Relationship of pulmonary arterial pressure and terrain use of Angus cows grazing high-altitude foothill rangelands

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ABSTRACT: Pulmonary arterial pressure (PAP) score is used as an indicator trait for risk of hypoxia-induced pulmonary hypertension, which is commonly termed high altitude disease and observed in cattle grazing at altitude ≥ 1500 m. We hypothesized that cows with higher PAP score would avoid using high elevations, steep slopes and areas far from water while grazing foothill rangeland. During 2013 and 2014, forty-one mature Angus cows from a breeding population of cattle selected for tolerance to high altitude were tracked with global positioning system (GPS) collars for 27 and 17 days, respectively. These cows grazed a 1210 ha foothill rangeland pasture with a vertical relief of 2150 to 2411 m. Pulmonary arterial pressure was measured for each animal at 1 year of age (yearling PAP; $38.2 \text{ mm Hg} \pm 5.1 \text{ SD mm Hg}$) and before tracking (mature PAP; $42.6 \text{ mm Hg} \pm 3.7 \text{ SD}$). Yearling PAP score was not correlated with the mature PAP score ($r = 0.23$, $P = 0.15$). Terrain use varied among individual tracked cows, and the range among cows within the same pasture was 59 m ($2204 \text{ m} \pm 15 \text{ SD}$) for average elevation use, 4.7 percentage points ($8.9\% \pm 0.2 \text{ SD}$) for average slope use and 247 m ($446 \text{ m} \pm 77 \text{ SD}$) for average distance from water. No correlation was detected between mature PAP scores and terrain use metrics (mean elevation, slope and distance from water of tracked locations; $r = -0.16, 0.24, 0.25$; $P > 0.10$). Similarly, no correlation was detected ($P > 0.10$) between yearling PAP score and terrain use metrics. Yearling and mature PAP scores were not correlated ($P > 0.50$) to indices of terrain use that combined elevation and slope use (rough index) and elevation, slope and distance from water (rolling index). Yearling PAP and mature PAP were not useful predictors ($P > 0.10$) of terrain use in multiple regression analyses. Angus cows in this study were apparently adapted to high elevations and PAP score had little, if any, relationship with their metrics of grazing distribution of foothill rangeland. In situations where

42 elevation was higher, terrain was more rugged or cattle were not adapted, results may differ from
43 those observed in this study.

44

45 Key words: beef cattle, high altitude, grazing distribution, pulmonary arterial pressure (PAP)

1. Introduction

It is common for cattle to graze at elevations ≥ 1500 m during at least part of the year in the western United States. In these production environments, high altitude disease has been documented for at least a century (Glover and Newsom, 1917; Salman et al., 1991). This disease is caused by pulmonary hypertension, which is measured by pulmonary arterial pressure (PAP). Cattle with PAP scores greater than 50 mm Hg are considered at risk for developing pulmonary hypertension and its consequential disease phenotypes (Holt and Callan, 2007). Pulmonary arterial pressure score has been determined to be a moderate to highly heritable trait ($h^2 = 0.20$ to 0.4) in yearling cattle, and therefore useful in the selection of breeding cattle for high elevation beef production systems (Enns et al., 1992; Shirley et al., 2008; Cockrum et al., 2014). However, there are examples where calf mortalities remain above normal at high elevation ranches despite selection for low PAP scores for several decades (Neary et al., 2013 and 2015ab).

Grazing distribution is a critical issue for cattle ranchers using extensive and rugged rangelands typically used in high elevation, mountainous beef production systems. Cows typically avoid steep slopes (Mueggler, 1965) and areas far from water (Valentine, 1947; Roath and Krueger, 1982). Many management practices designed to improve grazing distribution, such as water developments and herding, are expensive and (or) labor intensive (Bailey, 2004). Selection and (or) culling has been described as a potential, cost effective approach to improve grazing distribution (Roath and Krueger, 1982; Howery et al., 1996; Bailey et al., 2006). Cattle grazing distribution was associated with multiple genetic markers and appears to be a heritable trait (Bailey et al., 2015). This recent finding increases the potential for genetic selection and identifying bulls that will likely sire daughters that use rough terrain. To implement a successful selection program, a thorough understanding of grazing distribution traits and its potential trait

antagonisms are needed. The objective of this study was to evaluate the relationship between PAP score and metrics of terrain use of beef cows grazing a high-elevation foothill rangeland pasture. We hypothesized that cows with higher PAP score would avoid high elevations or steep slopes. We also expected cows with higher PAP scores would not travel as far from water or walk as far each day as cows with lower PAP values in a high elevation beef production system.

