ranchers and managers can use to help refine and update the initial stocking rate guidelines developed by Holechek.[4]

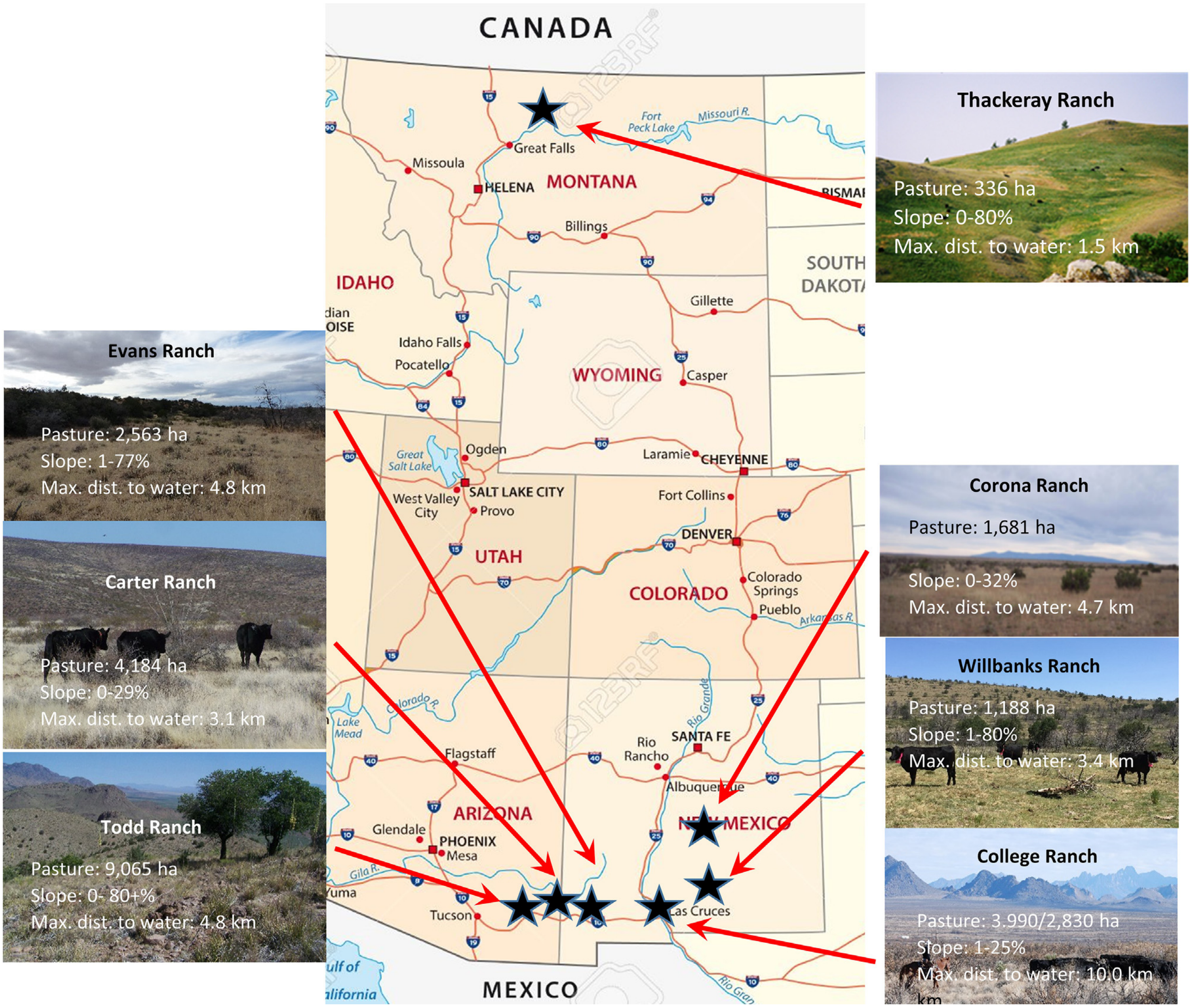

Figure 1. Pasture size, percent slope, distance to water, and locations of the seven ranches used in our study.

