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HABITAT USE AND TRAJECTORIES OF BEEF CATTLE IN SOUTH CENTRAL OKLAHOMA

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HABITAT USE AND TRAJECTORIES OF BEEF CATTLE IN SOUTH CENTRAL OKLAHOMA

A THESIS APPROVED FOR THE

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BY THE COMMITTEE CONSISTING OF

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Acknowledgements

If younger me could see me now, I am sure she'd be proud, a little confused, but mostly proud. I could write an entire other 64-page document on people I would like to thank, because it is not just who has been with me the past two years, but everyone who has helped shape me into the women I am today. So instead, I am going to keep my acknowledgements short and sweet to my immediate family and committee and hope that one day I can express my gratitude face-to-face to the people not mentioned by name.

Mom, you are the best mom and friend I could ask for. Thank you for answering nearly every call multiple times a day. Dad, I love you so much and am so thankful I have your humor. Dan, Carlee, and Thomas you three are unstoppable and I literally look up to each of you. I love you all. Grandma and grandpa thank you for always admitting I am your favorite grandchild.

Thank you to my committee, for agreeing to be here and for taking the time to advise me, help me with my research, and giving me the opportunity to expand my knowledge in GIS and rangeland management.

I am so incredibly thankful to have had this opportunity and am eager to see what the Lord has planned as I begin my career with a Masters of Geospatial Technologies.

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Abstract

Rangelands continue to hold a prominent role in ecological systems and cultural history. Management of rangelands comprises the science and art of sustainably maintaining intensive production from the grasslands and scrubs. The production of beef cattle in the United States, especially in Oklahoma and Texas, is dependent on the sustainable management of rangelands. The first chapter provides additional background on the focus of this study, that is, rangelands and their associated management practices. The second- and third chapters present research toward improved management following two different objectives. Each respective objective evaluates an analysis methodology over a common set of data. These studies aim to examine 19 individual beef cattle in southcentral Oklahoma on 4,499 acres during a predetermined time-activity budget. The data was collected using collars fitted with global positioning system receivers and was analyzed using Esri ArcPro 3.0.2. The time-activity budgets focused on three diurnal periods and one non-diurnal: morning (0700 – 1000), afternoon (1100 – 1400), evening (1500 – 1800) and night (1900 – 2200). The second chapter focuses on the habitat use of the herd as captured in trajectory data collected by GPS collars. The objectives were to determine the general habitat use characteristics of the herd, throughout the day in context with identifying their main water source use. The results of chapter two suggest that during this study period the herd stayed within the herbaceous land that allowing for grazing and preferred a nearby man-made water source. The third chapter focused on an analysis of trajectory characteristics, where average relocation distance and Euclidean distance from the water source were of particular interest. The results of the third chapter found the herd traveled at a consistent distance during the diurnal periods and then decreased their travel by half during the night. The results of both chapters offer information useful in the guidance of livestock producers for rangeland design and grazing practices. In the third chapter I present an extended discussion of the results from earlier chapters as well as avenues for future research using similar datasets.

Keywords. GPS collars, beef cattle, rangelands, spatial distribution

Chapter 1: Background on Rangeland Management and Habitat Use

1.1 Rangelands

Rangelands can be defined as lands where the native vegetations is predominately grasses, or grass-like plants, forbs, and shrubs (Society for Range Management, 1998). The rangeland organization is differentiated from pastures because it is managed as an ecosystem in concert with its inherent ecological principles, as opposed to agronomic principles (University of Idaho Rangeland and Ecology Management, n.d.; Pfander & Kruger, 2019). The definition of rangelands varies in climate and vegetation characteristics. The differences among classifications are highly dependent on the annual precipitation; while some rangelands are mostly grass, others have additional plants, and combinations of grasses and shrubs (Pfander & Kruger, 2019). The terminology for rangeland may also vary depending on its location; these locations can be referred to as grasslands, deserts, prairies, plains, savannas, shrubland, etc (Arizona Board of Regents, 2018a; Pfander & Kruger, 2019).

Rangelands provide benefits to both biodiversity as well as human livelihoods. Some of the obvious benefits present rangelands as supportive of watersheds, carbon sinks, and as habitats for wildlife (Tang & Cordon, 2019). Approximately 47% of the world's land areas are rangelands that support most of the world's sources of meat, milk, hides, wool, and other animal products (Williams & Allred, 1968). Over the years, large rangeland areas have been destroyed or altered for a variety of reasons; this has caused a negative impact on local communities' income and sustainable livelihoods (Behmanesh et al. 2016). Specifically in the United States, there are over 300 million ha of rangelands, including both public and private lands, that are characterized by low and variable precipitation, nutrient-poor soils, and high plant production (Havstad et al. 2007). It is important to inform rangelands management in order maintain the numerous goods and services possible, such as production from a rangeland-based livestock industry (Havstad et al. 2007).

A rangeland is not defined solely by its human use, because each range has unique characteristics that determine how a society can sustainably utilize it (Pfander & Kruger, 2019). The traditional use of rangeland is for livestock grazing. Other economic uses such as oil, coal mining, natural gas, and in recent years wind, and solar energy also represent developments in human use of rangelands (Thorne & Harper, 2018). From a cultural perspective, rangelands are a place of social and cultural value to indigenous tribes and ranching communities; these groups provide historical and local knowledge to the management practices of the rangelands (Arizona Board of Regents, 2018b, Arizona Board of Regents, 2018c, Pfander & Kruger, 2019). Protection of historical and cultural resources, as well as the numerous goods and services provided by these lands, is of high importance to society.

1.1.1 Rangeland Management

Range management is the management of lands on which the natural vegetation is dominated by grasses, forbs, and shrubs (SRM, Rinehart, 2008). When livestock ranchers use pasture or rangeland it benefits the farming, watershed, and the surrounding human communities in significant ways. The rangeland management philosophy promotes a sustainable agricultural practice that values the health of people, animals, plants, and soil. Some examples of the environmental stewardship found in range management include concern for and management of off-farm inputs such as diesel, fertilizer, and purchased feed (Rinehart, 2008).

The management of rangelands has been practiced for centuries, but it wasn't until 1948 when the American Society for Rangeland Management (SRM) was founded, providing a forum for the development of positive rangeland practices. The focus of the society was to bring together anyone who was "engaged or interested in any aspect of the study, management, or use of rangelands" (Howery, 2015). A recent turn in events and literature to focus on the management of rangelands in the United States can be contributed to events before and during the 1940s; such as the great depression, the dust bowl, and the second World War. The society didn't only include members from the United States, some of the founding members of the SRM were from Canada, Italy, and Iceland (Pfander & Kruger, 2019).

Along with the SRM, other agriculture-based organizations were founded on similar premises. For example, the Noble Research Institute, in Ardmore, Oklahoma, USA was founded in 1945 to help regenerate agriculture after the dust bowl (Noble Research Institute). One of the most important aspects of rangeland managers' responsibilities is reducing overgrazing. Overgrazing is when livestock grazing pressure exceeds the capacity of the pasture. Overgrazing can be characterized as continuous grazing which allows livestock to selectively graze the most appetizing plants repeatedly, not allowing the plant to regrow before grazing again (Rinehart, 2008).

Since the 1940s, the SRM has grown and information on how to manage rangelands in nearly every climate is readily available. Information from all over the world, from different groups, has made available various management practices that anyone can implement. For cattle ranchers, one important practice to manage is cattle grazing habits. Today, there are different types of grazing practices used throughout the world that are dependent on resource availability and climate of the rangeland.

1.2 Grazing Practices

1.2.1 Types of Grazing Practices

Continuous Grazing Practices

Grazing lands consist of the biological, physical, cultural, and sensory environment that many people call home or work and is where many people enjoy recreational activities (Valentine, 2000). Rangeland varies depending on the climate, and its management differs due to the traditions and strategies of the people managing the land. The most traditional grazing practice is known as continuous grazing. Continuous grazing often takes the form of cattle roaming a pasture for an extended period with infrequent rest periods for plant populations. The advantages are a low fencing cost, little daily management effort, and occasionally, acceptable animal gains. The method is often effective when the forage is abundant, and the herd size is consistent. When allowing a herd to continually graze it is difficult to control the timing and intensity of where they graze, making over grazing more probable. Additionally, if the crop growth is slow the grazing area would need to be increased to maintain herd quality and growth (Muir et al., 2014). For continuous grazing of bovines, the acreage per cow varies depending on the climate, weight of the cow, and length of time the cow will be grazing on the range. For example, if the range is at top efficiency with an average production of three tons of feed per acre, a manager would need 2.6 acres of dry matter per 1,000-pound cow for an entire year (Shelton, 2020). There are many resources that help managers know how many acres are required to feed their herd; but many cattle ranchers have individual knowledge of their respective ranges and of what is required for their particular herd.

Deferred Rotational Grazing

Deferred rotational grazing utilizes more than one pasture and rotates the cattle from one to the other at varying intervals in time. With this method, management can defer grazing during the ideal plant growing periods to properly set seeds to sustain the pasture. This method requires a higher cost for fencing and water than continuous grazing, as the level of effort and intervention for the herd is higher. There is also additional time required for moving and planting the ranges. Despite these disadvantages, this method will improve grazing distribution, plant vigor, and habitat for ground nesting birds (Smart and Bauman, 2021).

Rest Rotational Grazing

The rest rotational grazing system is like the deferred method, except that there is one or more pastures that are not grazed for an entire year. This method maximizes plant recovery and ensures maximum cover for wildlife (Smart and Bauman, 2021). Additionally, this method also reduces the need for artificial fertilizer and reduces feed costs overall. Although this method has many advantages it requires higher costs for fencing and management of the fence, along with a strategic plan for the paddocks (at least five) that maintains enough water resources for the herd during the rotations. Climate is also an important factor when applying this method. For example, this method would look different for northern states where the growing season is shorter and the acres per cow is greater. This method has been used in southern Australia as a holistic grazing method (Badgery, 2017).

Management-Intensive Grazing

A management-intensive grazing method requires the greatest investment, financially and physically. With this method there are smaller paddocks, and the livestock are moved more frequently (Smart & Bauman, 2021). There are five major advantages of this method: (1) daily intake of feed available on the pasture is more efficiently rationed, (2) pasture plants are allowed to recover, (3) pasture yield is increased as the distribution of the forage is improved, (4) cost of machinery is reduced, and (5) animal waste is more consistently distributed (College of Agriculture & Environmental Sciences University of Georgia). To apply this method, it is recommended that there are at least eight paddocks. The cons of this method include additional expenses on fences and water sources; additionally, the cattle are moved every 20 to 40 days depending on the season and climate (Pfost et al., 2000).

It is important to regard grazing as a central part of rangeland management because grazing lands play a prominent role in rangeland conservation. Allowing livestock to sustainably graze on rangelands benefits the enrichment of the soil structure, cover, and organic matter (USDA). Although, if the land is not properly grazed it can not only compromise the soil and plant health but also the health and productivity of the livestock themselves (USDA).

1.2.2 Water Source Use

Some research has found cattle distribution over the grazing area can be linked to one single water source within the land paddock (Lange, 1969). One study found that cattle will travel 2 km to 10 km per day from their focal water source depending on grazing conditions (Hodder & Low, 1987; Granskopp, 2001; Tomkins & O'Reagain, 2007). In a different study from 2004 it was shown that when comparing hill climbing and bottom dwelling cows, they did not appear to regularly associate with each other and would use different water sources (Bailey et al., 2004). The different results in the study may be attributed to the difference in terrain, habitat, and location of water resources studied.

1.2.3 Habitat Use

Examining livestock habitat use allows researchers to link the preferences of cattle to their environment via habitat-use or step-selection functions. These analyses are commonly used to answer questions related to wildlife management and conservation (Fieberg et al., 2010). Technologies, such as Global Positioning System (GPS) collars and remote sensing have made habitat use analyses and step-selection functions possible by collecting location data at exceptionally fine spatial and temporal scales (Kays et al., 2015; Robinson et al., 2020). Habitat-use functions are used to recognize habitat features as relevant to cattle populations. Additionally, the results of these analyses allow researchers to infer ecological needs and limitations, distributions, and advise demographic predictions across space and time (Boyce & McDonald, 1999; Matthiopoulos et al., 2015, 2019).