2. Materials and methods

2.1 Study site and cattle

The study was conducted at the Colorado State University Beef Improvement Center (i.e., One Bar Eleven Ranch) located 14 km east of Encampment, WY. Angus cows grazed in the United States Forest Service Beaver Hills Allotment (latitude 41° 14.9', longitude 106° 38.8' W). This native grass-sagebrush rangeland pasture consisted of 1210 ha, and the elevation ranged from 2150 to 2411 m. The average elevation was 2228 m. Slopes varied from 0 to 72% with an average slope of 12%. The average and maximum distance from water was 679 and 1755 m, respectively. Cattle grazed and were tracked in the Beaver Hills Allotment pasture from May 19 to June 14 during 2013 and from May 19 to June 4 during 2014. Cattle were tracked with Lotek GPS 3300 collars (Newmarket, Ontario, Canada). Positions were recorded at 10-min intervals. Similar to Ganskopp and Johnson (2007), our evaluations indicate that the GPS collars were accurate within 5 to 7 m. Other researchers have recorded similar accuracies for Lotek GPS 3300 collars when operating in non-forested terrain similar to this study site (Lewis et al., 2007; Hansen and Riggs, 2008).

Cattle in the study were mature purebred Angus cows with calves of the Colorado State University Beef Improvement Center breeding herd (n = 430 cows), which is an agricultural

experiment station breeding population where cattle are selected for tolerance and performance in a high elevation beef production system. In 2013, nineteen 8 year-old cows were tracked, and in 2014, twenty-two 5-year old cows were tracked. The age groups of cows that were used in the study had the greatest variance in yearling PAP scores compared to other age groups of mature cows in the herd at this time. Variance of yearling PAP for cow age groups used for tracking in 2013 and 2014 were 34.7 (n = 26 cows) and 21.6 (n = 27 cows), respectively. Within a selected age group, cows with similar aged calves were selected for tracking in order to minimize potential confounding of calf age and terrain use of cows. Average weight of the tracked cows was 552 ± 7.0 kg, and average body condition score (BCS) was 4.8 ± 0.1 using a beef cattle scale of 1 to 9, where 1 is emaciated and 9 is obese (Mathis et al., 2002). The tracked cows comingled in a herd of approximately 300 Angus cow-calf pairs during both 2013 and 2014. All cows in the Beaver Hills allotment pasture had spring-born (March to April in northern hemisphere) calves that were 3.1 ± 0.3 months of age during the tracking period

2.2 Pulmonary arterial pressure

The PAP score of each cow was measured when they were approximately 12 months of age (yearling PAP) and again approximately 2 weeks prior to GPS tracking (mature PAP). The PAP measures were collected by a Colorado licensed veterinarian using the procedures of Holt and Callan (2007). In brief, a catheter was inserted into the jugular vein and maneuvered through the right atrium and ventricle into the pulmonary artery. A pressure transducer and data-oscilloscope capable of measuring invasive blood pressure were used to record PAP in mm Hg. This type of system records systolic, diastolic, and mean PAP pressures. For this study, mean

PAP score was used as the indicator of cardio-pulmonary status and PAP scores > 50 mm Hg signified cattle at risk for developing high altitude disease.

2.3 Terrain use metrics

A digital elevation model (DEM) was obtained from the USGS Seamless Data Warehouse (seamless.usgs.gov) for the Beaver Hills Allotment pasture. The DEM was used to provide an elevation for each recorded position using the Spatial Analyst Extension in ArcMap tools (ArcGIS software, Redlands, CA, www.esri.com). Similarly percent slope was derived from the DEM for each collar position. Watering point locations (artesian-springs and available sections of Beaver Creek) were used to determine the distance from water for each collar position. The average elevation for each cow was calculated from all recorded positions for that cow during the tracking period. Similarly, the average slope and distance from water for each cow was calculated from all positions recorded during the tracking period.