Methods

Data were collected on seven different ranches in New Mexico, Arizona, and Montana (Fig. 1) as part of a separate study conducted by Bailey et al.[7] Study pastures at all of the ranches were ≥336 ha (830 acres) and had different degrees of slope, size of pasture, and vegetation. At all but the College Ranch there was one study pasture per ranch. Cattle were tracked at two adjoining pastures at the College Ranch. The Carter Ranch, the College Ranch (Chihuahuan Desert Rangeland Research Center) and the Corona Ranch (Corona Range and Livestock Research Center) all were characterized by gentle terrain (Fig. 1). In contrast, the Evans Ranch, Wilbanks Ranch, and the Montana State University Thackeray Ranch were characterized by rugged terrain. Lastly the Todd Ranch was 9,065 ha (22,400 acres) and had both rugged and gentle terrain. The Todd Ranch also had developed an extensive water system to distribute livestock with numerous watering locations throughout the ranch. Correspondingly, it had few places where cattle could be far (horizontally) from water except in the northwest corner that the cattle did not utilize (Fig. 1). Ocular assessment of study pastures indicated that during our study all pastures were lightly to moderately stocked. No instances of heavy or severe grazing were observed in pastures used at any of the seven ranches.

Previous sudies[8,9] conducted at ranches in Montana showed an association between GPS-assessed cattle distribution and utilization of key vegetation using height − weight curves, a common metric of livestock grazing intensity. Although these relationships were not verified at our Arizona and New Mexico ranches, we considered it reasonable to assume that the relationships between density of GPS locations of livestock and key plant species utilization measured in Montana held true across our entire study area.

Ranches in the study

The Carter Ranch located approximately 25 km (15.5 miles) north of San Simon, Arizona (Fig. 1) had a gentle terrain wais gentle with an average slope of 4%. Dominant grasses were tobosa (*Pleuraphis mutica* Buckley), dropseeds (*Sporobolus* spp.), and grama (*Bouteloua spp*). Dominant shrubs included honey mesquite (*Prosopis glandulosa* Torr.), creosote (*Larra tridentata* [DC.] coville), catclaw acacia (*Acacia greggii* A. Grayand), and whitethorn acacia (*Acacia constricta* Benth).

The College Ranch managed by New Mexico State University and located approximately 34 km (21.1 miles) north of Las Cruces, New Mexico (Fig. 1) had rolling terrain interspersed with arroyos and small ridges. Common grasses included dropseeds, threeawn (*Aristida spp*.), and bush muhly (*Muhlenbergia porteri* Scribn. Ex Beal). Dominant shrubs were honey mesquite and creosote. In the larger pasture at the College Ranch, the average slope was 6%, and in the smaller pasture the average slope was 7%.

The Corona Ranch also managed by New Mexico State University and located about 13 km (8.1 miles) east of Corona, New Mexico (Fig. 1) had rolling terrain with undulating plains and an average slope of 4%. Dominant grasses were blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), New Mexico feathergrass (*Hesperostipa neomexicana* [Thurb.ex J.M. Coult.] Barkworth), and other grama grasses. Patches of tree cholla (*Cylindropuntia imbricata* [Haw.] F.M. Knuth) occurred in swales, and juniper trees (*Juniperus spp*.) on rockier soils in the higher elevations of the pasture were present.

The Evans Ranch located 57 km (35.4 miles) southwest of Silver City, New Mexico had mountainous terrain and bottom areas characterized by gentle and moderate slopes (Fig. 1). The average slope was 12%. Side oats grama (*Bouteloua curtipendula* [Michx.] Torr.) was the dominant grass, but other grama grasses and tobosa were common. Juniper, live oak (*Quercus spp*.) and mountain mahogany (*Cercocarpus spp*.) were dominant woody species.

The Thackeray Ranch managed by Montana State University and located in the Bear's Paw Mountains approximately 24 km (14.9 miles) south of Havre, Montana (Fig. 1) had an average slope of 28%. Dominant grasses were Kentucky bluegrass (*Poa pratenis* L.), rough fescue (*Festuca idahoensis* Elmer) blue bunch wheat grass (*Pseudoroegneria spicate* [Pursh] A. Love), and Idaho fescue (*Festuca idahoensis* Elmer). Ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) and aspen (*Populus tremuloides* Michx.) occurred primarily on north facing slopes.

The Todd Ranch located 11 km (6.8 miles) northwest of Willcox, Arizona had variable terrain with 0% to >80% slopes and >50% of the pasture with mountainous terrain and the remaining area with gentle slopes in bottom lands. The average slope was 20%. Dominant grasses were dropseeds and sacaton (*Sporobolus airoides* Torr.), grama grasses, threeawns, and tobosa. The trees and shrubs that characterize the ranch were mesquite (*Prosopis* spp.), desert willow (*Chilopsis linearis* [Cav.] Sweet), acacia (*Acacia* spp.), juniper, and oak.

