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Association patterns reveal dispersal-aggregation dynamics among cattle in a South Texas Rangeland, USA

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Abstract

Introduction: The spatial association dynamics of free-ranging cattle herds are not fully understood; however, they can have a direct influence on the spatial patterns of resource utilization. The aim of our study was to examine new analytical methods of identifying the spatio-temporal patterns of behavioral dynamics that determine cattle herd dispersal in the semi-arid rangelands of South Texas. We fitted 10 free-ranging cows with global positioning system collars and obtained positions every 5 min for each animal for 21-day trials, twice during the summer and winter period. We used an association pattern recognition software (ASSOC1) and the herd center of gravity to identify the spatial and temporal thresholds that defined dispersion-aggregation patterns and individual position to determine their relation to social dominance.

Results: The association pattern defining herd membership was that animals spent 70% of their time within 200 m of each other. Dominance ranking did not appear to influence association membership or position within the herd. The cattle showed a more dispersed distribution during summer, but in winter, herd members behaved in a more aggregated pattern. This distribution is contrary to patterns described in more northerly and mountainous regions.

Conclusions: The spatial thresholds of the cattle herd and the overall distance of all members to the center of the herd were smaller during winter and larger during summer, indicating that this study herd congregated during the winter and dispersed during the summer. Although this study uses a herd of 10 individuals in a 100 ha pasture to evaluate spatio-temporal dynamics, our results provide evidence of the ability of current tracking and spatial association tools to detect and quantify seasonal changes in cattle herd dispersion-aggregation patterns. The use of these data collection and analysis methods could prove useful in larger cattle herds, increase our understanding of herd spatio-temporal behavior, and subsequently help in the development of improved management practices.

Keywords: *Bos taurus*, Global positioning system (GPS), GPS collar, Herd dispersal, Social dominance, Sub-herd, Spatio-temporal pattern of resource use

Introduction

Cattle are important domestic herding ungulates throughout much of the world. Understanding their spatio-temporal dynamics is important because herds have a significant impact on ecosystem productivity and landscape structure at multiple scales (Launchbaugh and Howery 2005; Harris et al. 2007; Ramseyer et al. 2009). Rangeland beef cattle herds provide a good model for empirical testing of large herbivore herd movement patterns, dispersal dynamics, and social interactions because individuals are often maintained long enough for social relationships to be established within the herd and animals can follow natural daily and seasonal rhythms with minimal human intervention (Reinhardt 1982; Šárová et al. 2010). Although the nature of herd social associations is not fully understood, they could have direct influence on spatial patterns of pasture use and resource utilization (Launchbaugh and Howery 2005). Many studies have identified topography, water location, shelter, and forage characteristics as the main factors governing the distribution of cattle (Owens et al. 1991; Bailey 1995, 2005). Few have considered the social hierarchies that influence

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individual access to resources and thus influence spatial distribution within and between herds (Šárová et al. 2010).

Distribution of animals within herds is often influenced by social factors. Dominance occurs when the behavior of one animal is affected by the presence or threat of another animal (Šárová et al. 2010). In small, well established groups, dominant animals can limit the access of subordinates to food, water, and shelter when these resources are limited in space and time and can be defended (Friend and Polan 1974; Arave and Albright 1981; Grant and Albright 2001; Estevez et al. 2007; Stephenson et al. 2016). Social hierarchies may be indiscernible during times of ample resource availability but become more evident during periods of low resource availability. Social dominance in cattle has been strongly associated with age, body weight or height, seniority, and breed (Stricklin 1983; Harris et al. 2007). Contrary to male social groups, female social groups exhibit a stable dominance status among members (Harris et al. 2007). Dominance among cows seems to be based on mutual familiarity, where individuals prefer to be in close proximity to herd members with similar rank (Syme et al. 1975; Arave and Albright 1981). Dominance behavior can affect the spatial associations among members of a herd. In the case of domestic farm animals in an arid or semi-arid environment, dominant animals tend to gather around defendable limited resources such as supplemental feeders and water while subordinate animals wait in the periphery (Estevez et al. 2007). This phenomenon is also known as the selfish herd principle mostly observed in wild herd populations (Wagnon et al. 1966; Šárová et al. 2010). Exclusion from key resources can have negative effects on subordinate individuals especially during periods of limited and patchy resources (e.g., droughts), and this can negatively affect individual weight gain and overall herd productivity (Wagnon et al. 1966).