1.2.4 Effects of Terrain on Habitat Use

Overgrazing has been attributed to an undesirable spatial distribution of livestock (Coughenour, 1991; Bailey & Sims, 1998). Cattle remember food locations and scientists have demonstrated that they associate spatial location with food quality (Bailey et al. 1989b). The terrain of livestock rangeland can constrain and/or increase the availability of foraging land during diet use in cattle. A study from 2014 found that when livestock were on gentle terrain the herd would change their grazing location 70% of the time over the one-to-three-month study period (Bailey et al., 2014). In contrast, cattle with a combination of mountainous and gentle terrain remained at the same feeding site for 42% of the study period or 10 consecutive days (Bailey et al., 2014). Some breeds are found to perform better in rugged topography then other breeds of cattle (Bailey et al., 2001).

1.3 Advancements in Technology for Observing Livestock

Before GPS technologies, researchers followed livestock on horseback or on foot and would periodically record an estimated position (Herbal & Nelson, 1966; Roath & Krueger, 1982; Bailey et al., 2018). Within the last 20 years GPS collars have aided in the study of livestock grazing behaviors. With collars (or ear tags), livestock movement patterns can be monitored on a 24-hour basis and tracking data can answer a variety of space-time questions related to cattle movement, space use, and habitat preferences. For most collar or ear tag location-aware devices, the location and motion information are stored within the tracking devices and cannot be accessed until the end of the monitoring period when these devices are physically retrieved from the animal wearing them (Bailey et al., 2018). The primary limitation to this technique was that GPS collars original cost was approximately $1,500 to $2,000 per collar (Paudel & Anderson et al., 2013). As of 2016, the tracking collars and ear tags range between $150 to $300 (Allan et al., 2013; Knight, 2016). Since 2016 the cost has decreased and there are more options and new developments, such as solar ear tags.

Scientists have used GPS data to monitor livestock for a variety of reasons. One example is livestock researchers using GPS information to observe the behavioral difference in free grazing (Swain et al. 2010). Another scholar looked for the impact of grazing in relation to livestock watering points (Andrew, 1988). Then in 2001 Ganskopp used GPS and GIS to assess the manipulation of cattle distribution with salt and water in large pastures. One study even focused on the development of low-cost GPS collars suitable for large-scale deployment among livestock (Trotter et al., 2009). These are just four examples of how GPS data has been used to track and understand livestock.

1.4 Summary and Structure of Thesis

The intent of this research is to further understanding of livestock habitat use and trajectories during a time of changing pasture vegetation. The present analysis uses similar methods to previous researchers using GPS collars, but instead applies a time-budget during three diurnal periods and one non-diurnal period. In Chapter Two, I explore this idea by using ArcPro geoprocessing tools to uncover the inferred habitat use behavior of cattle, between forest/wooded and prairie/pasture landcover types. Additionally in chapter 2, I look at the time spent within an a 100-meter buffer around the water resources within the rangeland. Chapter Three is an analysis of the trajectory of the cattle and their Euclidean distance from the water sources. The fourth and final chapter includes an extended discussion of research using GPS collars and GIS technologies. The intent is to publish the second and third chapters as two peer-reviewed manuscripts. This research will add to the growing body of literature on the use of GPS technologies in collar or ear-tag form to track livestock, the use of GIS technologies in general, and the use of time-budgets to study livestock behaviors and activity.

Chapter 2: Analysis of Global Positioning Systems to Assess Landcover and Water Use of Beef Cattle in Southcentral Oklahoma

2.1 Abstract

The activities of livestock often center on watering resources within rangeland boundaries in both space and time. Habitat use models can be used to quantify animal-habitat relationships, predict differences in space use, and identify habitat importance. In Oklahoma and Texas, USA, beef cattle production is one of the largest agricultural enterprises. Therefore, understanding the habitat needs and habitat use of beef cattle on native rangeland is crucial to maintaining the industry through proper land management and grazing practices. This study focuses on beef cattle habitat use on a fenced rangeland located in south central Oklahoma. For this study, we focus on habitat data collected during the daytime in the spring season, at a period of changing vegetation and phenology for this study area. The objectives of the study are to determine general habitat use patterns for livestock throughout the day, then determine the herd's main water source use. The results suggest the largest portion of herd groups remain in the prairie and pasture. The available wooded and forest areas have the greatest cattle use during the warmest times of the day while still having less than area overall than prairie and pasture in the study area. Furthermore, the results indicate that herd members have access to man-made water sources more often than open water sources provided within the pasture boundary. The results from the study provide livestock producers with information on daily habitat requirements and water source location preferences for cattle.

Keywords. GPS collar, beef cattle, habitat use, rangeland management, spatial distribution

2.2 Introduction

As an intensive agricultural practice, there have been cattle grazing rangeland in the United States for over 125 years (United States Senate 1936; Roath & Krueger, 2022). Since then, cattle managers began fencing and restricting the livestock to concentrate grazing on key vegetation while other areas were left under grazed (Roath & Krueger, 2022). An important aspect of a rangeland manager's responsibilities is to reduce overgrazing. Overgrazing is when the grazing pressure exceeds the capacity of the pasture. Continuous grazing lets the livestock selectively graze the most appetizing plants repeatedly, not allowing the plant to regrow before grazing again (Rinehart, 2008). Understanding the time spent, behaviors, and habitats selected by livestock can provide range managers with more information to help develop a monitoring and evaluation plan (Montana, DNRC, 1999; Rinehart, 2008).

In the past few decades, automatic recording devices have been used as an alternative to human observations (Langbein et al., 1996). Advancements in global positioning systems (GPS) technology have led to new methods of analysis for the behavior and movements of cattle. For example, this technology allows for a collar around the neck of an individual to track movement (Gordon, 1995; Frost et al., 1997; Bradshaw et al., 1995; Roath & Krueger, 2022). Additionally, new methods in reducing GPS error and related technological advancements have enabled researchers to use these collars for the purpose of tracking herd movements (Adrados *et al*. 2002; Frair *et al*. 2004; Rutter et al., 1997; Schlecht et al., 2006, Tomkiewicz*et al*. 2010). Given the need to conserve and use rangelands in a sustainable way, these advancements can be used to evaluate land use practices of cattle at finer spatial and temporal scales than previously possible (Akasbi et al., 2012).

Vegetation and land-use classification are common methods of identifying habitat types for a given region (Bailey et al., 1978; Gauch, 1982; Bailey, 1996; Hoagland, 2000). The Oklahoma Wildlife Conservation group found 166 landcover types across 77 counties in Oklahoma, with approximately 29 million acres of herbaceous land that would be suitable for cattle grazing. Despite the prevalence of cattle ranches in Oklahoma there are relatively few studies that have focused on the habitat use of cattle in this region. Two habitat types of concern for cattle access are grazing pastures and water sources. Cattle prefer areas that offer the greatest rate of digestible energy and crude proteins, such as prairie grass, while avoiding areas far from water (Pinchak et al. 1991). Cattle grazing distribution often surrounds a single water point (Lange, 1969) but individuals can travel up to 2 km to 10 km per day from this water source (Hodder & Low, 1978; Ganskopp, 2001; Tomkins & O'Reagain, 2007). An understanding of beef cattle grazing patterns and water use on Oklahoma rangeland can provide cattle managers better decision-making tools that consider livestock habitat use, including how these preferences may impact the surrounding vegetation (Rutter, 2007; Akasbi et al., 2012). Specifically, this study highlights how GPS collars can be used to determine habitat use of cattle throughout the day, including the water source preference.

2.3 Methods

2.3.1 Study Area and Data

This study was conducted on a 4,499-acre fenced rangeland located in south central Oklahoma. Using a landcover dataset from Oklahoma Wildlife Conservation, 21 cover types were identified within the boundary of the rangeland, including 4 man-made water sources, and 11 natural water sources. These 21 landcover types were consolidated into three individual classes to distinguish between potential grazing and resting areas, and water sources. These classes are woodland/forest (n= 2,235 acres), prairie/pasture (n= 2,221 acres), and open water (n= 10 acres). The remaining 33 acres excluded from the analysis were barren and urban low intensity.

Cattle movement data was collected by the Noble Research Institute on the Oswalt Ranch. GPS collars were placed on 19 different herd members depending on the year. The collars collected location information for an individual animal every hour for a total of 60 days between March 1st to April 30th for the season, over a period of three years (2018-2020). The 2018 tracked individuals of the herd included 5 heifers, in 2019 included 7 cows, and in 2020 tracked 7 cows, totaling 19 beef cattle movement datasets used for this study. The difference in designation is noted here as a heifer is a female cow that has not had any offspring and a cow has given birth to at least one calf. The distinction is thought to impact the animals' behavior and therefore amounted to a stratification of the sampled herd.

2.3.2 Data Analysis

The data was analyzed using ArcPro 3.0.2 (ArcPro v. 3.0.2, ESRI, Inc). An activity budget was constructed using the cattle and landcover dataset over the course of a 24-hour period (1 day). Each 24-hour day was divided into four periods following the morning-afternoon-evening-night approach used by Downs et. al. (2017). An equal number of points (4400) were grouped into each of the four periods utilizing a total of 17,600 points for the herd. Three daytime periods included includes points captured between morning (7:00am-10:00am), afternoon (11:00am-2:00pm), and evening (3:00pm-7:00pm). One nighttime period included points captured between the hours of 8:00pm-11:00pm. The hours between 2300 and 0600 were excluded to focus on mostly diurnal periods like Downs et al. (2017).

The first objective was to establish an activity budget for how the tracked cattle used different habitat types throughout the day. To determine the percentage time spent in each habitat type, points were grouped based on the four time periods described above, and associated with a given type if the point was completely within the cover type. Results were summarized into a total percentage based on the number of cover types selected.

The second objective was to identify an expectation for distance between cattle and the herd's main water sources over time. A 100-meter buffer was created around 15 natural and man-made water sources within the ranch and sorted by location. The man-made water troughs and natural open water sources buffers were numbered separately to distinguish between the two. Next, the subset of cattle location points for each diurnal period were associated with a water source if they fell completely within the buffer boundaries; these were considered 'at' that water source, following a method similar to Frank et al. (2012). Next, the herd member locations that fell completely within the boundaries for each day overall were selected and associated. The results were summarized by the frequency of the water source use during the two months of data collected at the specified time segment. The maps in Figure 1 illustrate the locations of both types of water sources and the numbering scheme that was used in the analysis of the results.

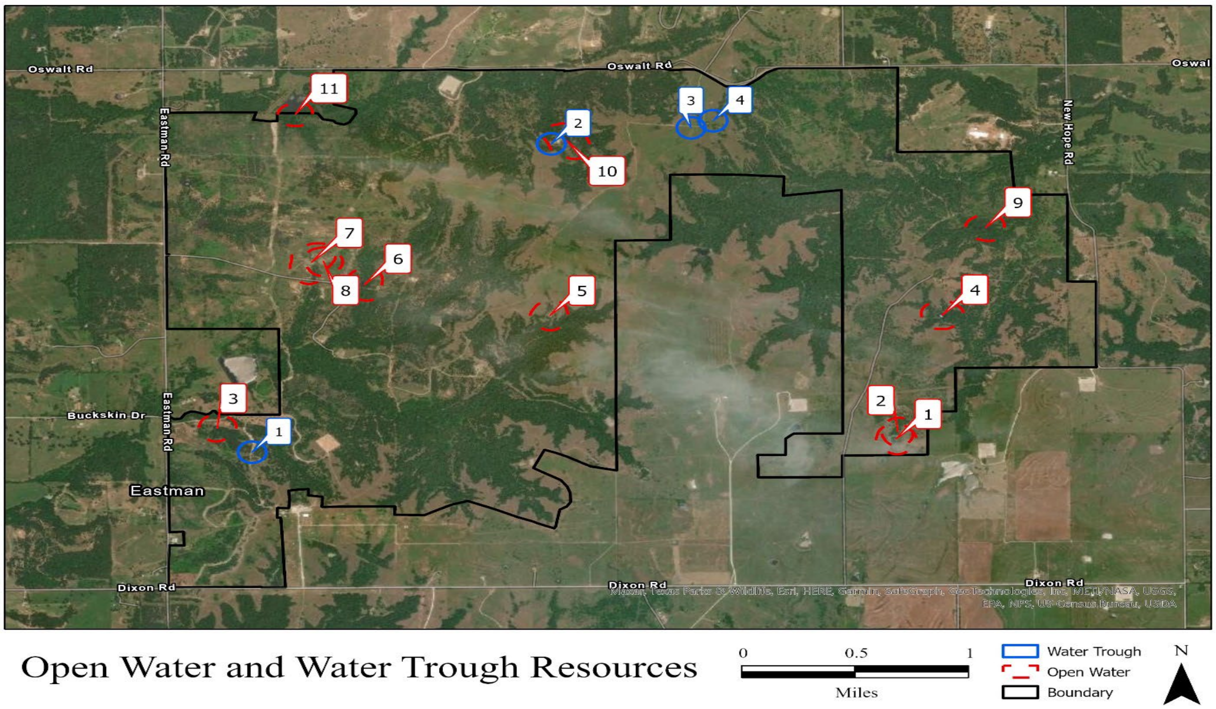


Figure 1. This map displays the open water sources (n= 11) in red and the water troughs (n= 4) in blue with a 100-meter buffer within the 4,499-acre study area. Each water source is numbered to better recognize the source.