The Wilbanks Ranch located in the Sacramento Mountains 2 km (1.2 miles) north of Mayhill, New Mexico consisted of rough and rolling terrain with an average slope of 23%. Dominant grasses were dropseeds (*Sporobolus airoides* Torr.), sideoats grama, black grama, and other gramas. Juniper, pinion pine (*Pinus edulis* Engelm.), ponderosa pine, and aspen were on the north facing slopes and ridges.

GPS tracking

Twelve to 28 cows were randomly selected from each ranch and tracked with GPS collars (Lotek GPS 3300) between 2009 and 2015; collars were configured to record animal locations at 5, 10, or 15-minute intervals (Table 1). Cattle with GPS collars were placed with the remainder of the herd and allowed to graze for 1 to 3 months before retrieving their collars. After the GPS collars were removed, tracking data were downloaded from the collars and latitude and longitude were converted to Universal Transverse Mercator (UTM) using CORPSCON geographic software (US Army Corps of Engineers, Washington, DC) with the NAD83 datum. Collars that recorded <90% of the potential positions were excluded from our analysis. Tracking data recorded during the first 24 hours after placement of the collar on a cow were not used in our analyses to allow for the cow to adjust to the presence of the collar.

A 1/3 arc-second digital Elevation Model (DEM) was obtained from USGS Seamless Data Warehouse (http://www.seamless.usgs.gov) for all of the ranches and added as a layer in ArcGIS software (ESRI, Redlands, CA, www.esri.com). Slope and elevation were calculated using ArcGIS from the DEM. Locations of water in study pastures were recorded with handheld GPS units and the Euclidean distance feature of ArcGIS was used to create a distance to water layer. Elevation, slope, and distance to water were extracted for all the locations recorded by the GPS collars using the Spatial Analyst Extension of ArcGIS.

Classification of cattle locations

For horizontal distance to water, cattle locations were classified into one of three categories: 0 to1.6 km (0 to 1 mile), >1.6 to 3.2 km (>1 to 2 miles), and >3.2 km (>2 miles) based on distance to water classes proposed by Holechek[4] for stocking rate adjustments. Because the GPS collars recorded locations at specific time intervals, we calculated time spent within each one of these distance ranges as the number of times a cow was located within each category divided by the total number of GPS locations recorded for each cow in a study pasture at a ranch. For example, if 100 GPS locations were collected from a collared cow and 25 of the locations fell in the >1.6 to 3.2 km category, then 25% of her time was spent in the >1.6 to 3.2 km category. Values from tracked cows at each ranch were averaged. At the College Ranch values from both pastures were averaged. Slope use was calculated similarly using the categories of 0–10%, >10–30%, >30–60%, >60%.

Ranches were evaluated in two slope groups, which were gentle rolling terrain (i.e. 0–32% slopes) and rough mountainous terrain (0–80+% slope). The gentle rolling terrain

Table 1. Ranches, livestock breed, age of cattle, year, physiological status of cattle, number of cattle tracked with GPS, number of cattle in pasture, starting and ending months of GPS tracking, number of days cattle were tracked with GPS, and time interval for each GPS fix.

Ranch	Breed	Age	Year	Physiological status	Cattle tracked	Cattle in pasture	Start of tracking	End of tracking	Length of tracking (days)	GPS fix interval (min)
Carter	Brangus	Mature cows	2011–2012	Not lactating	12	125	Oct	Jan	75	15
College	Brangus	Mature cows	2011	Lactating	16	43	Jun	Aug	33	10
			2012–2013	Not lactating	18	40	Dec	Jan	38	
Corona	Angus cross	Mature cows	2010	Lactating	17	120	May	Jul	68	10
			2011		13	110	May	Jun	40	10
			2012		28	120	Jun	Aug	51	5
Evans	Angus	Mature cows	2012	Not lactating	16	80	Aug	Oct	59	10
Thackeray	Simmental cross	Mature cows	2011	Lactating	18	213	Aug	Sep	37	10
Todd	Limousin	Mature cows	2011	Not lactating	15	250	Jan	Apr	92	15
Wilbanks	Angus cross	Mature cows	2015	Lactating	13	48	Jun	Oct	112	10

group included the College, Corona, and Carter ranches. These ranches included rolling terrain with large pastures, which allowed cattle to utilize areas >3.2 km from water (19–72% of the pasture >3.2 km). The second group of ranches (Evans, Thackeray, Todd and Wilbanks ranches) had rough terrain and allowed cattle to utilize steep slopes and locations with varying elevations, but the horizontal distance from water only exceeded 3.2 km for ≤14% of the pasture.