Previous studies have addressed questions regarding the relationship between spatial interactions and social dominance in a cattle herd (Stricklin 1983; Grant and Albright 2001; Šárová et al. 2010; Stephenson et al. 2016) as well as independence among individuals (Stephenson and Bailey 2017) in herds of various sizes. Stephenson et al. (2016) reported that in herds of 40 or less cows no strong or weak association pattern was detected using visual observations suggesting that these animals had equal association with all other cows in the pasture. Previous work has indicated that small herds of cattle tend to stay and graze relatively close to each other, and larger groups (i.e., more than 40 animals) tend to show sub-grouping behavior and use different parts of the pasture (Harris et al. 2007; Stephenson et al. 2016). However, there is a need to determine if current tracking technology such as global positioning systems (GPS) and association analysis tools such as ASSOC1 can detect more subtle dispersal-aggregation dynamics in a small cattle herd and whether any effects of social dominance can be observed. The use of GPS collars to track animal movements during 24 h day cycles and longer time frames (e.g., year-round, seasonal), and the development of validated animal association tools has improved our understanding of livestock behavior and distribution dynamics (Weber et al. 2001; Stephenson and Bailey 2017). The aim of this work was to examine the seasonal dispersal-aggregation patterns in a small cattle herd in a South Texas Rangeland using GPS technology and the spatial association software ASSOC1 (Weber et al. 2001). Our specific objectives were (1) to define the spatio-temporal parameters that characterize the distribution of individuals within a small herd, (2) to quantify seasonal dispersal-aggregation patterns at different spatial scales, and (3) to evaluate the relationship between spatial associations and dominance ranks. We hypothesized that group dispersal and the effect of social dominance on individual spatial distribution would be detected using GPS and ASSOC1 tools, and that these patterns would be more evident during the winter season when resources are limited.

Methods

Study area

Our study site (29°19.13′N, 99°42.9′W) was located in South Texas in the transition zone between the South Texas Plains and the Edwards Plateau Ecoregions. Topography is mostly level with gentle undulating planes (Taylor et al. 1999). This area has a semi-arid climate characterized by dry winters and hot, humid summers (United Sates Department of Agriculture 1976). Mean annual precipitation in the study area is 406 mm (Perotto-Baldivieso et al. 2012). Over two thirds of the precipitation occur during the warm summer season from May to October, usually with the highest amount of rainfall in May followed by a second rainfall peak in September. Mean temperature ranges from 2.9 °C in winter to 36.7 °C in summer. The 100 ha study site was an externally fenced pasture containing two water troughs but no natural water sources. This pasture was part of a 457 ha cattle ranch that was under a continuous/yearlong grazing schedule with light/moderate stocking rate (15 ha/AU stocking density). This system provided no resting period for vegetation and herds were hay-fed year-round. The study area had a 29.4% woody cover with a diverse variety of thorny shrubs, including catclaw acacia (*Acacia greggii*), twisted acacia (*Acacia schaffneri*), agarita (*Mahonia trifoliate*), spiny hackberry (*Celtis palida*) and succulents like Texas pricklypear (*Opuntia engelmannii*), tasajillo (*Opuntia leptocaulis*), and *Yucca* spp. Mottes of small live oak (*Quercus virginiana*) trees were scatted throughout the landscape. Forbs formed a diverse but ephemeral food resource. Common grasses were Halls panicum (*Panicum hallii*), hairy tridens (*Erioneuron pilosum*), common curlymesquite (*Hilaria belangeri*), Texas grama (*Bouteloua rigidiseta*), sideoatsgrama (*Bouteloua curtipendula*), threeawn (*Aristida* spp.), plains bristlegrass (*Setaria leucopila*), slim tridens (*Triden muticus* var. *muticus*), red grama (*Bouteloua trifida*), and Texas wintergrass (*Nassella leucotricha*) (Cooper et al. 2008; Perotto-Baldivieso et al. 2012). An extensive network of dirt roads facilitated cattle and deer management on the ranch.

Animal selection

We randomly selected 10 individuals from a herd of 31 free-ranging Angus × Bonsmara cows (*Bos taurus*) born at the study site, then moved them to the 100 ha study pasture; this number maintained the current local management stocking rates. The work focused on an in-depth study of a single herd, and is comparable to other studies that have addressed questions at the herd scale (Ganskopp 2001; Bailey and Welling 2007; Cooper et al. 2008; Šárová et al. 2010). Although previous research has demonstrated that larger study herds (i.e., more than 40 animals) are needed to observe subgrouping dynamics (Stephenson et al. 2016), our small study herd can shed light into more subtle dispersal-aggregation patterns within a herd that may be detected using GPS technology and association tools such as ASSOC1 software.