2.4 Results

2.4.1 Habitat Use

Prairie and Pasture. To infer the percentage of habitat use the points within the land cover type divided by 4,400 (points per period) multiplied by 100. The analysis considered (n= 3,875) herd member relocations, or GPS capture points, within pasture/prairie during the morning period. Within the afternoon periods there were (n= 3,698) heifers and cows' locations available. The evening period found (n= 3,683) cattle, and night included (n= 3,961). The percentage of each subset in the overall dataset was as follows: morning (n= 22.01%) afternoon (n= 21.01%), evening (n= 20.93%), and night (n= 22.51%).

Wood and Forest. There were (n= 304) GPS points found within the boundary of wood and forest cover during the morning. During the afternoon (n= 449) cows and heifers were within the shaded forest cover boundary, and (n= 474) were found in forest during the evening. The night periods found (n= 245) herd members within the boundary. The percentage of available relocations in wood and forest was (n= 1.73%) during morning, (n= 2.55%) throughout afternoon, (n= 2.69%) within evening, and (n= 1.39%) for the night.

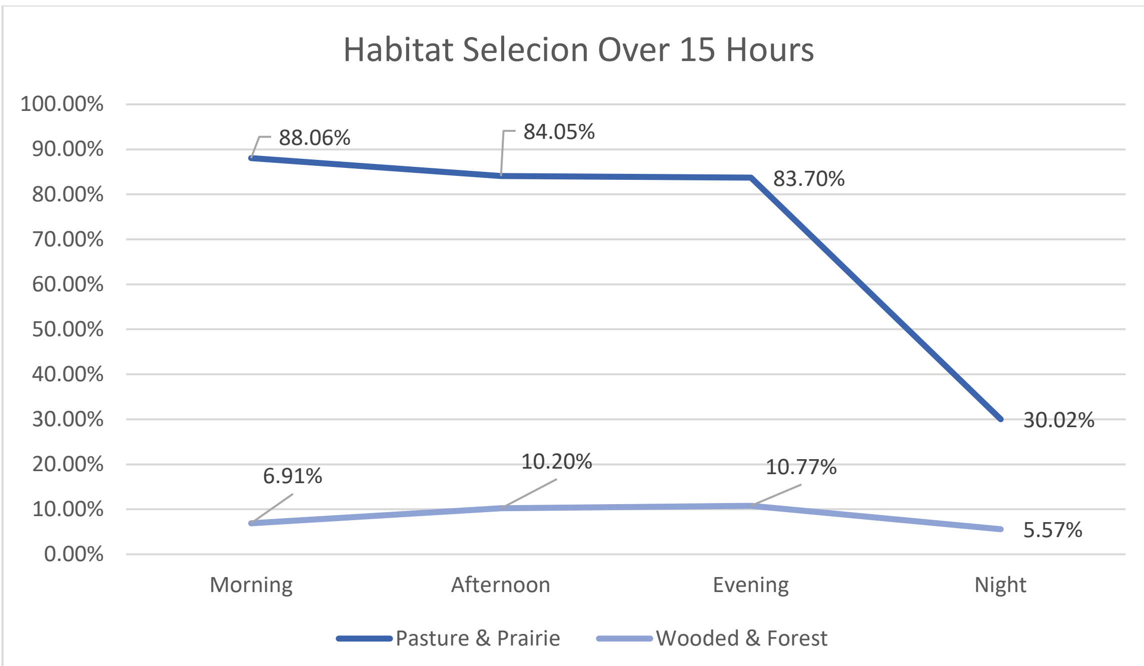


Figure 2. Habitat Use of cattle during study period in percent. Percent was calculated by taking points within land cover type divided by 17,600 (total points) multiplied by 100. These results were completely within the boundaries of either pasture and prairie or wooded and forest.

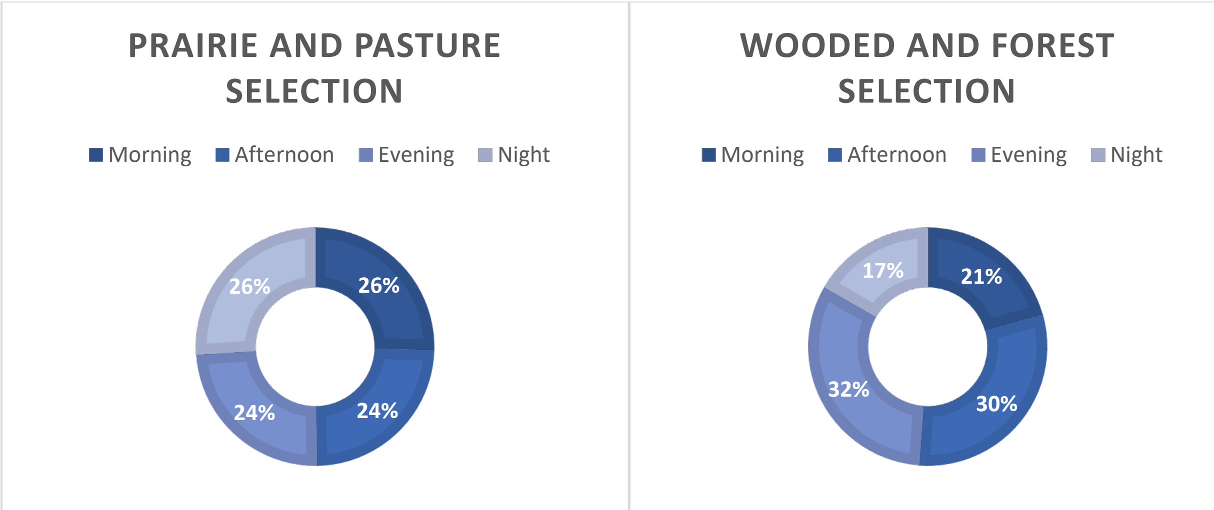


Figure 3. Habitat use of cattle during study period in percentage.

The study area included a total of 4,499 acres with two landcover types. The first landcover type in comparison was prairie and pasture and covered approximately 2,221 acres; and the wooded and forest covered 2,235 acres. The two areas had a 14-acre difference with the wooded and forest covering more.

2.4.2 Distance to Water Source

From 0700 to 1000 there were a total of (n= 49) animal relocations or visits within the open water buffer and (n= 229) herd members inside the water trough buffer. They occupied nine of the 15 water sources within the study area over the course of observation. There were three water troughs that had cattle within the 100-meter buffer. WT one (n= 1) herd member, WT three (n= 138) and WT four (n= 95). There are (n= 5) herd members that are within both WT three and WT four boundary.

There were seven OW boundaries occupied during the morning. In OW five the group size was (n= 11), and in OW six the size was (n= 9). The largest occupation was within OW seven with a group size of (n= 24); and in OW eight there were (n= 7). The last two were drastically smaller with (n= 3) in OW ten and (n= 1) in OW eleven. There are (n= 6) herd members that were found within both OW seven and OW eight boundaries.

From 1100 to 1400 three of the four water troughs were visited. WT one had (n= 1) visit within the boundary. The second WT had (n= 5) cattle within the boundary and WT four included (n= 121) cows and heifers' occurrences. There was a total of (n= 299) water trough visits over the two months period.

There were six open water sources visited during the afternoon over the two months of observation. The third OW source had (n= 1) visit, and the fifth OW supply included (n= 63) official visits. OW six had (n= 5) cows and heifers; and OW seven clocked (n= 12) visits. The remaining two OW supplies were OW eight with (n= 4) and OW 10 had (n= 14) herd members; and a total of (n= 97) open water trips within the boundary. Additionally, there was an overlap of two cows within the boundaries of OW seven and eight.

During the evening there were (n= 6) participants who visited WT two and (n= 131) went to WT three. There were (n= 58) cows and heifers within the fourth WT during the two-month study period. The total WT visits was (n= 191) with (n= 4) cows overlapping within the third and fourth water trough boundaries.

The open water resources had a total of (n= 105) visits over the 61 days of observation. OW one had (n= 3) trips and OW two had (n= 3). The fifth OW boundary had (n= 42) and OW six included (n= 14). The seventh OW saw (n= 18) and OW eight included (n= 8). The ninth OW had (n= 2), OW ten had (n= 19), and the eleventh OW had (n= 3). There was a seven-member overlap in terms of individual animals transiting multiple water sources.

The night had a total of (n= 40) water trough visits. WT three had (n= 25) cattle within the boundary. WT four had (n= 15) cows and heifers within its boundary. This daybreak had zero overlap within the boundaries.

The open water resources had a total of (n= 21) cattle visits during the fourth period. The fifth and sixth OW source had (n= 4) members visit them. OW seven had the most visits during the daybreak with (n= 12) members; and OW eight and eleven each had (n= 1) member within the boundary. There was a one-member overlap among these open water sources during this period.

Man-made vs Natural Water Source Use

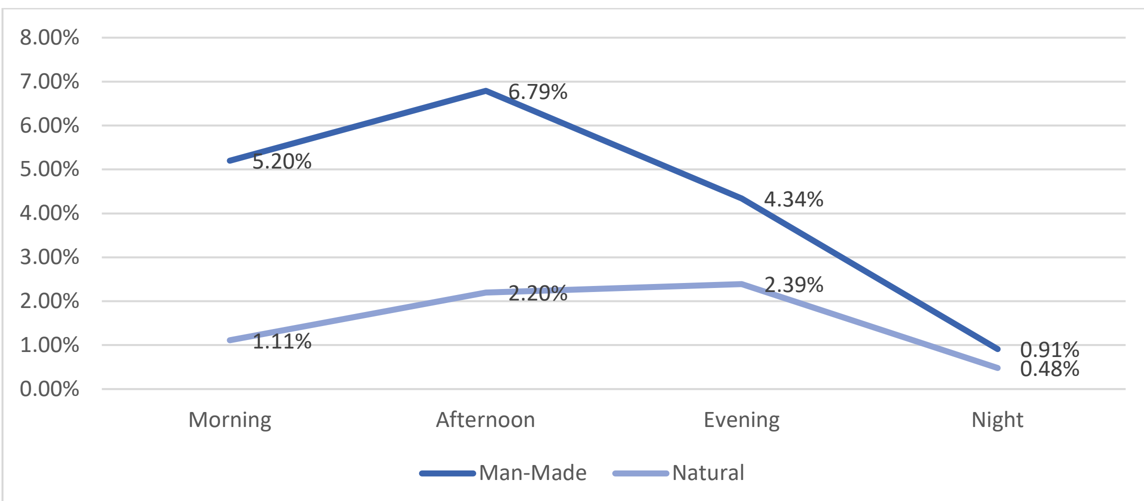


Figure 4. Water source use of cattle during study period in percentage. Percent was calculated by dividing points found within 100-meter water buffer and divided by 17,600 (total points) then multiplied by 100.