Stocking rate adjustment techniques

Both the Holechek[4] method for adjusting stocking rate and the GPS tracking data were used to calculate the percentage of grazeable areas within study pastures at each ranch. The Holechek[4] distance to water adjustment includes all the area within 1.6 km of water and 50% of the area within >1.6 to 3.2 km from water. Areas >3.2 km from water were not included. For example, if 45%, 40% and 15% of pasture area was within 1.6 km, >1.6 to 3.2 km and >3.2 km, respectively, the adjustment was 0.65. That is, only 65% of the pasture area would be included in stocking rate calculations[4] (Equation 1). Holechek's[4] adjustment for horizontal distance to water for stocking rates expressed as a percentage of grazeable area is:

$$[(d1 * 1) + (d2 * 0.5) + (d3 * 0)] * 100 \tag{1}$$

Where;

d1 = proportion of pasture within 0–1.6 km
d2 = proportion of pasture within >1.6–3.2 km
d3 = proportion pasture >3.2 km from water.

In contrast, the GPS tracking based adjustments developed in our case study used the proportion of time spent within each Holechek[4] water category. The proportion of time spent within a category is divided by the proportion of the pasture in each category (Equation 2). If this ratio for a given category was >1, a value of 1 was used, which ensured area was not added to a distance category that did not exist. The calculation of the percentage of grazeable area adjusted for horizontal distance to water using time spent within each distance from water category based on number of GPS locations is:

$$[(d1 * 1) + (d2 * (p1/d2)) + (d3 * (p2/d3))] * 100 \tag{2}$$

Where

d1 = proportion of pasture within 1.6 km of water,
d2 = proportion of pasture within >1.6–3.2 km of water,
d3 = proportion of pasture >3.2 km from water,
p1 = proportion of total GPS locations within >1.6–3.2 km from water, and
p2 = proportion of total GPS locations >3.2 km from water.

For the 0 to 1.6 km category, all the area was used irrespective of the proportion of time spent there. Following the example described above, where 45%, 40% and 15% of the area was within 1.6 km, >1.6 to 3.2 km and >3.2 km, respectively, and assuming a cow spent 40% of her time within 1.6 km of water, 50% of her time within >1.6 to 3.2 km from water, and 10% of her time >3.2 km from water. Using Eq. 2, the GPS location adjustment for distance to water would be [(0.45) + (0.4*1) + (0.15 * (0.10/0.15))] * 100 = 95%. For the >1.6 to 3.2 km category in this example, the proportion of this category was multiplied by 1, because the ratio of 0.50/0.40 was >1.

Holechek[4] also recommended adjusting the grazeable area for slope when calculating stocking rates. The Holechek[4] method calculation of the percentage of grazeable area adjusted for slope is:

$$[(s1 * 1) + (s2 * 0.7) + (s3 * 0.4) + (s4 * 0)] * 100 \tag{3}$$

Where

s1 = proportion of pasture with 0–10% slopes,
s2 = proportion of pasture with >10–30% slopes,
s3 = proportion of pasture with >30–60% slopes, and
s4 = proportion of pasture with >60% slopes.

The GPS tracking adjustment for slope is calculated similarly to distance water. The percentage of grazeable area adjusted for slope using the GPS tracking method is:

$$[(s1 * 1) + (s2 * (p1/s2)) + (s3 * (p2/s3)) + (s4 * (p3/s4))) * 100 \tag{4}$$

Where

s1 = proportion of pasture with 0–10% slopes,
s2 = proportion of pasture with >10–30% slope,
s3 = proportion of pasture with >30–60% slope,
s4 = proportion of pasture with >60% slope,
p1 = proportion of total GPS locations with >10–30% slope,
p2 = proportion of total GPS locations with >30–60% slope, and
p3 = proportion of total GPS locations with >60% slope.

Classification of cattle locations and calculation of grazeable areas were determined with and without cattle GPS locations that were within 200 m (656 feet) of water sources. Results in our case study focus on values determined without locations recorded within 200 m of water because only one of the seven ranches (Thackeray Ranch) had any perennial streams and livestock water at the six other ranches was from installed dirt tanks (i.e., artificial ponds) and water drinkers. Water at the Thackeray Ranch included a dirt tank and a small stream (0.5 to 1.5 m wide and [1.6 to 4.9 feet] and 450 m long [1476 feet]) with a narrow riparian area (1 to 3 m [3.3 to 9.8 feet]). Typically, cattle loafed or rested when within 200 m (656 feet) of any water source. Hence, time spent within 200 m of water was not reflective of the grazeable area within a study pasture and was excluded from our analysis of cattle locations within 200 m of water. By doing so, we likely eliminated GPS locations during which cattle were loafing. However, because we did not classify GPS locations