During the study period (December 2008–August 2009), cattle were 5 to 6 years old and had a mean weight of 542 kg (Table 1). Animals used in this study were in good condition and met the Institutional Animal Care and Use Committee guidelines set by Texas A&M University (Animal Use Protocol [AUP] #2007-167). These animals were separated from the main herd and moved into the study pasture to avoid the influence of non-collared cows on the behavior and distribution of the selected individuals for the study group. Changes in the natural behavior of the selected individuals due to separation from the original herd were expected to be minimal because these were mature animals used to regular management actions (Harris et al. 2007). Current calving management practices were maintained where cows calved during the spring and calves were present during the summer season. We determined social dominance rankings using only the study herd of 10 cows by recording antagonistic interactions, such as bluffing, head butting, and fights, during feeding sessions in the ranch corrals. To facilitate observation of these interactions during the dominance test, we divided the herd into smaller groups (i.e., four to five individuals) and we assigned ranks based on their higher priority to feed (Arave and Albright 1981; Harris et al. 2007). Once the ranking was determined in the smaller groups, animals from the different groups were combined on subsequent dominance tests to obtain a final ranking for all cows in the study herd. Ranks ranged from 1 to 10 with 1 being the most dominant individual and 10 the most subordinate (Table 1).

Table 1 Cow identification numbers, dominance rank, weight, and age of animals at the beginning of the study

Cow ID	Dominance rank	Weight (kg)	Age (years)
2039	1	584	6
2031	2	593	6
2022	3	518	6
2003	4	528	6
3045	5	593	5
2026	6	423	6
3050	7	597	5
3002	8	556	5
3560	9	495	5
3028	10	532	5
Average		542	5.5

Sampling period and GPS data processing

We fitted each animal with the same model of global positioning system (GPS) collar (Lotek GPS 3300LR; Lotek Engineering, Newmarket, Ontario, Canada) to obtain GPS locations every 5 min for each animal in the herd (Perotto-Baldivieso et al. 2012). We conducted four trials of 21 days each between 2008 and 2009 to compare effects of winter and summer seasonality on the grouping behavior. During winter, considering a period of low forage resource availability, we scheduled trials in December (2008) and January (2009) and during summer, when forage resources are more abundant, we scheduled trials in June and August (2009).

At the end of each trial, we retrieved data from the collars and differentially corrected the data using reference data from Base Station located at Del Rio, Texas (< 100 miles). When differential corrections were not possible, an uncorrected position was used (Ganskopp and Johnson 2007). When no locational data was obtained for up to three consecutive locations, mean *X* and *Y* values were calculated by interpolating consecutive records. If more than three successive fixes were not obtained, that portion of the dataset was omitted from analyses. Frequent data is essential for behavioral observations but spatial data with successive records separated by short time intervals can produce distance serial autocorrelation (Perotto-Baldivieso et al. 2012). Therefore, location samples used for this study were separated by at least 120 min to minimize the possibility of autocorrelation.

Spatio-temporal parameters that characterize a cattle herd

Based on individual location information, we analyzed the herd association dynamics with the ASSOC1 software (Weber et al. 2001), which uses association matrix, association pattern and pattern recognition to provide information on the association of animals using spatial and temporal thresholds. The spatial threshold is the maximum straight-line-distance at which any two members of a herd can be considered associated and the temporal threshold is the minimum percent of time they have to spend together over the sampling period to be considered associated. With different spatial thresholds, we were able to quantify two association pattern metrics: (1) mean temporal association, which is the percent of time animals are together within each spatial threshold and (2) mean percent similarity, which refers to how similar the pattern of association was between individuals and the template individual (a template individual was defined as the individual with the largest number of associations in the herd). A more complete description of the software and its operation can be found in Weber et al. (2001) and Harris et al. (2007). We used ASSOC1 with coarse spatial thresholds to identify the distance where members of our herd start behaving as a single herd. The coarse spatial thresholds selected were 25 m, 50 m, 75 m, 100 m, 125 m, 150 m, 175 m, and 200 m based on field observations of herd spatial extent, size of the study site, and previous studies of animal associations (Harris et al. 2007).

Analysis of dispersion-aggregation patterns using association techniques

Once herd spatial and temporal thresholds were defined, using ASSOC1 we conducted a more detailed analysis of dispersion-aggregation patterns using spatial increments of 5 m to investigate subtle association dynamics and the spatial extents that were relevant to this study herd. Spatial and temporal association calculations were summarized to estimate the mean and standard error for all trials. We used Kruskal-Wallis one-way analysis of variance on ranks test ($\alpha = 0.05$) to compare seasonal patterns of spatial and temporal associations between each pair of cows.