Individual cows from each ranch were ranked by an index identified as “rough” which is a “normalized average” of elevation and slope (Bailey et al., 2015). The mean elevation of each cow was divided by average elevation use of all cows tracked at the Rouse Ranch during that tracking period and multiplied by 100. Similarly, mean slope use of each cow was divided by the average slope use of all cows tracked at a study site and multiplied by 100. The corresponding products associated for elevation and slope for each cow were then averaged.

$$\text{Rough Index} = ((\text{slope}_k / \text{slope}_i) * 100) + ((\text{elevation}_k / \text{elevation}_i) * 100) / 2$$

Where; k was the respective mean of a collared cow and l was the respective mean of all collared cows during a given tracking period.

The rough index reflected relative differences in elevation and slope use. A value of 100 indicated that the mean elevation and slope use for that cow was equivalent to the average of all tracked cows. Values less than 100 corresponded to gentler and/or lower terrain use than average, and values over 100 indicated use of steeper slopes and/or higher terrain.

An index termed “rolling” was used to evaluate a combination of elevation, slope, and distance to water (Bailey et al., 2015). Mean values of each cow for these variables were divided by corresponding averages of all tracked cattle at the study site during the entire tracking period and then multiplied by 100. These corresponding ratio variables were then averaged together.

$$\text{Rolling Index} = ((\text{slope}_k / \text{slope}_l) * 100) + (\text{elevation}_k / \text{elevation}_l) * 100 + (\text{distance from water}_k / \text{distance from water}_l) / 3$$

Where; k was the respective mean observation of a collared cow and l was the respective mean observation of all collared cows during a given tracking period.

We used these terrain indices because a single measure of terrain use, such as slope, does not fully explain the impact of terrain on cattle grazing distribution (Bailey, 2005). For example, steep slopes located near water do not reduce cattle use near as much as steep slopes that are located over 1.5 km from water or steep slopes located on high elevations (large vertical distance from water).

Distance traveled per day was calculated as the cumulative distance between successive positions when the cows were active. When cows were inactive the distances between

successive positions were not included in the average. Definitions of activity were based on the criteria used by Russell et al. (2012). Cows were inactive when the distance between positions was less than 20 m, the horizontal head movement sensor was less than 50 and the vertical head movement sensor was less than 50. Ganskopp and Johnson (2007) recommend excluding periods when cattle are inactive and likely stationary when calculating distance traveled per day to reduce the bias that may occur from GPS error. Using this protocol, these authors found that the error in distance traveled using GPS collars was only about 2%.

2.4 Statistical analyses

Analyses were executed using SAS (version 9.4, SAS Institute, Cary, North Carolina, USA). Pearson correlation coefficients were calculated for all pairs of variables and included yearling and mature PAP scores, average elevation, slope and distance to water during tracking, rough index, rolling index and distance traveled each day. Tracked cows were the experimental units ($n = 41$).

Using PROC MIXED of SAS (Littell et al., 2006), PAP measurements were used as continuous independent variables to predict each of the terrain use metrics. Year was also included in the model as a fixed effect. In addition, yearling and mature PAP scores were evaluated independently to determine if there were linear, quadratic or cubic relationships with each of the terrain use response variables. In all of these models, year and interactions of year and PAP (yearling or mature) were included in the model.

3. Results

The GPS collars recorded 84% of the potential positions (144 positions / d for when recorded every 10 min) in 2013 and 98% in 2014. Terrain use varied among the tracked cows (Table 1). Average elevation use of individual cows varied by 59 meters, and distance traveled varied by 4.1 km/d. Average slope use of individual cows varied from 6.3 to 11.0%. The yearling and mature PAP scores varied by 24 and 16 mm Hg, respectively.