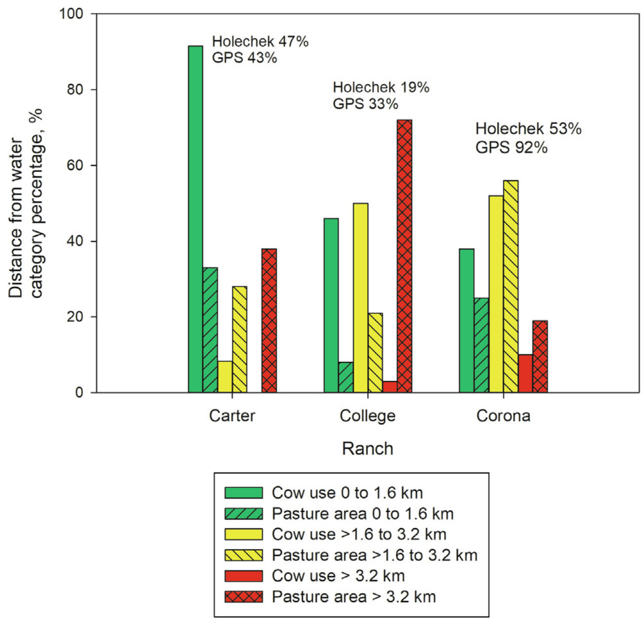

Figure 2. Percent of time GPS collared cattle spent at varying horizontal distances from water on three ranches with gentle terrain (mean pasture slope of 4 to 7%), excluding GPS locations <200 m from water. The grazeable area available in each distance from water category is calculated from the time spent in that category and the area the category comprises of the pasture (Equations 1 and 2). The Holechek[4] and GPS grazeable area adjustments for stocking rates are listed above the bars for each ranch.

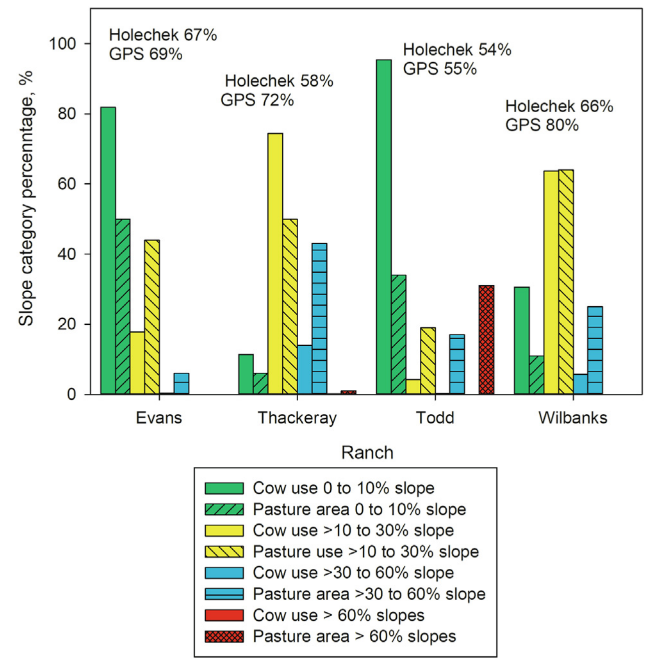

Figure 3. Percent of time that all collared cattle spent on varying slopes at each ranch with rugged terrain (mean pasture slope of 12 to 28%), excluding GPS locations >200 m from water. The grazeable area available in each distance from water category is calculated from the time spent in that category and the area the category comprises of the pasture (Equations 3 and 4). The Holechek[4] and GPS grazeable area adjustments for stocking rate are listed above the bars for each ranch.

>200 m from water by activity categories (resting, grazing, traveling), our GPS-based calculations may have overestimated actual grazing time in different areas of our study pastures.

Results

GPS locations

Cattle spent over half their time (>50% of their locations) >1.6 km from water at the College and Corona ranches with gentle terrain. If the time cattle spent near water (within 200 m) is excluded, this increases to almost 60% (Fig. 2). Cattle at Corona Ranch spent about the same amount of time >1.6 to 3.2 km from water as the area available. At the College Ranch, cattle spent over twice as much time as the area available. In contrast, cattle at the Carter Ranch spent 92% their time within 1.6 km from water.