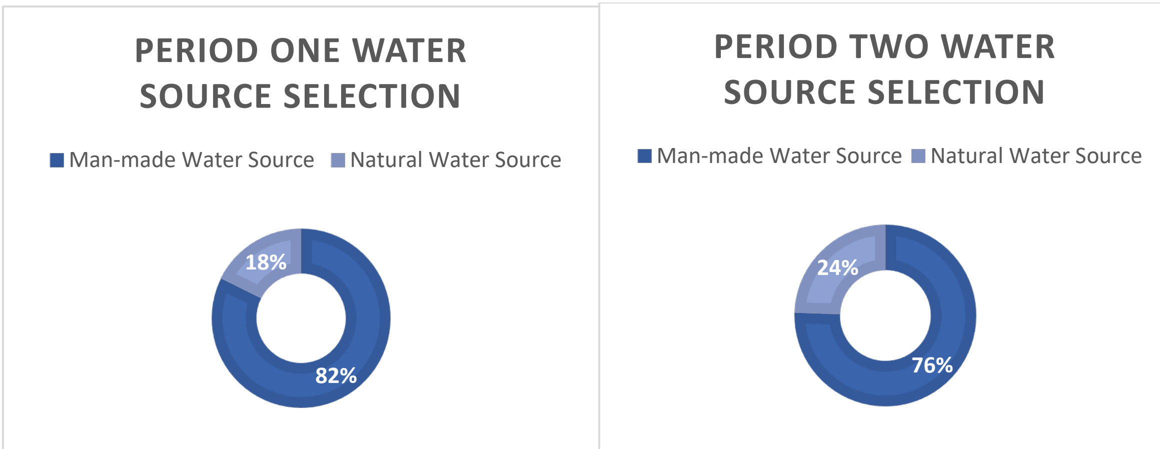
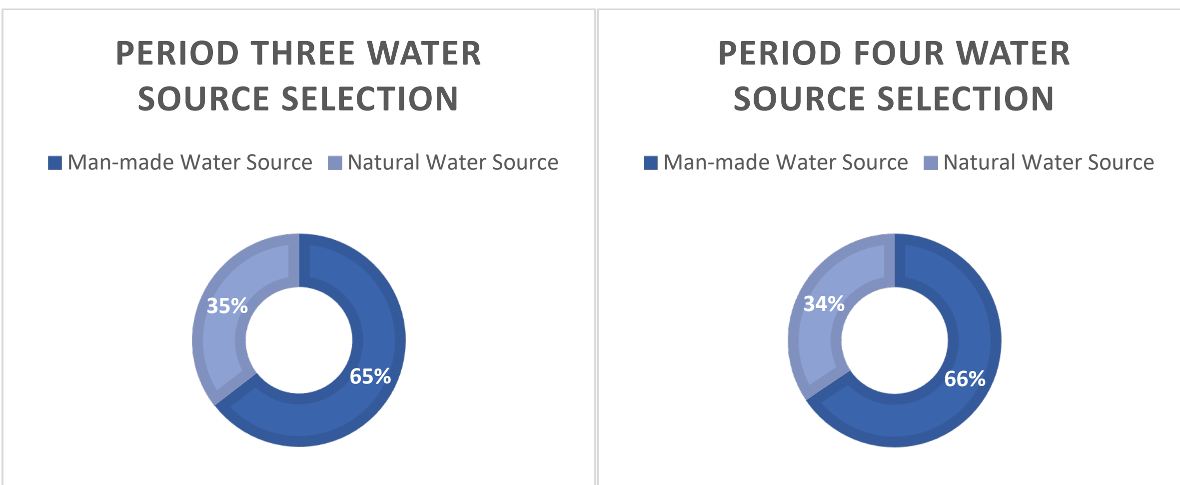


Figure 5. Morning and afternoon water source use comparison in percentage. Percent is calculated by dividing the total points found within buffer and divided by 4,400 (total points per period) and multiplied by 100.



Figures 6. Evening and night water source use comparison in percentage. Percent is calculated by dividing the total points found within buffer and divided by 4,400 (total points per period) and multiplied by 100.

2.4.3 Overall Water Source Use

There was a total of four man-made water sources within the study area boundary. The first WT (water trough) was only visited a total of (n= 2) times during the two months of observation. The second water trough had slightly more with (n= 11) visits over the 61 days of herd observation. Water trough three was visited the most with (n= 294) cows and heifers found within the 100-meter boundary; and WT four had (n= 289) herd members captured via GPS within the boundary.

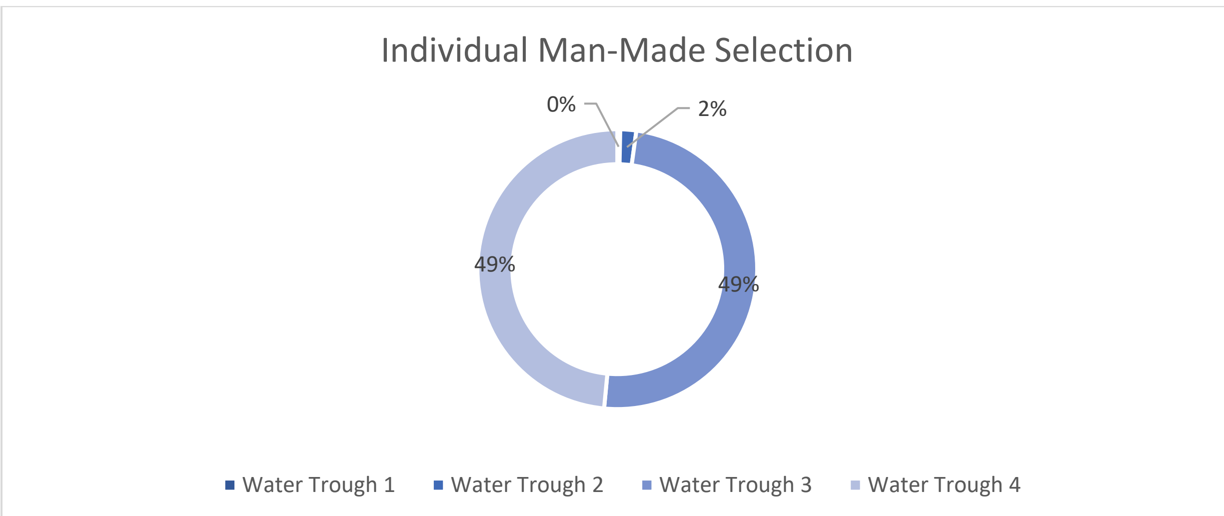


Figure 7. Man-made water source use for location preference within the rangeland boundary. Percent was calculated by dividing the points within water trough buffer divided by total points found within them overall (n= 589) and multiplied by 100.

There were 11 natural water sources within the boundary. The first and second OW buffer each had (n= 3) visitors. The third OW buffer had (n= 1) visit and the fourth OW buffer had (n= 0) cattle enter the buffer during the period the herd was observed. The fifth OW buffer had the most visits with (n= 120) GPS captures falling within the buffer. Open water boundary six had (n= 32) cows and heifers within, and OW seven had (n= 66). With OW eight (n= 27) cattle and OW nine had (n= 2) within the buffer. The last two buffers showed OW 10 with (n= 36) and OW 11 with (n= 5) GPS captures within their buffer areas.

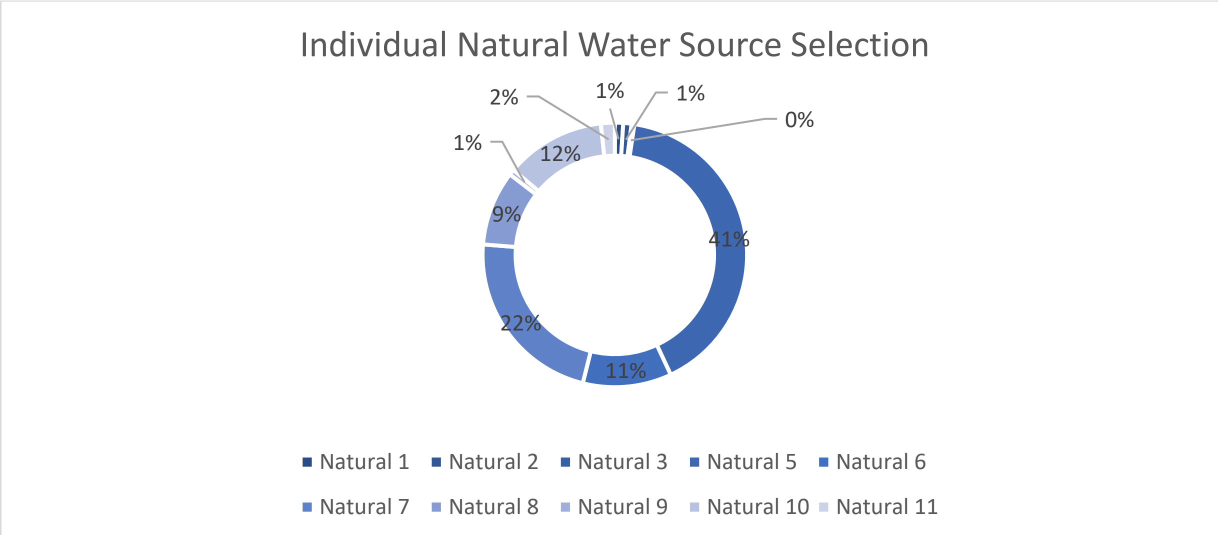


Figure 8. Natural water source use for location preference within the rangeland boundary. Percent visitation was calculated by dividing the points within pond buffer divided by total points found within them overall (n= 295) and multiplied by 100.

2.5 Discussion

The current study included two objectives. The first objective was to determine the respective shares of habitat use by cover type, according to the current time budget. Central to this approach is the understanding that visit frequency, as observed in GPS trajectories or relocation data, is an indication of animal habitat preference. More animal presences translate to higher preference for a given cover type or landscape feature. The pre-determined time budget was based on Downs et al. (2017) habitat use analysis of Muscovy Ducks. The second objective determined the herd's main water source use according to visitations found within a 100-meter buffer around water sources. The methods employed to meet these objectives were based on the Frank et al. (2012)

approach. The time budget was set at four three-hour time periods from 0700 to 2200, for days occurring during the months of March and April. These months were chosen because they correlate with a time of changing vegetation and phenology in the study area. Using the ArcGIS Pro software, the approximate habitat and water use information observed during the time budget was analyzed. The empirical evidence gathered in this study highlights the times when herbaceous or non-herbaceous vegetation cover was most likely used by cattle and the importance of water source location during observed months in context with average temperature.

According to the Mesonet Climatological Data summary the average maximum temperatures during the months of March and April in Ardmore, Oklahoma is between 66- and 72-degrees Fahrenheit during the three-year period of observation. The average low temperatures ranged from 45- and 48 degrees Fahrenheit. Corresponding to Mesonet's *cattle comfort index*, the cattle are most comfortable at temperatures ranging from 15 to 85 degrees Fahrenheit. According to both Mesonet resources the cows were at maximum comfort during and there was no cause for weather-related adjustment in observed preference during the study period.

During the months of March and April the sun rises between 0700 and 0730 and sets between 1825 and 1951 (timeanddate.com). The results suggest the herd spent 24 percent of their overall time in both morning periods and 26 percent in corresponding evening periods from 1500 to 2200. Although the time spent between these divisions only has a two percent difference in magnitude, the results imply that more of the herd members may be grazing later in the day as temperatures cool down.

The results of the wooded and forest use varied slightly more. The findings imply that the herd is within the shaded area during the warmer times of the day. According to the results the heifers and cows were within the wooded and forest area the most from 1100 to 1800. This further implies the herd is returning to grazing often at 25-minutes before sunset in March and nearly two hours before it sets in April. The results of this study are consistent with Tomkins and O'Reagain (2007) landscape preferences of cattle. In the 2007 study, the Authors' findings confirmed that the cattle use proportion was 0.55 (count of animal locations per land-type/total count) within cleared pastures (Tomkins & O'Reagain, 2007); and the wooded areas were used approximately 23 percent of the time for their study area and herd.

The second objective of this study was focused on understanding water source use. Watering distance is optimal for cattle where travel up to 4,000-meters from water (Lange, 1969) appears acceptable. A 100-meter buffer was applied, and individuals were considered 'at' water when within the buffer (Frank et al. 2012). Overall, the results found the cows and heifers 'at' a water source the most during afternoon (n= 396) and evening (n= 296). These results suggest that the cattle would choose a water source within or near a wooded or forest area when at the water source during afternoon and evening.