The correlation coefficient between yearling PAP and mature PAP was 0.23 ($P = 0.15$). No correlations were detected between yearling PAP score and the average elevation, slope and distance from water of positions recorded for tracked cows (Table 2). Similarly, no correlations were detected between mature PAP score and average elevation, slope and distance from water of locations of tracked cows. There was no evidence that yearling or mature PAP scores were associated with rough and rolling terrain use indices (Table 2). The significance of the correlations between PAP scores and grazing use indices were $P \geq 0.25$; therefore, we were unable to reject the null hypothesis that the associative relationships of these variables differed from zero.

Using an analysis of variance approach, the combination of PAP scores collected from the females as yearling heifers and mature cows, were not useful predictors of any measure of terrain use ($P > 0.05$). Similarly, no linear, quadratic or cubic relationships were detected ($P > 0.05$) between yearling PAP and measures of terrain use (average elevation, slope and distance from water of recorded cow positions). Yearling PAP was not a useful predictor ($P > 0.10$) of the rough and rolling terrain indices. No linear, quadratic or cubic relationships were detected ($P > 0.10$) between mature PAP scores and average elevation, slope and distance from water of recorded cow positions. Yearling and mature PAP values were not useful predictors ($P > 0.10$) of the rough and rolling terrain use indices (Fig. 1 and 2).

4. Discussion

There was no evidence that yearling and mature PAP scores were correlated. This lack of phenotypic correlation suggests that PAP measured when heifers are one year of age may be a different trait than those obtained later in life. The reports of Neary et al. (2015a, 2015b) support this statement as PAP scores changed with both age and elevation. Most PAP measures in the U.S. are collected from yearling cattle as an indicator trait used in the selection processes for replacement bulls and heifers in high altitude beef production systems. This measure has been found to be a moderate to highly heritable trait (Enns et al., 1992; Shirley et al., 2008; Cockrum et al., 2014).

Growth trait genotype by environment interactions have been reported in Angus cattle managed at different altitudes across the United States (Williams et al., 2012). In an Angus herd of close proximity to experiment station cattle of the current study, Shirley et al. (2008) reported no phenotypic correlation between PAP score and birth weight and weaning weight, but genetically, PAP score was unfavorably associated with growth traits. This positive, yet unfavorable association, is concerning due to interests in most beef production systems to improve growth rate. Pulmonary arterial pressure is a physiological indicator of hypertension that leads to remodeling and narrowing of the pulmonary vasculature, and potentially, right heart failure (Rhodes, 2005; Humbert et al., 2004; Simonneau et al., 2009; Pugliese et al., 2015). Therefore, high PAP score could be considered an antagonism to production traits such as growth, and in the case of this study, grazing distribution. However, it appears much more data is needed before conclusions can be developed for these relationships.

Cows tracked in this study used the pasture in different ways. The variation among cows in this study was similar to that observed at mountainous ranches with rough topography reported by Bailey et al. (2015). Although there was variation in terrain use of tracked cows, this variability could not be explained by yearling and mature PAP scores. There was no evidence to support our hypothesis that cows with higher PAP scores would use lower elevations, gentler slopes or areas near water. However, the study was conducted with cows that were adapted to the pasture and altitude of the Colorado Beef Improvement Center.

Recent research by (Bailey et al., 2015) suggested that cattle grazing distribution could be inherited. This study showed that up to 25% of the variation in terrain use indices (rough and rolling) were explained by one genetic marker on chromosome 29 and multiple markers across several chromosomes explained over 35% of the variation in terrain use. The lack of phenotypic correlations between PAP scores and terrain use in the current study suggest that beef cattle producers could successfully select for both improved grazing distribution patterns and reduced PAP scores. These breeding objectives could thereby improve the adaptability of cattle that graze high elevation mountain pastures. However, larger data sets need to be constructed so the genetic correlations between terrain use and PAP scores can be estimated to evaluate the effects of selection for PAP on grazing distribution or selection for grazing distribution on PAP.