Relationship between herd membership, spatial associations, and dominance ranks

To determine whether low ranked cows tend to position on the periphery of the group and dominant animals in the center of the herd, we used the center of gravity of the herd (Wagnon et al. 1966; Šárová et al. 2010). This method allowed us to determine which ranks positioned closer to the center of the group at any given time. We defined the center of gravity of the herd as the average X and Y coordinates of the 10 individuals for each GPS fix interval. We then obtained the Euclidean distance from each individual to the center of gravity of the herd. We used Kruskal-Wallis one-way analysis of variance on ranks test ($\alpha = 0.05$) to examine statistical differences in the average distance to the center of gravity between individuals. To further investigate the relationship between spatial associations and dominance rank, we wanted to determine whether dominant or subordinate individuals had a closer spatial association. We calculated the average dominance rank of the herd at each spatial threshold increment (25 m, 50 m, 75 m, etc.) for each trial (early and late summer and winter). If the average dominance rank of the herd decreased (e.g., from dominance rank 3 to 7) with an increase in the spatial threshold, that meant that subordinate animals were added to the herd as the spatial threshold increased. This, in turn, would indicate that dominant animals were closer to each other as shown by their initial detection at small spatial thresholds.

Results

Spatio-temporal parameters that characterize a cattle herd

In winter, the herd had a higher mean temporal association (Kruskal-Wallis test: $H_{15} = 985.97$, $p < 0.05$; Fig. 1) at all spatial thresholds (74.52% ± 0.81%) than in summer (63.90% ± 1.08%). This pattern was consistent within trials conducted on the same season with no significant changes within seasons. Cattle spent, on average, 70% of the time within 25 to 200 m from each other. Using this mean percent similarity value to define the herd parameters, we identified the spatial thresholds where individuals were detected as a herd as 75 m in early winter (December 2008), 125 m in late winter (January 2009), 100 m in early summer (June 2009), and 225 m in late summer (August 2009) (Table 2). We identified the spatial threshold at which individuals were detected independently as 25 m in early summer, 75 m in late summer, 25 m in early winter, and 25 m in late winter.

Analysis of seasonal dispersal-aggregation dynamics using association techniques

During early summer, animals appeared dispersed with two groups of animals (composed of two individuals and six individuals) identified at 60–65 m spatial thresholds, and during late summer, animals appeared more dispersed with two groups of animals (composed of two/three individuals each) identified at 100–115 m spatial thresholds. In each case, the remaining members where included in the herd at larger spatial thresholds. The members in each group remained consistent but no ranking, age, or animal characteristic (e.g., frame score, temperament score) explained the membership pattern.

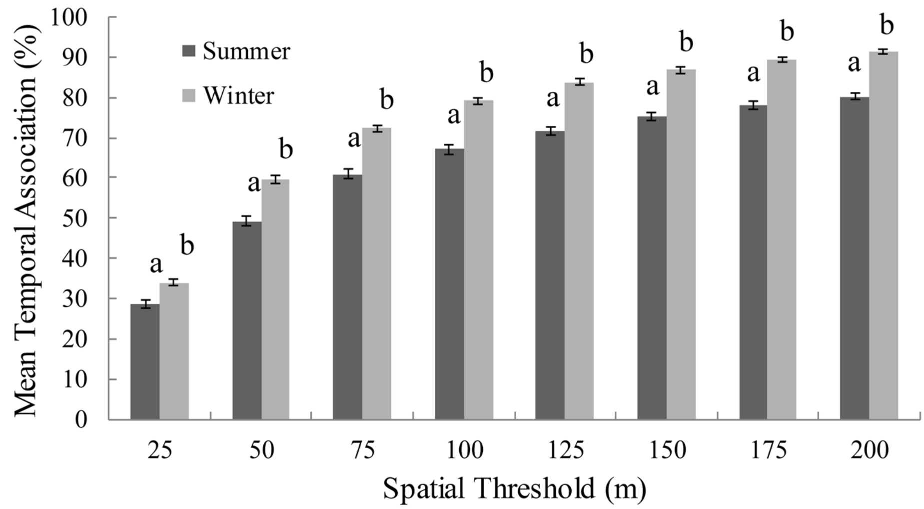

Fig. 1 Mean and standard error of the temporal association (%) spent per cow pair within specified spatial thresholds (25–200 m) of a free-ranging cattle herd ($N = 10$) during 6 weeks in winter (December 2008) and summer (August 2009)

Winter trials did not show this dispersed pattern at any spatial threshold. The minimum spatial thresholds at which individuals started to show association and where the members of herd behaved as individual units was refined as 50 m in early summer; 100 m in late summer; 40 m in early winter; and 50 m in late winter. For all trials, except late summer, the majority of individuals became part of the herd unit at approximately 70 m (Fig. 2).