Within the study boundary there were (n= 11) natural water sources and (n= 4) man-made water sources. The water sources were individually numbered to see if there was an area or water source that was selected the most. Water troughs one and two are mostly within a forest and wooded area, whereas water troughs four and three are within the prairie and pastureland cover type, respectively. Senft et al. (1985) found that resting often happened near the water tanks during the mid-morning hours. Every natural water source is mostly within the wooded/forest cover found in the study area, except for ponds seven and eight. According to the results the overall water source preference of the herd centered on the four man-made options during each period. The cows and heifers choose the man-made option over 60 percent of the time for every period studied. The results showed that the top two man-made sources were number three with (n= 294) and WT four (n= 289) in terms of overall visits during the study period. Both water troughs are within the Northeast area of the boundary, additionally, the 100-meter buffer boundaries of these water sources overlap. The water troughs are within the prairie and pasture vegetation type.

The natural water sources that had the most visits within the boundary were number five (n= 120) and OW seven (n= 66). Open water seven is mostly within the prairie and pasture type and was visited the most during evening periods. OW 7 is located near the western extent of the study area. The most visited water source was visited during periods two and three and is mostly within the forest and wooded area. This source is located southeast of the second most visited natural water source. Tomkins and O'Reagain (2007) noted that cattle drank primarily at a man-made source during times of dawn or dusk but would not return for approximately three days. It is their assumption that their herd was utilizing natural water sources during those interim days. Although the results of this study do not look to identify specific days the water source was used; this point could account for the use of the natural water sources within the present period of study.

This study was subject to several limitations. The reliance on the information available from the GPS points assert limits upon which variables could be adequately measured. For example, GPS receivers are subject to a range of signal disturbances, some of which are independent of the study area's cover or topography, including cloud cover or the presence of magnetic or thunderstorms. This study referenced a sample of points related to the location of nineteen beef cattle on rangeland in southcentral Oklahoma for a short period of time. Future research may reference other seasons with more extreme temperatures or expand the period of observation overall. Alternative methodological approaches, including ones based on group sizes (Frank et al., 2012) might serve future efforts as well. Additionally, a larger buffer of 4,000 meters would add additional information for optimal grazing (Lange, 1969). Although limited in scope, the results from this study can guide livestock producers on habitat and water choices of beef cattle. Lastly, additional analysis to test significance should be conducted. One test in consideration would be the one-way ANOVA statistical test. The ANOVA analysis will require an individual comparison rather than the group analysis that was conducted for this study.

2.6 Conclusion

This study demonstrates the importance of habitat and water location for cattle. Objective one looked to characterize habitat use during each daybreak between prairie and pasture or wooded and forest. The results imply that the herd was consistently within the prairie and pasture; but the use of prairie or pasture cover slightly increased at the later hours of the day. The findings also suggest that most of the herd chose to be within the wooded and forest, more shaded areas, during the warmer times of the day from 1100 to 1800. The second objective looked to identify the water source use preference of the herd. The end results indicate that the man-made water sources in the northern portion of the boundary was the most visited option. These findings are consistent with similar studies using GPS collars and habitat use. This study demonstrated not only the potential of data collected by GPS collars but the importance of water source location for grazing purposes.

Chapter 3: Trajectories of Beef Cattle on Rangeland in Southcentral Oklahoma

3.1 Abstract

The production of beef cattle is among the largest agricultural enterprises in the United States, especially for operations in Oklahoma and Texas, USA. It is important that managers of beef cattle enterprises obtain as much information about their product as possible, towards better business practices, sustainability, and compliance outcomes. The present study seeks to inform livestock managers on the daily movement trajectories and proximity to water of beef cattle, operationalized using GPS, geographic information systems (GIS), and ArcPy. The objectives of this study are to highlight how data collected by GPS collars can be used to determine (i) the average characteristics of cattle trajectories (average distance, elapsed time, and velocity between GPS captures) and (ii) the average Euclidean distance from water sources within the rangeland. The study focuses on (n= 19) beef cattle observed in March and April (a period of changing vegetation cover/phenology) during 2018, 2019, and 2020. Data collected include times diurnal (0700-1800) and nocturnal (1900-2200). Esri ArcPro 3.0.2 and Python were used in determining the average characteristics of trajectories stratified to four daily periods: morning (0700 – 0900), afternoon (1000 – 1200), evening (1300 – 1500), and night (1600 – 1800). The results corresponding to objective (i) above suggest that average distance traveled is consistent during the diurnal periods but decreases by roughly half upon sunset. The second (ii) objective's results revealed that during a three-hour daily span, the average distance from cattle to water supplies ranged from (n= 0.33) miles to (n= 0.38) miles. This study offers information useful in the guidance of livestock producers, where summary measures taken from trajectories of cattle

representing different segments of the day provide information for grazing plans and water source placements in the rangeland.

Keywords. Time geography, GPS collar, cattle-management, ArcPro

3.2 Introduction

The extensive rangelands in North America are diverse in both the quality and efficiency of forage. The presence of large rangelands having limited quantity of man-made and natural water sources propagates uneven grazing patterns. Information describing cattle foraging behaviors allow livestock managers to better predict how cattle will respond to spatial variability in forage and water supply. Additionally, this information assists in understanding how the configuration of geographic features in rangelands modify cattle foraging preferences (Turner et al, 2000; O'Reagain, 2001; Baily, 2005; and Tomkins & O'Reagain, 2007).

Automatic, location-aware recording devices have been observing animal movements for over 20 years (Langbein et al., 1996). This is enabled foremost with global positioning systems (GPS) technology, where camera traps, radio telemetry and field surveys represent other means for data capture. Animal-mounted GPS technology saw significant, practical developments in the 1990s resulting in the collar-mounted GPS tracking used by researchers today (Gordon, 1995; Frost et al., 1997; Bradshaw et al., 1995; Roath & Krueger, 2022). Since 2000, the positioning error of the GPS collars data has improved from roughly ~30 to ~4 m decline due in part to the cancellation of Selective Availability constraints enforced at the system level (Adrados et al., 2002; Frank et al., 2004; Tomkiewiczet et al., 2010, Akabaski et al., 2012). Since these and other important developments, more scholars have applied similar location-aware techniques for their research examining subject matter such as cattle (Turner et al. 2000), moose (Moen et al. 1996), white-tailed deer (Coulombe et al. 2006), red deer (Adrados et al. 2003), and Japanese black bears (Yamazaki et al. 2008).

Trajectory datasets capture movement as a sequence of time-stamped locations (Ahearn et al., 2017; Long, Dodge & Laube, 2018; Loraamm et al., 2020). Time-geographic studies have been proven relevant in multiple disciplines; but most importantly for the present study, Time-geographic contributions have yielded a clearer understanding of animal interactions and habitat use (Downs et al., 2014; Loraamm et al., 2014; Loraamm et al., 2020). With respect to computer implementations for constructing and leveraging the otherwise conceptual elements of Time-geography, PySTPrism presents a GIS toolbox generates the trajectory datasets (Loraamm et al., 2020).

Cattle roam around the rangeland to graze, hydrate, and rest. Studies have shown that slope often affects or otherwise influences cattle trajectories and water usage (Roath & Krueger, 1982). The location of water has also been identified as a crucial determinant of grazing distribution in large enclosures (Ganskopp, 2001). Further, cattle often select grazing that offers the highest intake rate of edible energy and crude proteins, which may correlate with the presence of water sources (Pinchak et al., 1991). Spatial distributions for observed grazing behaviors have been linked to single water points (Lange, 1969) where cattle may routinely travel 2 to 10 kilometers per day from the water source (Hodder and Low, 1978; Ganskopp, 2011; and Tomkins & O'Reagain, 2007).

The objectives of this study are to highlight how data collected by GPS collars affixed to cattle can be used to determine (i) the average distance traveled (miles) during each time period and (ii) the average Euclidean distance from water sources within the rangeland. Each analysis study period uses a predetermined time budget comprised of four three-hour time segments (three diurnal and one nocturnal). The study area is in south-central Oklahoma, collar data was collected during the months of March and April in 2018, 2019, and 2020.

3.3 Methods

3.3.1 Study Area

This study entailed a 4,499-acre fenced study area located in south central Oklahoma. Within the boundary were (n = 4) man-made water sources, and (n = 11) natural water sources. This study uses a landcover classification dataset created by the Oklahoma State Wildlife Biologist and other natural resource professionals made available on the Oklahoma Department of Wildlife Conservation website. The original dataset indicated (n = 166) different land cover types; where (n = 21) cover types occur in the study area, including open water. The available landcover types were further condensed into three individual units: woodland/forest (n= 2,235 acres), prairie/pasture (n= 2,221 acres), and open water (n= 10 acres). The remaining 33 acres of the study area were excluded from the analysis as these were of barren and urban low intensity cover types.

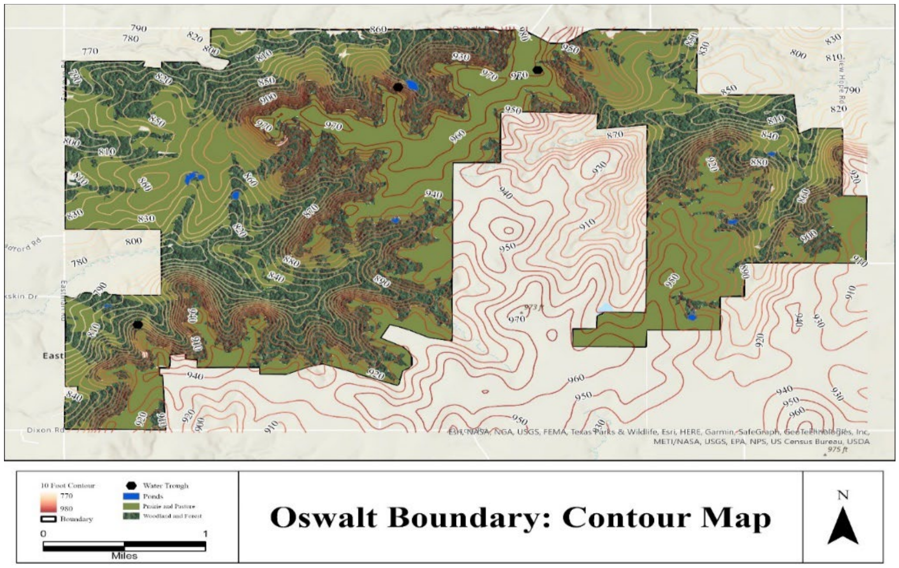


Figure 9. Oswalt Ranch Boundary with 10-foot contours lines. The DEM was collected in 2018 and downloaded from the USGS Lidar Explorer and converted to contour lines using ArcPro.

3.3.2 Study Phase

Data for the present research was collected by the Noble Research Institute at their Oswalt Ranch in Oklahoma, USA. GPS collars were placed on different herd members depending on the year; each collar collected coordinates every hour. Overall collection intervals for these herds ranged from March 1st to April 30th in the years 2018, 2019 and 2020. The 2018 herd included (n= 5) heifers, the 2019 herd included (n= 7) cows, and the 2020 herd had (n= 7) cows. For the purposes of this study a heifer is a female cow that has not had any offspring and a cow is a female which has given birth to at least one calf in its life history. The methodology employed for the present study examines all three different herds as a group totaling (n= 19) beef cattle, for all years collected. An activity budget set for this study divides the dataset into three diurnal and one nocturnal period. The budget periods are as follows: morning (0700 – 1000), afternoon (1100 – 1400), evening (1500 – 1800) and night (1900 – 2200). The time budget selected was based primarily on information first presented in Downs et al. (2017) as a diurnal time budget. Table 1 identifies the GPS collar observation counts for each of the budgeted daybreak(s).

Table 1. Four Observations per Time Budget Period

Day Breaks	Total Points
Morning (0700 – 1000)	4,400
Afternoon (1100 – 1400)	4,400
Evening (1500 – 1800)	4,400
Night (1900 – 2200)	4,400
Total	**17,600**

3.3.3 Data Analysis

The data for this study were organized and visualized using tools available in ESRI ArcGIS Pro 3.0.2 and Jupyter Notebook. The analysis approach satisfying objective one used the PySTPrism geoprocessing tool for ArcGIS Pro developed by (Loraamm, et al 2020). Data pre-processing functionality present in this toolbox allowed for the generation of Trajectory datasets from ordered collections of GPS locations. Here, the PySTPrism toolbox enables calculation of the displacement between GPS observations in terms of time elapsed and distance traveled. Computer codes reproducing the PySTPrism toolbox are available on the GitHub social coding platform and were applied to individual heifers and cows' trajectories, each of which were preprocessed for alignment or labeling on the time axis using Python standard library functionality in Jupyter Notebook. The average distance traveled among relocations for all individual trajectories was converted to miles and the overall average distance traveled was calculated.