At the Thackeray Ranch with rough terrain, cattle did not travel >1.6 km from water, but there were few areas where the distance to water was >1.6 km within that study pasture. At the other three ranches with rough terrain cattle spent 46% (Evans), 9% (Todd), and 17% (Wilbanks) of their time at distances >1.6 km from water. Excluding time spent near water, increased the percentage of time spent >1.6 km from water at the Evans, Todd, and Wilbanks Ranches to 50%, 10%, and 20% of their time, respectively.

At two ranches with rough terrain (Thackery and Wilbanks) cattle spent >60% of their time on moderate slopes (>10 to 30%), but at the other two ranches (Evans and Todd) with rough terrain cattle spent <20% of their time on slopes >10%. Excluding areas within 200 m from water had minimal impacts on the use of the various slope use categories (Fig. 3). At the Wilbanks Ranch cattle spent an equal amount of time on moderate slopes (>10 to 30%) as the percent of these slopes in the pasture, and at the Thackeray Ranch cows spent more time on moderate slopes than area available (Fig. 3). All cattle spent less time on the steepest slopes (>30%) than the availability. Slope had little effect on cattle grazing patterns at three ranches with gentle terrain. Cattle at the Carter, College and Corona ranches spent <10% of their time on slopes >10%.

Comparisons of Holechek and GPS tracking based grazeable area adjustments

We report differences in our methods based on one year or one season of GPS tracking data of different cattle breeds, which are valid for the breed of mature cows tracked and for seasons and years in which cattle were monitored (Table 1). Differences between methods would vary with fluctuating precipitation, quantity and quality of forage, stocking rate, and cattle age and breed for the same ranches. Ranch managers using GPS-based adjustments would require longer monitoring periods to derive robust grazeable area reduction factors when adjusting stocking rates.

Horizontal distance to water adjustment

The percentage of each pasture on each of our seven study ranches that was calculated as grazeable based on the Holechek[4] and the GPS tracking adjustments for horizontal distance to water differed by 10 percentage points or more for four of our seven ranches. We observed the largest difference at Corona ranch where the grazeable area was 39 percentage points larger for the GPS tracking adjustment for horizontal distance to water compared to the Holechek[4] recommended adjustment (Fig. 2). In contrast, the GPS tracking adjustment for the grazeable area at the Wilbanks Ranch was 10 percentage points less than the Holechek[4] adjustment for horizontal distance to water.

Two of the three ranches with gentle terrain (College and Corona) only had one water source for cattle. These cattle used areas far from water (>1.6 km), and the reduction to stocking rate of 50% for areas >1.6 to 3.2 km away from water recommended by Holechek[4] was not supported by our results (Fig. 2). The Carter Ranch also had gentle terrain and areas >1.6 km from water, but grazing patterns differed from College and Corona Ranches. The Carter Ranch had six water locations located 1.5 to 2.5 km (0.93 to 1.5 miles) apart and cattle spent 92% of their time within 1.6 km of these water sources. The stocking rate recommended by Holechek[4] adjustments estimated the grazeable area at Carter Ranch relatively well as indicated by the GPS tracking adjustment of 43% useable compared to 47% useable from the Holechek[4] recommendations (Fig. 2).

Slope adjustment

The GPS adjustments for slope indicated 14 percentage points more grazeable area than the Holechek[4] adjustment at the two of the seven ranches, Wilbanks and Thackeray Ranches (Fig. 3). The Holechek[4] and GPS tracking grazeable area adjustments based on slope were relatively similar at five of the seven ranches.

The College, Corona, and Carter ranches all have gentle rolling terrain and do not contain areas with steep slopes. Correspondingly, cattle did not and should not be expected to use slopes >10% because there was limited area meeting this criterion.

The remaining ranches (Thackery, Todd, Evans, and Wilbanks) contain rugged and mountainous terrain. At these ranches, cattle utilized slopes >10% (Fig. 3). At two of the four ranches (Thackeray and Wilbanks), the 30% reduction in stocking rate for >10 to 30% slopes recommended by Holechek[4] was not required because the cattle readily used moderate slopes.