Table 2 Association analysis of individuals using different spatial thresholds for four trials

	Spatial threshold (m)							
Parameter	200	175	150	125	100	75	50	25
Early summer								
Number associated	9	9	9	9	9	8	3	0
Mean % similarity	100	100	100	97.5	78.6	56.5	17.3	0
SD	0	0	0	4.7	19.5	29.9	33.7	0
Late summer								
Number associated	8	8	8	4	4	0	0	0
Mean % similarity	75.9	63.2	54.6	36.3	12.5	0	0	0
SD	25.6	32.7	34	32.8	33.6	0	0	0
Early winter								
Number associated	10	10	10	10	10	10	5	0
Mean % similarity	100	100	100	100	96.1	76	36	0
SD	0	0	0	0	6.8	18.5	41.2	0
Late winter								
Number associated	10	10	10	10	9	8	2	0
Mean % similarity	100	98	92.8	89.9	83	70.6	11.1	0
SD	0	4.1	12.7	19.5	23.8	39.3	32.3	0

Number of individuals associated with group template, mean percentage, and standard deviation of similarity for individuals as compared to group templates. The temporal threshold was maintained at 70%. Mean % similarity refers to how similar the pattern of association was between individuals and the template individual (a template individual is an individual demonstrating the largest number of associations in the herd)

Relationship between herd membership, spatial associations, and dominance ranks

High-ranking animals did not have a significantly different distance to the center of the herd than low ranking animals (Fig. 3). During late winter, the most dominant individual was farther from the center of the herd (Kruskal-Wallis test: $H_9 = 48.15$, $p < 0.05$) than most other individuals. In early summer, the average distance to the center of the herd was 78.15 ± 7.32 m; late summer 155.77 ± 10.36 m; early winter 54.98 ± 4.14 m; and late winter 81.80 ± 6.47 m. Thus, individuals were the farthest (most dispersed) from the center of the herd during late summer and closest (most aggregated) during early winter. In early summer and early winter at the smallest spatial threshold, the average herd dominance ranks were 4.67 ± 1.76 and 4.00 ± 3.00; while at their largest spatial threshold, the average herd dominance ranks were 5.44 ± 1.07 and 5.5 ± 0.96 respectively (Fig. 4). Therefore, dominant animals (i.e., high ranking animals) were close to each other, and low-ranking animals were added to the herd as the spatial threshold increased. No clear pattern was evident in late summer but in late winter presented the opposite pattern where the average dominance rank of the herd decreased from 9.00 ± 1.00 to 5.5 ± 0.96 as the spatial threshold increased. This means that during winter, subordinate animals were on average closer to each other than the dominant individuals.

Discussion

The information we obtained through combining animal tracking technology (i.e., GPS collars) with association

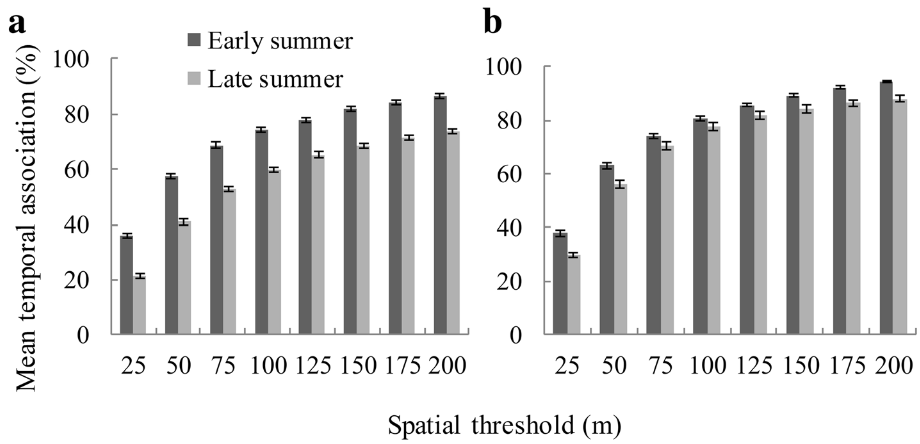

Fig. 2 Mean and standard error of the temporal association (%) spent per cow pair within specified spatial thresholds (25–200 m) of a cattle herd ($N = 10$) during (**a**) two summer trials and (**b**) two winter trials each composed of 3 weeks from December 2008 to August 2009

pattern recognition software (i.e., ASSOC1) provided the parameters needed to characterize the spatio-temporal distribution of a small cattle herd and detect subtle seasonal spatial dynamics. Association patterns defining membership showed that animals spent 70% of their time within 200 m of each other in our study. Although this herd of 10 individuals in a 100 ha pasture is too small to accurately evaluate sub-grouping dynamics (Stephenson et al. 2016), our results are comparable to field observations reported by Harris et al. (2007) and provide evidence of the ability of current tracking and association tools to detect and quantify seasonal changes