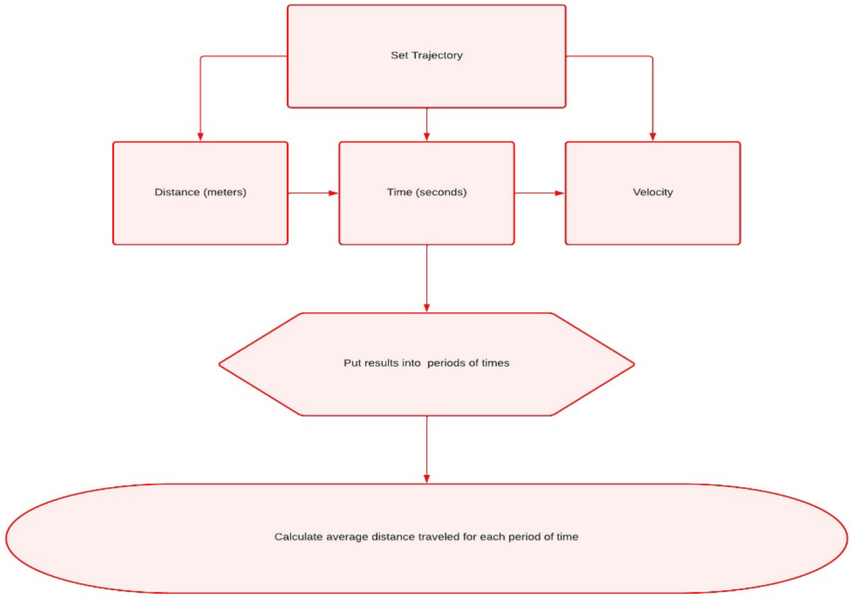


Figure 10. Methods flow chart art for objective one. This flow chart is a simplified explanation on how objective one was found once the trajectories were calculated using the PySTPrism toolbox.

Analysis satisfying the second objective calculated the distance of each relocation in the input trajectories to their nearest water feature for each time budget. For this study, cattle were observed drinking from both natural (ponds, creeks) and man-made (troughs, etc.) water sources. A similar approach established the nearest distance between herd members for each time budget, or the average minimum distance from one animal to another. Similar approaches engaging with animal proximities in space and time appear in studies such as Dudhat et al.'s (2022) analysis of marine mammals standing hotspots along Indian coastlines. Distances were specified in meters, with additional attribution in the results identifying the nearest water source type. Next, conversions were applied to report results in terms of miles

3.4 Results

3.4.1 Objective One

Objective (i) one determines the average distance traveled during animal relocations over each respective time budget period. The average distance traveled was (n= 0.17) miles during the morning of the study days. The second period found that the herd was traveling approximately (n= 0.15) miles on average during the afternoon, and (n= 0.16) miles during the evening period. These averages are based on hourly relocations collected by GPS collars for each time budget period. Lastly, the cows and heifers average travel distance was (n= 0.09) from the hours of 1900 to 2200 (Figure 1).

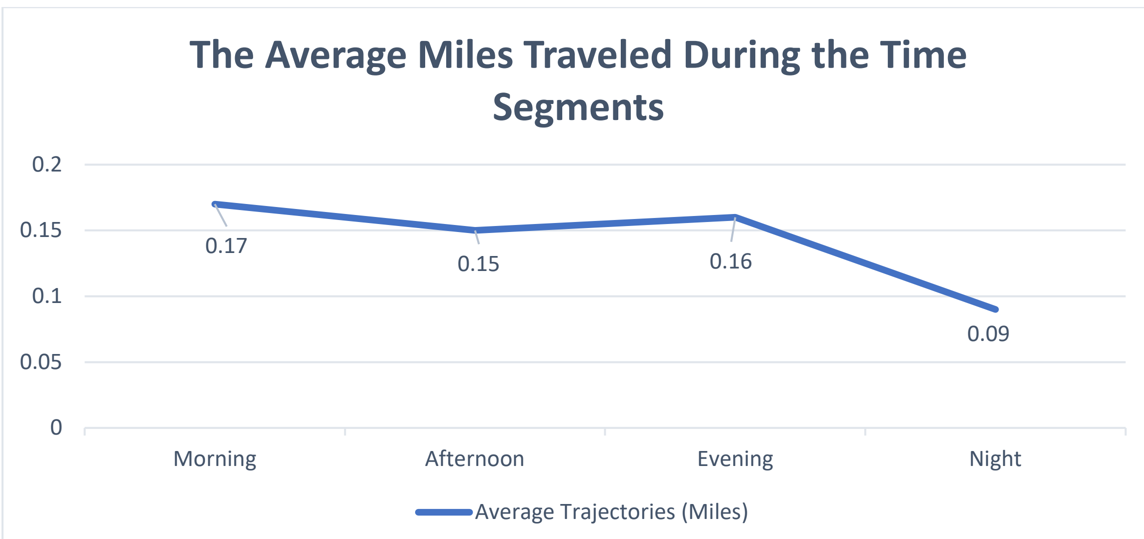


Figure 11. Average Animal Relocation Distance by Time Budget Period (miles). The y-axis is the miles traveled whereas the x-axis shows the four different periods in comparison. The average was calculated by dividing the total miles traveled during the specified time segment by 4,400 (the total points during each time segment).

In addition to reviewing the average miles traveled during the study period, a breakdown of the minimum (Figure 13), maximum (Figure 14), and total (Figure 15) miles traveled was considered. The minimum miles traveled during the morning was (n= 0.000378) miles. Then in the afternoon one cow traveled (n= 0.000372) miles, and in the evening (n= 0.000469) miles. Lastly, in the night the minimum miles traveled was (n= 0.000372).

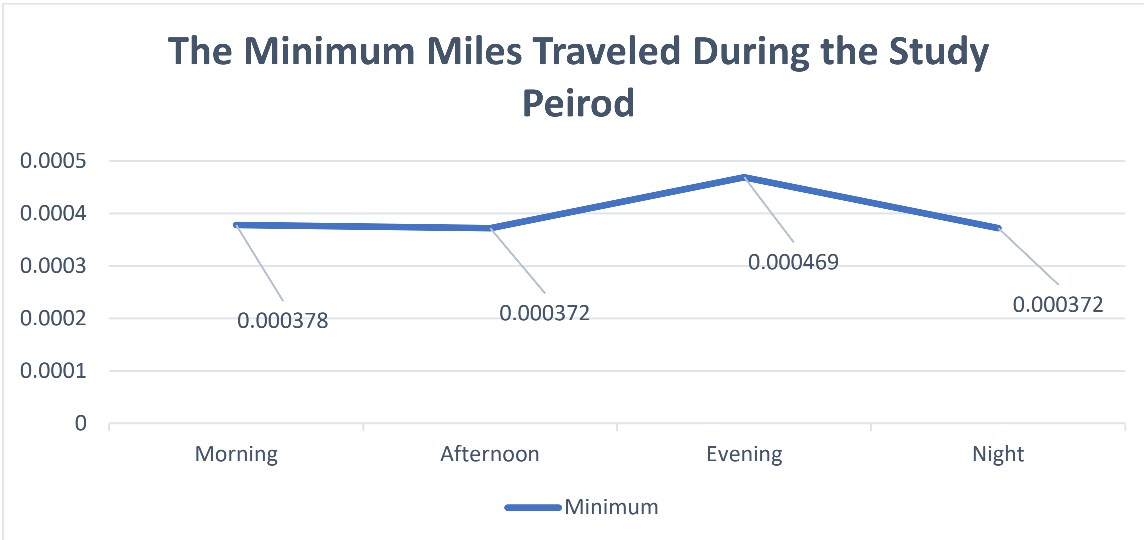


Figure 12. Minimum miles traveled during each time segment by one of the 19 herd members within the study. The y-axis is the in miles traveled and the x-axis is the time focused time segments.

The maximum distance traveled during the study period in the morning was (n= 4.22) miles. In the afternoon the maximum distance traveled was (n= 2.11) miles. Then in the evening the maximum distance traveled was (n= 7.05) miles, whereas during the night the maximum distance was (n= 1.43) miles.

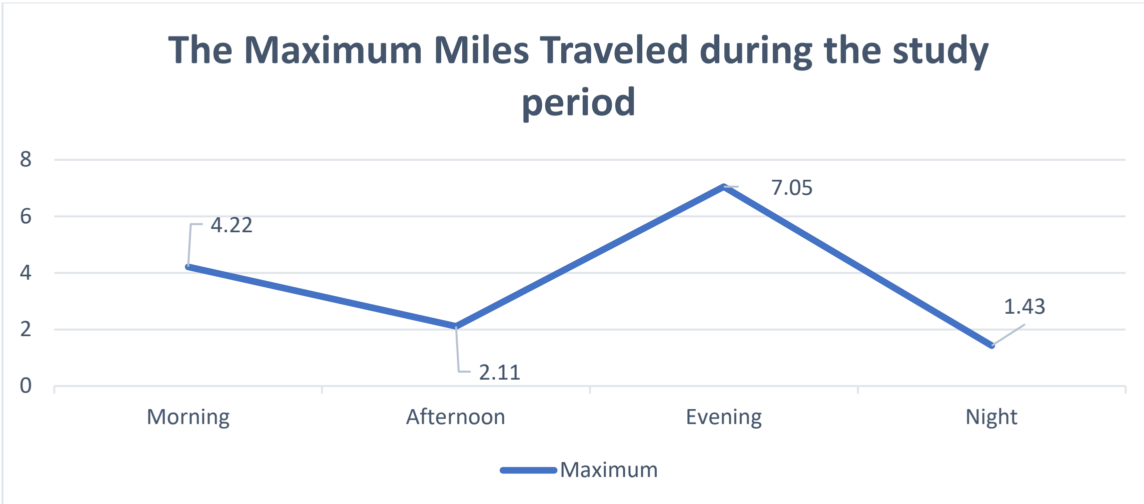


Figure 13. Maximum miles traveled during each time segment by one of the 19 herd members. The y-axis is the miles traveled and the x-axis is the time segments in focus for this study.

Lastly, the total distance traveled during the study period was (n= 769.99) miles in the morning. In the afternoon the herd travelled a total of (n= 677.50), whereas in the evening the total miles travelled was (n= 716.94) miles. Throughout the night the total miles traveled was (n= 386.52) miles.

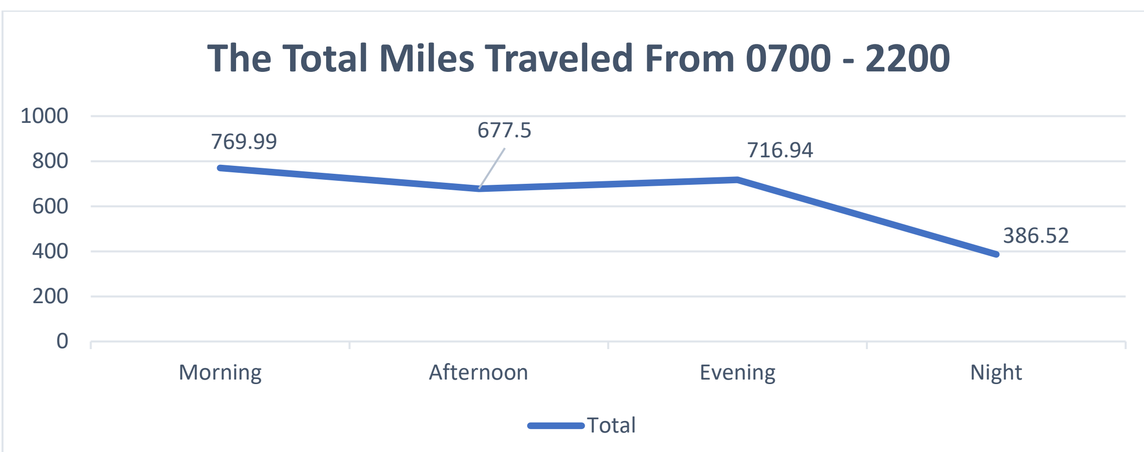


Figure 14. The total miles traveled from 0700 to 2200 during the months of March and April in 2018, 2019, and 2020. This is the total miles traveled from the 19 beef cattle within the study period from 4,400 GPS location points.