Monitoring grazing distribution

Grazing distribution has been recognized as a vital factor in setting stocking rates to prevent damage by overgrazing.[4] Our results demonstrate the importance of understanding grazing distribution patterns for calculating stocking rates. Rather than relying on adjustments based on assumptions of grazing distribution summarized in the literature, ranch managers could measure actual distribution patterns and adjust stocking rates based on site-specific data using Equations 2 and 4. For example, cattle at the Corona Ranch used areas >1.6 km from water and even areas >3.2 km from water (Fig. 4) where cattle are not expected graze.[2,4] To improve accuracy, GPS tracking data used for input into Equations 2 and 4 should be collected in the same season planned for subsequent grazing. If possible, cattle should be tracked annually, and the GPS based adjustments updated because of changes in precipitation patterns and forage and feeding site preferences of animals. If monitoring data are not available to verify grazing patterns, the recommendations suggested by Holechek[4] are appropriate and should work in many situations.[2,3,4] Using either adjustment, the available forage should be measured annually and the appropriate proper use factor be applied to ensure stocking rates do not adversely impact plant vigor and rangeland health.[1,4] The grazeable area adjustment (Holechek[4] or GPS-based) helps ensure that stocking rate calculations do not include portions of the pasture unlikely to be used by livestock.

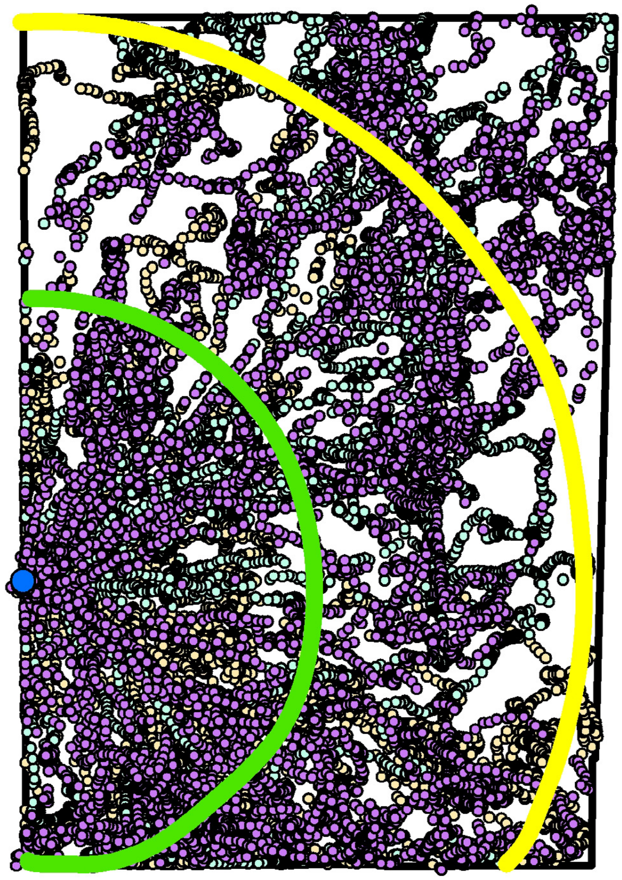

Figure 4. GPS locations of three randomly selected cows tracked at the Corona Ranch during the summer of 2012. Locations of each cow are shown in different colors. Boundaries of distance to water (blue dot) categories from Holechek[4] are shown with green (1.6 km) and yellow lines (3.2 km).

Livestock grazing patterns are not the only factor that should be used to evaluate grazing management.[1] Livestock tracking data do not necessarily reflect patterns of vegetation defoliation and do not account for differential use of forage species because GPS data, as analyzed in this study, included all animal activity categories (grazing, traveling, resting).[10] Managers should use long-term monitoring to ensure current stocking rates and grazing patterns are not adversely impacting rangeland vegetation and health.[11] Holechek[4] emphasized the importance of experience when setting stocking rates and managing rangelands. Long-term monitoring and livestock tracking data provide managers with information to make more informed decisions.

Grazing distribution can be measured several ways, but GPS is most likely the most efficient and accurate method currently available to rangeland managers.[6] GPS tracking provides an objective method of measuring grazing distribution. Ideally, GPS locations of cattle not grazing should be excluded to improve the accuracy of the GPS stocking rate adjustment. However, lower-cost GPS tracking units often do not contain accelerometers which can classify behavior into grazing and non-grazing.[12] Also, classifying behavior into grazing and non-grazing using GPS locations is not practical for most ranchers because analyses required to classify behaviors usually require statistical procedures, software, and training.[12] We present data with and without GPS locations recorded near water (<200 m) and at the ranches in our case study, cattle were usually loafing and not grazing while near water. At night, cattle typically rest near areas they grazed earlier that evening and near areas they graze the following morning.[13] Excluding the GPS locations near water, a standard analytical procedure in livestock resource selection research, should improve accuracy of the GPS adjustments, unless riparian areas impact cattle grazing patterns.[14,15] All GPS locations should be included in the GPS stock rate adjustment equations if pastures contain riparian areas that impact cattle grazing patterns.