Cows in this study were born and raised at the Colorado State University Beef Improvement Center (i.e., One Bar Eleven Ranch). Therefore, we conclude that cows in this study were apparently adapted to high elevations and PAP score had little, if any, effect on their grazing use of foothill rangeland. However, if the cows had originated from low elevations, and then transported to the study pasture immediately prior to the study, the results may have been quite different. Our prior studies revealed complex grazing behaviors adaptations in cattle that have

been transported (Bailey et al., 2010) and the incidence of high altitude disease is much higher in cattle adapted to low elevations that are transported to high elevations (Will et al., 1975; Rhodes, 2005; Holt and Callan, 2007; Neary et al., 2013). In such cases, development of cardio-pulmonary malformations may influence a cow's desire and ability to climb and graze high elevations and steep slopes.

5. Conclusions

This study did not provide evidence to support our hypothesis that terrain use was related to PAP scores in cows adapted to elevations ranging from 2150 to 2411 m. Although more research is needed, the lack of phenotypic correlations suggested that terrain use and PAP scores are independent traits and could both be used as selection criteria in high elevation beef production systems.

Acknowledgements

Research conducted in this study were funded in part by the USDA Western Sustainable Agriculture Research and Education program (SW15-015) and the Colorado State University John E. Rouse Endowments for Animal Breeding and Genetics Research for support of graduate students and faculty.

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363

FIGURES

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365 Figure 1. Relationship of yearling pulmonary arterial pressure (PAP) score and indices of terrain
 366 use of Angus cows grazing at the Colorado State University-Beef Improvement Center (2150 to
 367 2411 m of elevation).

368

369 Figure 2. Relationship of rough and rolling terrain use indices and pulmonary arterial pressure
 370 (PAP) score in mature Angus cows grazing at the Colorado State University-Beef Improvement
 371 Center (2150 to 2411 m of elevation).
 372

TABLES

373 **Table 1.** Means, standard deviations (SD) and ranges of yearling and mature pulmonary arterial
 374 pressure scores (PAP) and the average terrain use of 19 Angus cows tracked in 2013 and 22
 375 Angus cows in 2014 tracked at the Colorado State University-Beef Improvement Center (2150 to
 376 2411 m of elevation).

Trait	Year	Mean	SD	Minimum	Maximum
2013					
Yearling PAP (mmHg)		39.3	5.3	33	55
Mature PAP (mmHg)		44.4	3.4	39	51
Elevation (m)		2205	13	2182	2230
Slope (%)		9.5	0.9	7.7	11.0
Distance to water (m)		487	79	352	592
Travel (km/d)		6.2	1.0	4.5	7.9
Rough index		96.9	4.8	88.0	104.7
Rolling index		96.6	7.6	82.5	107.7
2014					
Yearling PAP (mmHg)		37.2	4.8	31	48
Mature PAP (mmHg)		41.1	3.4	36	52
Elevation (m)		2202	17	2174	2233
Slope (%)		8.4	0.9	6.3	10.1
Distance to water (m)		410	55	345	498
Travel (km/d)		5.4	0.8	3.8	6.8
Rough index		97.5	5.5	85.4	107.3
Rolling index		97.0	4.4	85.5	105.5

Table 2. Pearson correlation coefficients among yearling and mature cow pulmonary arterial pressure (PAP) scores and terrain use metrics measured on Angus cows grazing at the Colorado State University-Beef Improvement Center (2150 to 2411 m of elevation).

	Yearling PAP	Mature PAP	Elevation	Slope	Distance to Water	Rough Index	Rolling Index	Travel / d
Yearling PAP	1.00							
Mature PAP	0.23	1.00						
Elevation	-0.10	-0.16	1.00					
Slope	0.11	0.24	0.46 *	1.00				
Distance to water	0.25	0.25	0.25	0.36 *	1.00			
Rough Index	-0.04	-0.03	0.53 *	0.82 *	0.07	1.00		
Rolling Index	0.10	0.01	0.49 *	0.54 *	0.71 *	0.63 *	1.00	
Travel/ d	-0.18	0.18	-0.13	0.01	0.29 *	-0.23	-0.03	1.00

* Correlation coefficients were statistically significant ($P < 0.05$).