3.4.2 Objective Two

The second objective (ii) determines the average Euclidean distance of beef cattle from water resources during each time budget period. During the morning period their average distance from the nearest water source was (0.33) miles. The afternoon times found the herd was (0.34) miles from the water resources and during the evening period they were (0.37) miles. The last period found the cows and heifers to be (0.38) miles on average from a water source.

Additionally, the average Euclidean distance from each of the two different water source types (natural and man-made) was calculated. During mornings and time segment two (mid-days) the herd was approximately (0.34) miles on average from the natural water sources. During the third and night periods, the cows and heifers were approximately (0.36) miles on average from natural water sources.

The results for the average distance to man-made water sources found that during morning the cattle were (0.31) miles from these water sources on average and averaged (0.34) miles during the afternoon segment. For the evening period the members were approximately (0.39) miles on average from these man-made water troughs. Throughout the night period the cattle were located roughly (0.41) miles on average from the man-made sources.

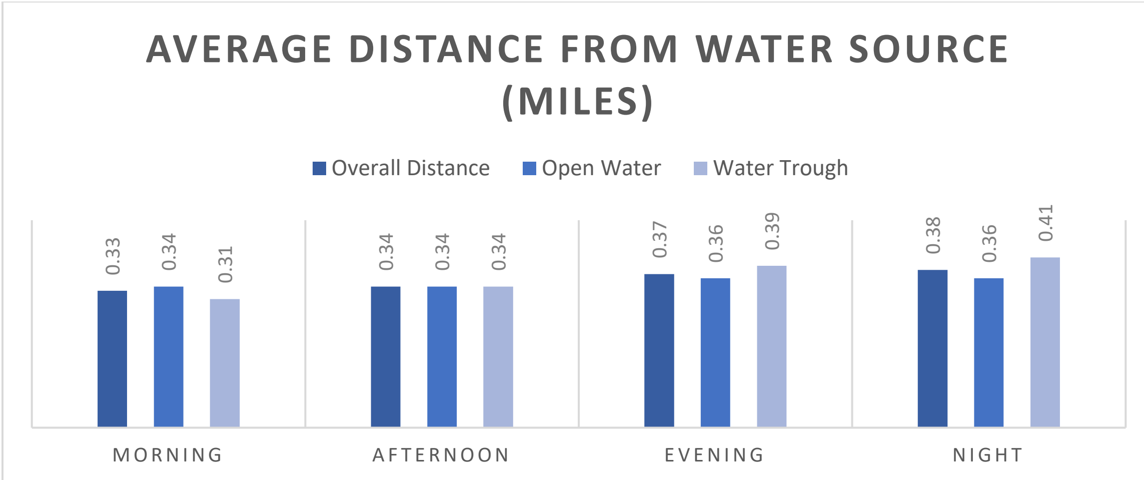


Figure 15. The average animal Euclidean distance from water sources is in miles. Overall is the average Euclidean distance from both water trough and open water, the average distance from the water troughs, and the average distance from the open water during the different segments of the time-budget.

In addition to the average Euclidean distance from each water source Figure 16 shows the minimum distance from the two different water sources. For all four-time segments there was at least one cow found completely within the boundary of an open water source with (n= 0) miles from the selected water source. Whereas during the morning the cow with the least Euclidean distance from a water trough was (n= 0.001) miles. During the afternoon and evening the minimum distance was (n= 0.0007) miles from a water trough. During the time the heifer or cow was at least (n= 0.0008) miles from a water trough.

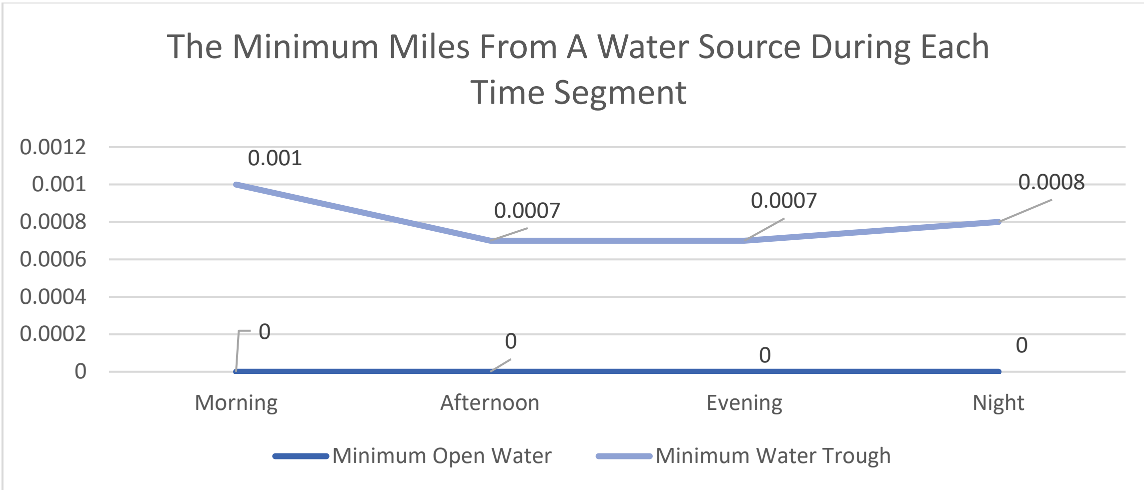


Figure 16. The minimum distance in miles from water sources. The darker blue line is the minimum distance of one of the 19 herd members to one of the open water sources. The lighter blue line is one of the herd members minimum distances to one of the four water troughs.

The maximum distance from the water sources was a little more diverse than the minimum distance. The morning distance found that the maximum distance from the open water was (n= 3.16 miles) whereas during the afternoon the maximum distance was (n= 1.33) miles. The evening had the greatest distance from the water trough at (n= 5.15) miles; and the night found that the maximum distance was (n= 1.54) miles.

The maximum distance from the water troughs was slightly steadier. One herd member was found (n= 1.45) miles in the morning. The afternoon there was (n= 1.33) miles, in the evening it was (n= 1.32) miles. Lastly, in the night the maximum distance was (n= 1.46) miles.

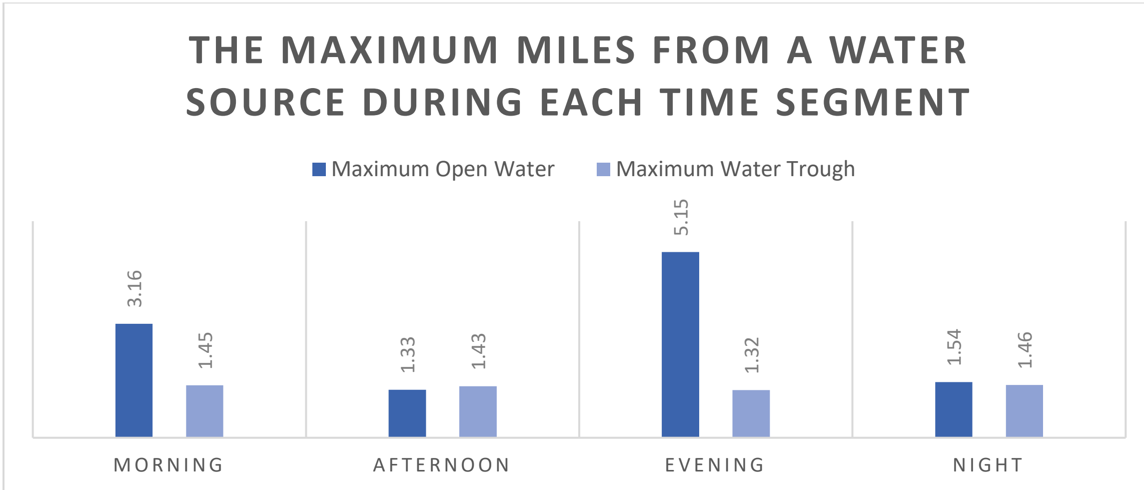


Figure 17. The maximum distance in miles from water sources. The darker blue line is the maximum distance of one of the 19 herd members to one of the open water sources. The lighter blue line is one of the herd members maximum distances to one of the four water troughs.

3.5 Discussion

The present research addresses two objectives. These are to (i) determine the average relocation distance for animals' trajectories, and (ii) to identify the average distance to the water resources within the time budget periods, respectively. A time budget adopted from prior work divided the observed data into four three-hour segments (three diurnal and one nocturnal) (Downs et al., 2017). The results suggest that cattle may have different travel trajectories depending on the time of day. This research may provide rangeland managers with a reference of when cattle are traveling more and how far from water sources they tend to be. The results in this case follow in the result borne from Lange, appearing in 1969. (Lange, 1969). This analysis looked at time of change in phenology and vegetation with respect to cattle management practice.

It is important for ranchers and other grassland livestock managers to understand the trajectory characteristics and grazing behaviors of each herd (Li et al., 2020). Understanding the trajectories of livestock can add additional information to the practices designated to improve livestock grazing distribution accurately while being cost effective (Bailey et al., 2018). One of the biggest concerns associated with livestock grazing, especially in the western United States, is uneven grazing distribution (Bailey, 2005). Tracking data provides a wealth of information that can be used to answer a variety of questions about rangeland livestock behavior (Bailey et al., 2018), such as the distance traveled during different times of the day. In the 1950s it was suggested to herd cattle to improve grazing distribution (Williams, 1954; Skolvin 1957; Bailey et al., 2018). Understanding the trajectories is just the first step to understanding the grazing distribution (Bailey et al., 2018).

The objective and methods of this study are somewhat outside the norm surrounding similar studies, so comparability in results becomes somewhat subjective. A study focused on trajectory characteristics may not be readily comparable to others, where more traditional approaches informed by direct observation, visit counts, etc. might prove more comparable. The trajectory is a data object carrying unique information and has unique limitations. One comparable study looked at the kilometers traveled per day at four different locations during three seasons for cattle; with results stating that during the study period the cattle travelled approximately nine to 17.9 kilometers per day (Feldt and Schlecht, 2016). The results for the present study found that the during the 15-hour study period the herd traveled a total of (n= 25.67) miles in the morning, (n= 22.58) miles in the afternoon, (n= 23.9) miles in the evening, and (n= 12.88) miles in the night. In total, 65.03 miles traveled over 15 hours by 19 cattle. In comparison to the Fedlt and Schlecht (2016) article that found a maximum of 17.9 kilometers which is 11.12 miles. The variance between average relocation distances reported in the present study versus Feldt and Schlecht could arise from contextual concerns (study area choice), management practices at the study area as they influence cattle behaviors, terrain, weather, cattle breed etc. Additionally, this study had different grazing itineraries in which the herd would not be left to free graze during the night (Feldt and Schlecht, 2016).

However, to identify our results as a departure from previous, similar work may act to add value. The outcomes of objective one illustrates that our herd is consistent in its movement during the diurnal periods of the day, but then average relocation distances in trajectories decrease by half the distance travelled from the hours of 1900 to 2200. The change in trajectory relocation distance is likely because it is after sunset, and cows are diurnally active mammals. The results suggest that the cattle may be grazing or traveling at a consistent speed during the diurnal periods of the day. The general consistency of results is also apparent within the minimum results, although due to the way the data was cleaned it is possible that a cow may not have moved during the study period but was not observed within the results. There is a slight change in the maximum miles traveled during the study period. The most miles traveled was (n= 7.05) miles during the evening; and the second most was (n= 4.22) miles during the morning. Third on the record for maximum miles was (n= 2.11) miles in the afternoon, the night period had the lowest miles covered in the maximum miles traveled analysis with (n= 1.43) miles.

A similar methodology and analysis were applied to goat grazing patterns in Southern Morocco (Akasbi, Oldeland, Dengler, and Finkh, 2012). This article addressed daily trajectories of goats at different four different villages in three different seasons. The results between this work and the present study differ due to the subject matter, focal species, and study area use, but both this article and the present research provide for further description of spatial grazing patterns given information recording animal position in space and time.

The second objective focused on the distance of the herd to water resources. The outcomes suggest that the average distance from the water supplies is at most (0.38) miles between both water supply types. Similar studies indicate that water location influences the grazing distribution of cattle. One study found that cattle are likely to travel two to 10 km per day from the water (Lange, 1969). One report found that water ultimately controlled the distance cattle traveled to graze (Hodder and Low, 1978). Unlike the previously mentioned authors, Roath and Krueger (1982) did not find water to be a strong influence on utilization of space; instead, the authors found the slope to be more of a determining factor on grazing (Roath & Krueger, 1982).