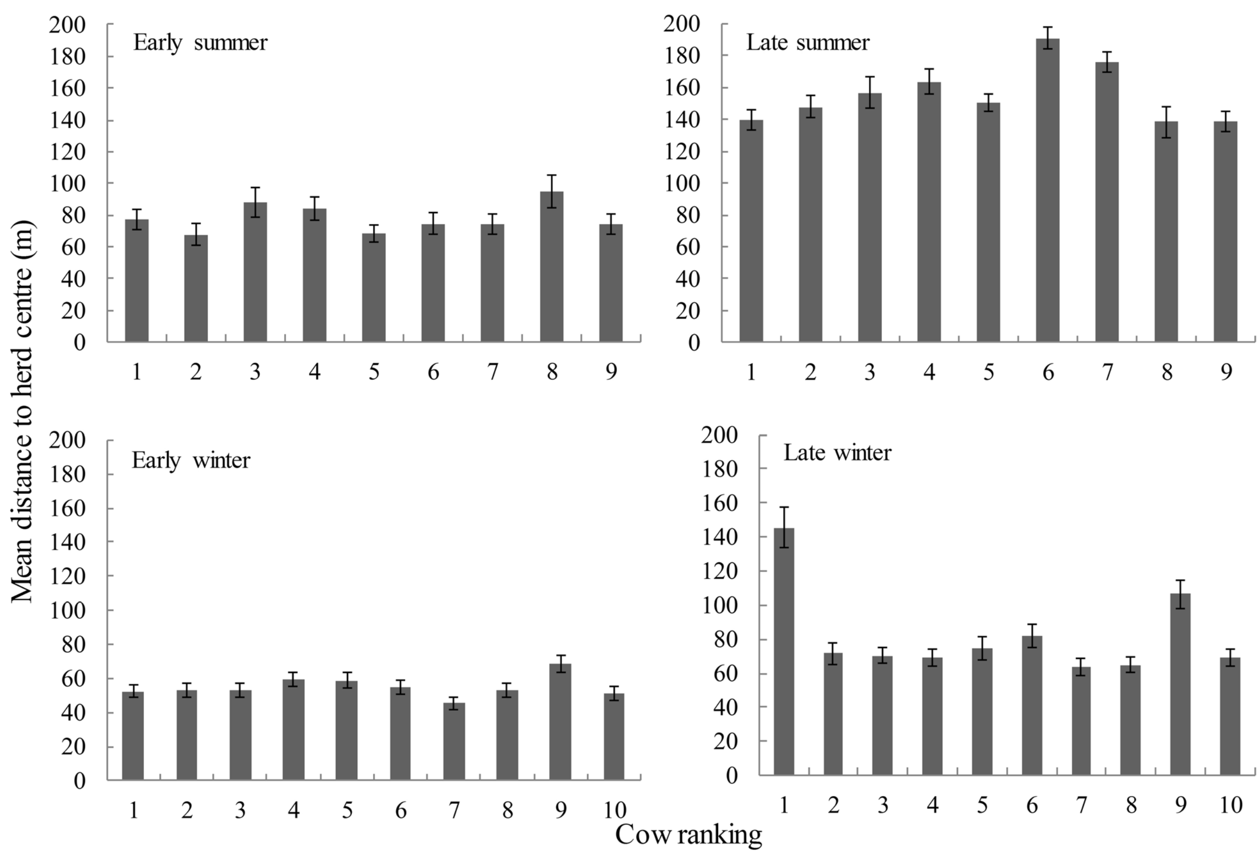

Fig. 3 Mean and standard error of the distance of each individual to the center of herd, classified by dominance ranking, within a cattle herd ($N = 10$) during two summer and two winter trials each composed of 6 weeks from December 2008 to August 2009 in a South Texas rangeland