Visual observations of animals are subjective and can be biased.[16] Utilization-based approaches using visually estimated forage, such as use pattern mapping, can also be subjective.[17] Quantitative forage utilization measures are time consuming, because of the widespread sampling required to estimate forage use patterns.[18] Similarly, fecal pat abundance can be measured quantitatively, but it requires extensive sampling and is time consuming.[19] In the past, GPS tracking would not have been cost effective for most cattle ranchers, because the collars were expensive, often greater than $1800 per collar.[20] However, GPS collars have been developed to track wildlife using commercially available GPS receivers.[21] Knight et al.[22] have developed a low-cost GPS collar for cattle based on this technology that cost roughly $250 per collar and can track cattle at 10-minute intervals for over five months. With the lower cost GPS tracking collars, it may be cost effective for some ranchers to monitor the grazing patterns of their cattle. However other costs should be considered, such as the labor required to place and retrieve GPS collars from cattle. Also, the tracking data must be analyzed using GIS software which requires training, or the ranch may need the expertise of a knowledgeable person.

The difference in potential stocking levels between the Holechek[4] and GPS grazeable areas may be sufficient to justify the cost of GPS collars, extra labor for collar deployment, and technical expertise to analyze tracking data. For instance, the difference between the Holechek[4] and GPS adjustments for slope at the Thackeray Ranch would be about 77 AUMs (24%) more for the GPS adjusted stocking rate estimate for that pasture (i.e., 398 AUMS for GPS tracking adjustment, 321 AUMS for the Holechek[4] adjustment). Without any distribution adjustments, the stocking rate would be 554 AUMs (336 ha [830 acres], 1680 kg/ha [1499 lbs/acres] standing crop and 40% proper use factor). At the Corona Ranch the difference in distance water adjustments is about 411 AUMs (73%; 970 AUMS for the GPS tracking adjustment, 559 AUMS for the Holechek[4] adjustment). Without any distribution adjustments, the stocking rate of this pasture would be 1055 AUMs (1601 ha [3956 acres], 670 kg/ha [598 lbs/acre] standing crop, and 40% proper use factor). At the other ranches in our study, the differences between adjustment methodologies would likely not justify the purchase of GPS collars and other expenses.

Adjusting stocking rate to meet actual grazing distribution patterns is part of the growing field of precision livestock management.[12,22] Recent technological advancements may allow "real-time" GPS tracking to become commercially available in the near future.[12] Real time GPS tracking would provide information to managers and facilitate implementation of distribution practices and stocking rates adjustments during the grazing season. With this technology, ranchers could be alerted to areas of concentrated grazing and respond before irreparable resource damage occurred. In addition, real time tracking, and accelerometers could monitor livestock for illness and other well-being concerns.[12] Implementation of precision livestock management should make GPS tracking more economically feasible for ranches in the future.

Take home message

In extensive pastures and in rugged terrain, cattle often do not use all the pasture and excluding unused areas in stocking rate calculations can provide more accurate recommendations and help prevent overgrazing. On average and without on-site monitoring, Holechek[4] recommendations provide a reasonable estimate of the proportion of a pasture cattle will use and his suggested stocking rate adjustments are appropriate. However, Holechek intended these adjustments to be guidelines and used for initial stocking rates that could be modified with experience.[4] In some cases, these guidelines may not reflect actual cattle distribution patterns, because rangeland managers can implement practices that improve the distribution of their cattle. Cattle can adapt to rugged terrain or extensive pastures and use steep slopes and areas far from water. If feasible, we recommend measuring the actual cattle grazing patterns and adjusting stocking rates based on monitoring rather than adjusting stocking rates for distribution with the Holechek[4] initial guideline values or other data published in the literature. The equations developed in our case study (Equations 2 and 4) can be used to calculate the area cattle use based on GPS tracking data.

Our data provide overall support for current stocking rate adjustment guidelines and suggest that monitoring of grazing distribution via livestock GPS trackers can, in some cases, improve stocking rate adjustment calculations. However, we recognize that our results must be interpreted with caution because we assumed that density of GPS points and grazing intensity of key rangeland species were strongly correlated across all sites (these relationships were only measured in Montana) and because our data do not account for: a) seasonal or inter-annual variation in forage conditions; b) effects of vegetation heterogeneity, which varied from ranch to ranch; and c) influence of animal genetics (cattle breeds, personalities) and management practices.

Declaration of interests

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rala.2020.04.001.

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