Additionally, the results of objective two further identify whether distance from man-made and natural water sources is a function of cattle preference between the two sources. The results are close in magnitude among time segments and do not suggest an obvious preference other than potentially during night, where taken at face value. During the night period the herds average distance from the man-made sources is (0.41) miles whereas they are (0.36) miles from the open water sources. One study found that Brahman cows were more likely to avoid areas dominated by steep terrain (Tomkins & O'Reagain, 2007). Cattle have been found to graze relatively close to the water source as the slope increases and will travel farther distances as the slope decreases (Roath & Krueger, 1982). These assessments could be consistent with the results of this study when referencing the elevation and water uses. Overall, the results of this study are consistent with the previous publications with respect to general trends reported surrounding water source location.

Although the slope was not analyzed for this study the minimum and maximum distance was. During each period the minimum distance from the an open water source was (n= 0) miles. From 0700 to 2200 there was at least one herd member found within the boundaries of the open water. Whereas the minimum distance from the water troughs varied slightly ranging from

0.00008 to 0.001 miles from a water trough. The discrepancy is likely due to the difference in presentation of the water trough versus the open water. The water troughs are often a round tank that cattle often cannot get into whereas ponds do not have a border that would prevent submerging. One study found that cattle prefer to drink from a water trough than a natural stream (Sheffield et al., 1997). This is especially interesting when comparing the maximum distances from the water sources. During each period the maximum distance from the water troughs is from 1.32 to 1.5 miles away whereas the maximum distance from the open water ranges. The least of the maximum distance is (n= 1.32) miles away whereas the greatest maximum distance is (n= 5.15) miles away. With further analysis of individual herd members this could highlight the preferred water source.

Future studies may include a more detailed look at the trajectories where time segments could be selected based on trends present in the trajectory data. Unsupervised clustering algorithms including K-means might do well to identify otherwise hidden commonalities in the trajectory data between times of day and movement magnitudes, turning angles, or distances to important features in the landscape such as water. Increasing the specificity of the present approach such that smaller time segments are considered would provide managers with a better understanding of cows' daily habits, where the interval at which behaviors are identified would be smaller, or finer in detail. A one-way ANOVA may also be considered to test significance in the future. The ANOVA will require a comparison of individual herd members rather than the group comparison done in the present study. Additionally, a corresponding approach to water location and use should be considered as a component for future research. Other considerations that may influence the use of the water source such as salt, vitamin tubs, elevation, and distance from facilities would further the understanding of cattle behaviors. This could help ranchers make a more informed decision on placement of man-made resources provided to the herds.

3.6 Conclusion

The results of this study determined the average relocation distance taken from cattle trajectories and their average distance from water sources during the specified time budget. The results found that the average distance traveled was consistent throughout the three diurnal periods but decreased once the sunset. These results are consistent with the studies published that had similar objectives. The second objective found the average distance traveled away from the water options was (0.34) miles during time budget. Future research would look at the trajectories from a smaller time period and apply more variables to the analysis for water use. The results of this study will give ranchers and livestock managers more information on a herd's average relocation distance in trajectories and water use preferences.

Chapter 4: Conclusion

4.1 Extended Discussion

Livestock management is a long-existing specialization that is practiced worldwide. The career, although often not glamorous, represents a hard-working group of people dedicated to taking care of their herds and communities. Despite the traditional methods of the field, there are still unanswered questions that were not as easily assessed until the development of recent technologies. With this development, researchers can answer time-space based questions and provide management with information at a finer scale that may aid in their rangeland management duties. This research worked to examine the habitat use and trajectories of beef cattle during a time of changing vegetation and phenology in south central Oklahoma. In general, due to the relatively new availability of capable software, the literature on time-space based research is limited compared to other livestock related research.

In my second chapter, I used location-based data to assess the habitat use of 19 beef cattle. The analysis focused on the GPS locations from March 1st to April 30th (2018-2020) as of 0700 to 2200 and was separated in two the following four time periods: (1) 0700 to 1000, (2) 1100 to 1400, (3) 1500 to 1800, and (4) 1900 to 2200. From the results I inferred that the cattle preferred to graze within the prairie and pastures during the cooler times of the day. Additionally, the results suggested that a large amount of the herd would occupy the shaded areas, woods, and forest, during the warmer parts of the day. A further objective within the second chapter sought to analyze the herds main water use. I concluded from the results that the herd would often visit the man-made water sources.

The third chapter comprised a second analysis of the same data that instead sought to review the average relocation distances held in trajectories of the herd and their average

Euclidean distance from the 15 water sources throughout the rangeland. I found that the average distance traveled remained consistent, approximately (0.16) miles during the diurnal periods and decreased by nearly half after sunset. The second objective found that the average distance from the 11 water resources was (0.33) to (0.38) miles.

Livestock distribution is relevant economically and is one of the main principles of grazing management (Vallentine, 2001; Bailey et al., 2018). The results of chapter two and three have the potential to contribute to a growing body of literature that focuses on the use of GPS collars to obtain a better understanding of wildlife movement and habitat uses. Before the development of GPS collars researchers would observe wildlife from a distance to obtain habitat use data (Herbal & Nelson, 1966; Roath & Krueger, 1982; Bailey et al., 2018). Although this research is not the first study to use similar data, it adds value to the methodology and opens doors to future researchers looking to research wildlife. In the future I plan to reference GPS data from an extremely cold season and warm season. A comparison of the seasons will be able to answer how seasons temperature changes not only livestock's habitat use but also their trajectories. Additionally, I intend to employ alternative methods under an expanded set of variables considered when reviewing the water source use question. This could involve larger, or multiple buffers in order to compare similar studies findings such as Tomkins and O'Reagain (2007) statement that cattle will travel 2 km to 10 km per day from the selected water source. Lastly, in the future I would like to look more into how the terrain affects travel and water source use. Future research may require new or additional data collection.

4.2 Study Limitations

The first limitation to this study was a result of my personal experience. Although I have some experience completing research, I do not have a degree in agriculture or rangeland management.

Due to this limitation my knowledge of prior art and practice was limited to my own experience growing up raising cattle and the literature I was able to acquire as part of this work. Additional sources of information, including those not made public due to intellectual property or proprietary practice concerns, most likely exist and were out of the proverbial reach of the present effort. I was required to take my personal knowledge from growing up on a ranch, 4-H (Head, Heart, Hands, and Health), and Future Farmers of America (FFA) and combine it with my education in geographic technologies to achieve the present result. When beginning this research, it was difficult to see how GPS data could inform the local livestock producers on their own herd. Due to this restricted vision, I was required to do more academic reading than maybe someone with an academic degree focused on livestock or rangeland management. Additionally, I am still learning everyday how to better use the ArcPro software and all the methods that could have been applied to this study and future research. I did not learn programming in Jupiter Notebook until the fall 2022 semester in an introduction course through the University of Oklahoma. This new skill was required within the third chapter but was restricted by my limited knowledge and experience.

The second limitation was the data. It was collected years prior to me entering the graduate program by researchers at the Noble research institution. Although the data was collected, I was only able to look at one aspect of the dataset. In the future I would like more experience in the data collection process. This would allow me to have objectives set before data collection and ensure I collected all the required variables to answer the objectives, while also enhancing my research experience. Additionally, it would allow me to look at different seasons, different time collection (every 10 or 15 minutes) and collect more information on additional resources that may affect their habitat use such as salt and other vitamin supplements often placed within rangelands. I could also observe the grazing with a more hangs on scale by taking soil samples or simply observing the change in grass weekly. Since the GPS points were collected every hour for this dataset, I think it would be interesting to see how the results would change at different time intervals. With a different time, interval, I could observe a shorter trajectory relocation interval and compare that to the hour interval observed in this study. Additionally, it would be interesting to observe the Euclidean distance from water sources every 15 to 30 minutes to get a closer look at when the herd is closest to water.

4.3 Future Work

4.3.1 Chapter Two

Future research may reference other seasons or over a longer period. If I was able to look at additional seasons, I would look at colder seasons in Oklahoma when the state is more prone to ice storms, or alternatively look at livestock that graze in a state that experiences extreme winters such as North Dakota, Montana, and Wyoming. If I was to compare livestock in Oklahoma, I would most likely look at the herds in January and February. This observation would allow me to compare herds grazing in a similar terrain, elevation, and vegetation to the results from this study. If the alternative states in the north were chosen there would be many changes in not only seasonal extremes but elevation, terrain, and common cultural practices that would need to be noted before analysis and comparison. It would also be fascinating to see how the herds' habitat use changes in the extreme summer months June through August when it is warmer, and the cattle are not as comfortable. Objective of a comparison to different seasons could look for difference in habitat use during cooler and warmer months and difference in water source use.

Alternative methodological approaches, including ones based on group sizes (Frank et al., 2012). Frank et al. (2012) observed group sightings within a 3 km zone. The zone was focused on water resources. A similar objective using a cluster or hot spot analysis approach would not require a zone while still answering hot spots for grouping. Additionally, a larger buffer of 2 km would add additional information for optimal grazing. It was stated that if grazing was optimal the cattle would not graze over 2 to 10 km from the selected water source (Hodder & Low, 1987; Granskopp, 2001; Tomkins & O'Reagain, 2007). If I was to assume the grazing is optimal within the data set used for this study a 2 km buffer could be applied to the water source(s) and the activity could be observed daily to see when multiple members are leaving the boundary. This method may not be optimal for the current dataset because there is multiple water sources within the boundary, some buffers would be likely to overlap. Although limited, the results from this study can guide livestock producers on habitat and water choices of beef cattle.

Furthermore, a future study could include an individual comparison rather than analyzing the herd as a group. Comparing the individual will allow for more analysis on a finer scale. For example, rather than referencing the group as whole the results will be able to answer which heifer(s) or cow(s) were within the herbaceous boundary the most. This can be due to age, bread, slope, etc. Further statistical analysis such as a one-way ANOVA test to test for significance is also possible with an individual dataset rather than a group dataset.

4.3.2 Chapter Three

The third chapter examined proximity to water every hour. Future studies may include a more detailed look at the trajectories with a smaller time gap. With a 15-to-30-minute interval rather than a one hour we can look at the distance traveled on a small scale. The results will be able to not only look at a shorter travel period but answer more behavioral questions. I propose this alternative because a lot of activities can happen in a one-hour interval. Comparing the trajectories of a herd at 15-to-30 minutes would answer questions such as what the herd was most likely doing between the hours this data was not collected. It is possible that the only difference observed during the small interval is a smaller distance traveled; but a preliminary analysis can be asked with this data because there are two heifers with 15-minute intervals during the study period.

Additionally, taking a deeper look at water location and use should be considered. Other implications that may add in the use of the water source such as salt, vitamin tubs, elevation, and distance from facilities would further the understanding of cattle; and could help ranchers make a more informed decision on placement of man-made resources provided to the herds. Ensuring optimal water and supplement placement is important and, in the future, this similar data could better inform producers to ensure their herds are getting everything required to maintain a growing healthy herd.

An individual analysis would also provide a valuable analysis of the trajectories. By reviewing the average distance traveled by each of the herd members it'll show a smaller average distance traveled rather than the groups average distance traveled as a whole. This is valuable information as it tells livestock management how far his or her individual cow is likely to travel over an hour assuming the topography is similar. Additionally, statistical analysis will also be an option such as the one-way ANOVA.

4.4 Concluding Remarks

In conclusion, this research is a representation of another piece of scholarship within a growing body of literature regarding GPS collars application in the analysis of wildlife movements and habitat use. This research could be submitted to a journal that contributes to literature on topics of ecology, rangeland management, socioeconomics, and policy-pertaining to rangelands with one mission being to promote sound rangeland stewardship. My findings provide insight into beef cattle habitat use and their travel trajectories in months of changing vegetation; and where the cattle are comfortable according to the cattle comfort index. As GPS technologies advance and become more easily acceptable, the information provided will offer information for comparison and an idea for rangeland management's grazing plans. In the future other scholars could compare results with similar data in a different region. Specifically, how do the trajectories change in a mountainous region compared to the herd observed in this study. These results would provide more relatable data to rangeland managers in states in countries at a higher elevation. Additionally, water source use could be observed in an area where the water sources are not in as proximity as they are within this boundary. Some herds water sources are only man-made or only natural depending on landowners' resources. This data and the results are just another glimpse into the potential for information to livestock managers.

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