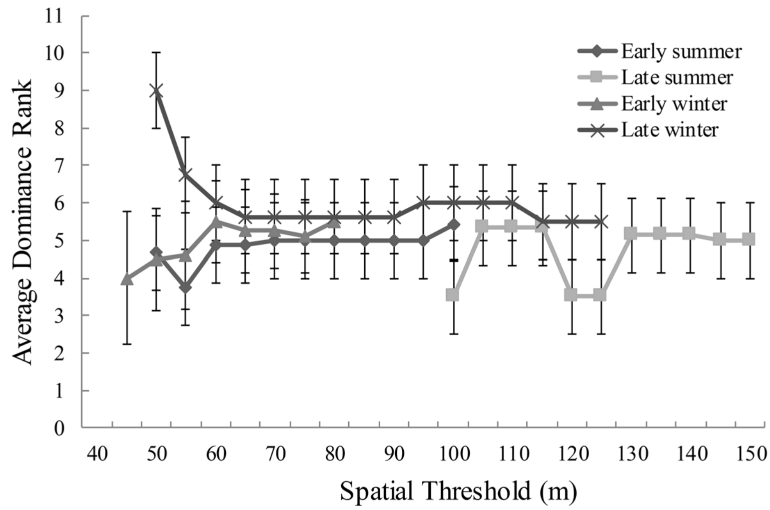

Fig. 4 Mean dominance rank of the members included in a cattle herd (*N* = 10) at different spatial thresholds during four trials each of 3 weeks duration in a South Texas rangeland

in group dispersion-aggregation patterns. Spatial thresholds of the cattle herd decreased from summer to winter, indicating that herd size became more compact in winter. According to Sato (1982), vegetation condition can be one of the most important factors influencing the dispersive movement for grazing animals in savanna pastures. The pattern observed in our study of stronger group aggregation during winter, and dispersal in the summer, was different from studies in northern and mountainous regions. There cattle tend to travel in larger and more compact groups in summer when forage is abundant (Dudzinski et al. 1982; Lazo 1994; Harris et al. 2002, 2007), and split into sub-herds in winter when forage is least abundant (Harris et al. 2007). However, Owens et al. (1991) concluded that in summer when large amounts of standing crop are accessible, the animals would be more selective, which would result in greater herd spread and larger variations of pasture utilization in shrubby semi-arid rangelands which may, in part, explain our observations. Furthermore, our study herd had calves during the summer season which may influence their spatial dynamics and associations by creating strong dyadic associations between cows and their calves (Bøe and Færevik 2003; Finger et al. 2014). In light of these previous studies, we hypothesize that the seasonal spatial pattern observed in our investigation may be related to a combination of thermoregulatory actions, forage distribution and availability, calves present during the summer, and provision of supplemental feed and water at consistent locations (Hinch et al. 1982; Coppock et al. 1986; Lazo 1994; Bailey et al. 1996; Howery et al. 1996; Sowell et al. 1999; DelCurto et al. 2000; Turner et al. 2000; Ganskopp 2001; Bailey 2004, 2005; Launchbaugh and Howery 2005; Ritchie et al. 2009; Cooper et al. 2008; Butt 2010). These hypotheses will require further research that integrates animal location, physiological information at the individual level, and environmental variables to develop herd emergent properties (Swain and Friend 2013). Furthermore, breed and herd and pasture size can greatly affect the spacing behavior and social association patterns in cattle herds (Bøe and Færevik 2003; Stephenson et al. 2016; Stephenson and Bailey 2017).

Our findings show the importance of studying herds at multiple scales to better detect spatial and temporal patterns. Broad temporal and spatial scales served to define the extent of the herd unit and finer scales were useful to identify a more dispersed herd during summer compared to a more aggregated herd during the winter, thus providing further insight on the spatial dynamics of herd distribution. One scale alone may not be sufficient to accurately understand the underlying mechanisms and responses of animals to landscape structure and resource availability. Although this is a study with a small sample size, it provides evidence that tracking technology coupled with group association tools such as ASSOC1 can be used to detect subtle seasonal dispersal-aggregation dynamics in a cattle herd. Understanding these spatio-temporal scales in herds could help quantify the spatial scales for vegetation composition and spatial pattern analysis.

Grazing by large ungulates may affect vegetation species composition, and it is considered an important management tool to maintain ecological diversity (Golodets et al. 2011). However, the spatio-temporal dynamics of vegetation pattern development are still not well understood and rely on model simulations (Okayasu et al. 2012). Our herd study showed that cattle used spatial thresholds ranging between 60 and 115 m and distances among animals were < 200 m, which is different to the scales used in typical vegetation studies in grazing systems (Thayn et al. 2008; Blanco et al. 2009; Golodets et al. 2011). Although vegetation dynamics were not part of this study, and the herd and pasture are probably too small to apply these spatial thresholds more generally, the use of GPS tracking devices and association methodologies to identify the spatial and temporal scales used by our herd underscore the need to explicitly reconcile individual versus group effect as processes of different scales acting on the landscape. Blanco et al. (2009) reported that results of grazing effects on vegetation dynamics and forage production were inconsistent and major constraints in this area were due to a lack of accurate and repeatable techniques for quantifying temporal variability and spatial heterogeneity in vegetation. This could also potentially be linked to a spatial scale mismatch (Pelosi et al. 2010) between gazing dynamics and vegetation ecological processes. Pelosi et al. (2010) reported that a main factor for spatial scale mismatch is a lack of systemic approaches to integrated management (i.e., grazing) and ecological (i.e., vegetation) processes. Therefore, the approaches used in this study could provide insights for matching scales of different processes operating in grazing landscapes that can be applied to small cattle herds and could prove useful to larger cattle herds and different herd species.

Spatial distribution of members within a herd may also be mediated by behavioral mechanisms. We found that social dominance appears not to be a major factor affecting herd configuration. Our results did not show any significant spatial pattern associated with social dominance. This is consistent with Šárová et al. (2010) who found that the selfish herd principle did not explain the distribution of beef cattle because dominant animals were not positioned more centrally in the herd than subordinate animals. Unlike behavioral patterns observed in many wild ungulate herds, the role of dominance in our study may not be as evident because safety from predation is not imperative and artificial selection through selective breeding and management might have developed more tolerant, less aggressive, and less dominant animals (Grant and Albright 2001). Prior studies have not come to any consistent conclusion on the relationship between dominance and spatial associations among members of cattle herds (Arave and Albright 1981; Harris et al. 2007). Behavioral responses and their effect on herd spatial patterns might be stronger in larger herds in areas with very limited resources. The relationship between dominance, competition for forage, and spatial associations is more evident in situations with limited foraging space, which makes this space a defensible resource (Grant and Albright 2001).

Conclusions

The spatial thresholds of the cattle herd and the overall distance of all members to the center of the herd were smaller during winter and larger during summer indicating that this herd congregated during the winter and dispersed during the summer. This study showed seasonal dispersion-aggregation patterns in a single herd of 10 Angus × Bonsmara cows in a 100 ha pasture; however, more studies are needed to determine whether these results are typical behaviors found in larger herds and different breeds. Nevertheless, our results showed that using the techniques outlined in this study such as seasonal and diurnal GPS tracking and the association analysis tool ASSOC1, it was possible to detect seasonal spatial association patterns in a small herd of cattle. The use of these data collection and analysis methods could prove useful in larger cattle herds, increase our understanding of herd spatio-temporal behavior, and subsequently help in the development of improved management practices. Although not specifically tested in this study, we hypothesize that aggregation of cattle around water sources and supplemental feeding areas (particularly during periods of low forage quantity and quality) may have detrimental effects on the landscape and ecological processes (e.g., soil compaction, degradation of vegetation). Further pasture investigation should be conducted to determine whether the seasonal aggregation behavior occurs at fixed areas in the landscape (e.g., water sources, supplemental feed, shade) and seasonally modify those pasture attributes to promote a more even and dispersed pasture use.

This study provides new insights for combining individual animal locations and herd association patterns to determine dispersal-aggregation patterns and identifying spatial and temporal patterns within a cattle herd. Disentangling cattle herd dynamics at multiple temporal, spatial, and social scales aids the understanding of the natural spacing of individuals. These scales are critical for assessing the impact of grazing spatio-temporal patterns on the composition and dynamics of vegetation in rangelands. Although our study uses a small number of animals, our results underscore the value of individual versus group behavior and the link to potential mismatches in scale for studies of grazing and their landscape impacts.

Abbreviations

AUP: Animal Use Protocol; GPS: Global positioning systems

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Availability of data and materials
Please contact author for data requests.

Authors' contributions
All authors made substantial contributions to conception, design, and acquisition of data and provided significant contributions to the analysis and interpretation of the data. All authors have been involved in drafting the manuscript and revising it critically for important intellectual content. CCN, HLPB, XBW, and SMC have given final approval of the version to be published; they take public responsibility for appropriate portions of the content; and they have agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval
Animals used in this study studies were in good condition and met the Institutional Animal Care and Use Committee guidelines set by Texas A&M University (AUP # 2007-167).

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests.

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